THE RESTLESS RIVER

YARLUNG TSANGPO-SIANG-BRAHMAPUTRA-JAMUNA

"This book tells a fascinating story of one of the world's longest and diverse river systems. It combines beautiful illustrations and a narrative based on good science and the ability to tell a complex story which should be of interest to a wide public".

Julia Marton Lefevre
Former DG, IUCN, Chair of the Board of Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT)

❄

"This truly exceptional book has taken the dry, technical data that feeds water diplomacy and turned it into an adventure down this beguiling river of many names and many voices. Anyone fascinated by how water shapes cultures, nature and well-being will treasure the book's diverse narratives and rich visuals and how, layer by layer, they reveal the river's personal stories and geopolitical calculus; its management alongside its spiritual heart; its ecology and engineering; and despite the river's timelessness, the urgency of cooperation to secure its future."

Mark Smith
Director General, International Water Management Institute

❄

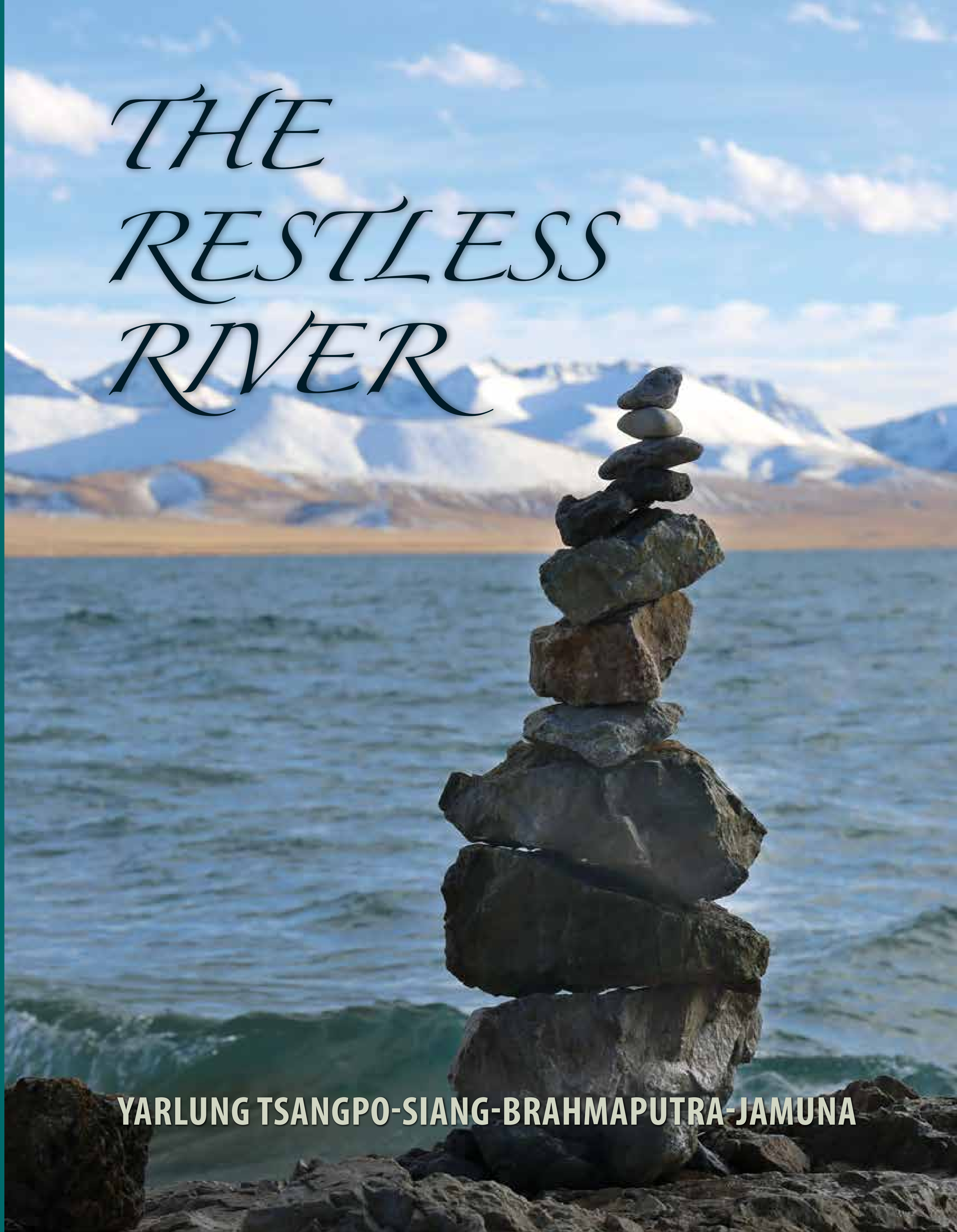
"This book is an extraordinarily successful attempt to narrate the natural characteristics, history, and present-day challenges of one of the most diverse transboundary rivers of the world. Based on science and accurate research, and written in a compelling way, it is an example to follow when setting the foundations for cooperation in transboundary rivers basins".

Michela Miletto
Coordinator, UNESCO World Water Assessment Programme (WWAP) and Director, UNESCO Programme Office on Global Water Assessment

WORLD BANK GROUP

THE RESTLESS RIVER

EDITORS: GANESH PANGARE · BUSHRA NISHAT · XIAWEI LIAO · HALLA MAHER QADDUMI



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YARLUNG TSANGPO-SIANG-BRAHMAPUTRA-JAMUNA

THE RESTLESS RIVER

EDITORS

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YARLUNG TSANGPO-SIANG-BRAHMAPUTRA-JAMUNA RIVER

ཡར་ཀླུངས་གཙང་པོ།

雅鲁藏布江

सिआंग

ব্রহ্মপুত্র

যমুনা

Foreword

TRANSBOUNDARY COOPERATION amongst riparian countries is crucial to managing the sustainable development and utilization of transboundary water resources and key to optimizing the mutual benefits that river basins provide. This fact is widely recognized. For example, the United Nations Sustainable Development Goal 6 Target 5 calls on the world community to implement integrated water resources management at all levels, "including through transboundary cooperation as appropriate."

The World Bank is committed to supporting its client countries to better manage transboundary water resources and plays a global leading role in promoting cooperation in transboundary river basins world-wide. Amongst its many engagements, the South Asia Water Initiative (SAWI) is a multi-donor trust fund supported by the United Kingdom, Australia, and Norway, and administered by the World Bank, which supports a rich portfolio of activities to increase regional cooperation in major transboundary Himalayan river systems.

The Brahmaputra Basin focus area under SAWI has aimed to promote shared understanding and management of the Brahmaputra Basin to deliver sustainable, fair, and inclusive development and climate resilience. From 2016, SAWI has supported the Brahmaputra Dialogue, an informal multi-lateral and multi-track dialogue process, which has provided an important platform for the four riparian countries to find common avenues for coordinated management of the river basin.

Over the years, the Brahmaputra Dialogue process has led to broader agreement on the need for cooperation amongst basin stakeholders and identified the lack of common understanding as one of the key barriers. This report aims to break down that critical barrier. It is the first of its kind to look holistically at the entire Yarlung Tsangpo – Siang – Brahmaputra – Jamuna River Basin. It is novel in that it examines this majestic system from the perspectives of the riparians themselves through contributions from top academics, researchers, diplomats, journalists, politicians, and policy makers from across the basin. As such, the report adds immense value to the comprehensive understanding of the basin and the importance of transboundary cooperation.

I would like to thank the many contributors, who generously gave of their time and knowledge and without whom this rich report would not have been produced, in addition to the many others who supported the preparation of the report. May all who have the pleasure of reading this stunning report be awed by the magnificence of the Yarlung Tsangpo – Siang – Brahmaputra – Jamuna River Basin.

Cecile Fruman
Director Regional Integration and Engagement, South Asia,
The World Bank

Acknowledgements

This book would not have been possible without the generous contributions of all of the authors who together produced a unique piece of work. We are grateful for their time, effort and commitment in sharing the knowledge of and insights on this incredible river basin.

Sincere thanks to Nagaraja Rao Harshadeep and his team member Aminul Islam for producing the maps for the book. Thanks also to Malik Fida A. Khan, Executive Director, CEGIS and Md. Firoz Alam for the maps and GIS work for the FLOW chapter.

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We would like to extend our sincerest thanks to all of those whose support has been critical to the long and fascinating journey that has culminated in this report:

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Preface

"THE RESTLESS RIVER" Perspectives on the Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna River Basin, is a first attempt at documenting the Brahmaputra as a one river system and presenting a multi-layered, holistic perspective of the entire river basin from the perspectives of the four riparian countries.

The genesis of the report is the stakeholders from the riparian countries themselves, who highlighted the need for one comprehensive, fact-based document that provides information on the various aspects of the entire river basin and that comprehensively captures the viewpoints of those from all riparian countries. It was felt that a document of this type would be important for supporting the dialogue process and policy discussions on cooperative river basin management.

It is natural to expect that such a document should be co-written by various stakeholders across the basin, along with other international experts. We are pleased that the report includes contributions from over 90 authors, which is a powerful expression of cooperation in and of itself.

The report consolidates the existing wealth of knowledge and information on the river system. At its heart, however, are the riparian's perspectives and insights that reflect how the river is deeply embedded in the cultures and the lives of the people living within it. The report portrays the inextricable interlinkages between those living in the countries that share the river system: even though they are divided by international borders, they are tightly connected through the basin's water resources.

It is our sincere hope the report will contribute to enhanced knowledge exchange, catalyze interaction and knowledge sharing amongst basin stakeholders, and ultimately foster a spirit of cooperation to manage and develop the basin optimally, holistically, sustainably, and for the benefit of all.

Ganesh Pangare
Bushra Nishat
Xiawei Liao
Halla Maher Qaddumi

1. THE BEGINNING

Story of a river

Ganesh Pangare
Bushra Nishat
Xiawei Liao
Halla Maher Qaddumi

Yarlung Tsangpo
Siang
Brahmaputra
Jamuna

RIVER BASINS have been the cradles of civilizations and people have flourished along riverbanks over the ages. Every river has its own unique ecosystem harboring within it a diverse flora and fauna and humans have adapted to live within this complex web of life.

THE BRAHMAPUTRA as it is commonly referred to, is actually known by this name only in about 40 percent of its length when it flows through Assam in India. Revered as the Yarlung Tsangpo where it originates in Tibet, known as the Siang, after it plunges down the Grand Tsangpo Canyon, celebrated as the Brahmaputra in the flat terrains of Assam, and flowing as the remarkable Jamuna as it crosses the floodplains of Bangladesh, where it meets the Padma (Ganges) and the Meghna to form the largest delta in the world. This is the





mighty river system of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna River, one of the biggest river systems in the world. On its way towards the sea many tributaries, each a unique river in its own right, merge into the main channel which flows through three countries, China, India and Bangladesh. The basin, however, also includes Bhutan, from where the largest number of tributaries originate. Hereafter we refer to this river system as the River.

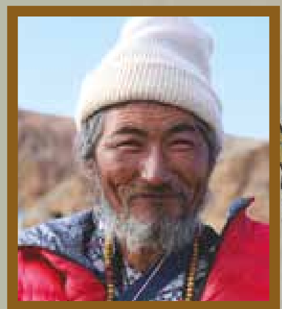
One river, many names; representing a continuum of change, and diversity, from upstream to downstream, as the River flows through borders and geographical regions. Each name has a story, giving it an identity that is more than a physical entity, imbibing it with history, culture and religion. The cultural and historical thread flows through the river system as it interacts with the people and communities that live and survive on its banks. Civilisations and kingdoms have come and gone, yet the river flows on, changing course over time, ebbing and flooding each year. Recent estimates show that about 130 million people live in the basin, of which about 86 percent live in rural areas.

The River remains largely unharnessed and with a few areas still uncharted, the basin remains one of the most intriguing regions of the world. Only recently, as documented later in the book, the origin of the river has been recharted, and the basin delineated. Based on this recent discovery the length of the River has been estimated at 3,350 kilometers from the source until it meets the iconic Ganges in Bangladesh, and 3,848 kilometers till it reaches the sea. The basin of around 712,035 square kilometers, encompasses a huge network of water courses formed by the numerous tributaries of the River.

A River of many superlatives, the Yarlung Tsangpo section of the river flows through the highest of landscapes, plunges 4,000 meters before it is known as the Siang, rushes through flat lands as the Brahmaputra, while as the Jamuna, the elevation of riverbed level falls well below mean sea level.

The diversity and complexity in the physiology, ecology and even ethnology makes the basin unique and enchanting. Shrouded in mythology, the River and its tributaries have been of great interest to researchers, scholars, as well as writers, journalists, artists and photographers not only from the region but from around the world. The literature is abundant, covering various aspects including hydro-morphology, biodiversity, cultural history, social development, livelihoods, resource utilization and management of the basin. But the literature has focused on only one or the other segment of the River or basin, and usually from one perspective, and not of the entire River system.

This book is one of the first attempts at documenting the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna as a one river system creating multi layered narratives of the basin. The book is divided into 8 chapters exploring the physical characteristics like geomorphology, climate and hydrology, biodiversity, as well as socio-economic and cultural aspects of the basin. The book compiles and collates 91 contributions from global, regional and national experts from the four riparian countries.



Giving the river its due place as one of the 20 longest rivers in the world

IF ONE LOOKS at any list of 20 or 25 longest rivers in the world there is sadly no mention of the Yarlung Tsangpo – Brahmaputra river. This needs to be corrected.

The length of the Yarlung Tsangpo- Brahmaputra river is **3,350 kilometers** from its source in Tibet till it meets the Ganges river in Bangladesh. After this the Ganges – Brahmaputra together meet the river Meghna and together they are known as the Lower Meghna which flows to the sea of Bay of Bengal. If one includes this length, from the confluence with Ganges till the sea, the total length of the river becomes **3,848 Kilometers.**

The Yarlung Tsangpo – Brahmaputra river should be ranked amongst the 20 longest rivers in the world. We hope that the River gets this recognition and China, India, Bangladesh and Bhutan can proudly say that one of the 20 longest rivers of the world flows through their lands.

We hope that this book is able to bring notice to one of the most fascinating river systems in the world and give the River its due recognition.

The Yarlung Tsangpo-Siang-Brahmaputra-Jamuna River

Deepest and longest canyon: The Yarlung Tsangpo Grand Canyon in Tibet, with depth upto 6,009 meters, is regarded as the deepest canyon in the world.

Highest navigable river: Originating at an altitude of 5,300 meters above sea level and flowing at an elevation of 3,500 meters above sea level through Tibet, China, the Yarlung Tsangpo is considered as the highest navigable river in the world.

One of the highest sediments carrying rivers: One of the most heavily sediment-laden large rivers of the world, exceeded only by the Amazon and Yellow River.

Joins the largest delta in the world: Over thousands of years, sediments carried by the Brahmaputra-Jamuna are being deposited in the Bengal Delta, the largest delta in the world. The Bengal delta slopes into the spectacular Bengal Deep Sea Fan, the largest submarine fan in the world.

Largest riverine island: Majuli, the largest riverine island in the world is located in the Brahmaputra in Assam.

Biodiversity Hotspots of the world: Listed as one of the 36 Biodiversity Hotspots in the world.

One of the oldest human migration routes: Major crossroad of movements of pre-historic ancestors from Africa to the Far East.

Largest riverine National Park in the world: With a total area of 340 square kilometers, Dibru Saikhowa National Park is the largest riverine island national park and one of the 19 biodiversity hotspots in the world.

2. FLOW

The River's Journey

Bushra Nishat

Malik Fida A. Khan

Harish Kapadia

Fanyu Zhao

S. S. Nandargi

Fuqiang Tian

Arun B Shrestha

Imtiaz Ahmed

Neera Shrestha Pradhan

Md Monowar-ul-Haq

Ahmmed Zulfiqar Rahaman

Eklavya Prasad

Xiawei Liao

Sudipta Kumar Hore

FLOW

The river's journey

THE YARLUNG TSANGPO-Siang-Brahmaputra-Jamuna river system is truly one of the most intriguing, vigorous and imposing fluvial systems in the world. The River originates in Tibet, China from a glacier over 5,300 meters above sea level and flows as the Yarlung-Tsangpo then as Siang and Brahmaputra in India and the Jamuna in Bangladesh. The basin is spread across 712,035 square kilometers[1] in four countries. On its 3,350 kilometers journey, the River flows through China, India and Bangladesh and is joined by numerous tributaries creating a huge network of water courses throughout its basin. Although the main channel does not flow through Bhutan a large number of tributaries originate from the Bhutanese Himalayas, thus Bhutan is also a part of the basin. In Bangladesh, the River joins the Ganges (Padma) and together they converge with Meghna, from where on the river is called the Lower Meghna, which eventually drains into the Bay of Bengal (shown in the Basin Map).

Each year, especially in the monsoon, the River carries not only a huge amount of water but also sediment towards the sea. The River is one of the most heavily sediment-laden large rivers of the world. As the ultimate carrier of freshwater and sediment in the region, the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna drives the hydrometeorological interactions, dynamics, and processes of the entire region.


CHINA
CHINA
NEPAL
INDIA
INDIA
MYANMAR
BANGLADESH
BAY OF BENGAL
LHASA
XIGAZE
GYANGZE
NYINGCHI
THIMPHU (BHUTAN)
GANGTOK
DARJILING
JALPAIGURI
DHUBRI
RANGPUR
BOGURA
RAJSHAHI
DHAKA
GUWAHATI
SHILLONG
TEZPUR
ITANAGAR
JORHAT
DIMAPUR
DIBRUGARH
PASIGHAT
DOGXUNG ZANGBO
YARLUNG TSANGPO
LHASA
NYANG CHU
YAMZHO YUMCO
PUMA YUMCO
DOGEN CO
SUBANSIRI
SIANG
LOHIT
RAIDAK
GADADHAR
TORSA
KALJANI
AIE
MANAS
TEESTA
JALDHAKA
BRAHMAPUTRA
KOPILI
DHANSIRI
BANGALI
ATRAI
JAMUNA
PADMA
MEGHNA
GANGA
The Yarlung Tsangpo-Siang-Brahmaputra-Jamuna Basin
LEGEND
Major Cities
Capital Cities
Major Rivers
Lakes / Reservoirs
Elevation (meter)
0
8,625
N
W
E
S
0
100
200 Km.
Data Source:
Elevation: GMTED, USGS
30° N
25° N
85° E
90° E
95° E

THE PHYSICAL SETTING OF THE BASIN

Depending on topography and morphology, the basin of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna is a mosaic of five different zones, the cold dry plateau of Tibet, the rain-drenched Himalayan slopes, the landlocked Brahmaputra Valley, the distinctive Lower Assam mountainous region and the vast deltaic floodplains.

THE TIBETAN PLATEAU covers around 50.5 percent of the basin, with elevations of 3,500 meters and above in the northern most part of the basin[2].

THE HIMALAYA BELT covers around 23 percent of the basin with elevations ranging between 100 meters to 3,500 meters above mean sea level and is sandwiched between the Tibetan Plateau and Brahmaputra Valley[3].

THE LOWER ASSAM MOUNTAINOUS REGION covers only 6.4 percent of the basin and includes the Shillong Plateau and Mikir Hills with elevation between 600 meters and 1,800 meters above sea level[4].

The River basin and adjoining mountain ranges are tectonically active, and a large part of the basin is geologically young

THE BRAHMAPUTRA VALLEY is long and narrow with elevations below 155 meters above sea level and takes up 9.7 percent of the basin.

THE DELTAIC FLOODPLAINS of Jamuna, situated in Bangladesh and West Bengal, India cover the remaining part of the basin. This region is extremely flat, and elevations vary from less than 10 meters above sea level to just under 90 meters above sea level[5].

The River basin and adjoining mountain ranges are tectonically active, and a large part of the basin is geologically young. Yet, the rivers in this region are antecedent[6], older than the mountains they flow through. Major morphological evolutions started to take place in Early Eocene[7], when the Indian plate collided with the Asian mainland and the rise of the Himalaya was initiated between 40 and 50 million years ago[8] (some scientists suggest this to be 55 million years ago[9]). The Yarlung Tsangpo currently flows through the suture zone that separates the Indian plate from the Asian Plate situated in the Tibetan Plateau. With vast expanses of pristine flatness at high elevations, this is the world's highest and widest plateau, and the geological history is closely linked to that of the Himalayas. East of this Plateau is the geologic wonder, the narrow deep Yarlung Tsangpo Grand Canyon entrenched between the Namcha Barwa and Gyala Peri mountains[10].

The Siang-Brahmaputra valley is bounded by the Himalayan ranges of northeastern India and Bhutan in the north; and the Shillong Plateau in the south. Huge amounts of sediment carried down from the Himalayas and deposited at the foothills, have created and shaped the valley. In the last leg of the journey, the River enters the Bengal Basin, one of the largest reservoirs of fluvial sediments in the world and represents the lower floodplain and delta plain deposits of the Brahmaputra, Ganges and Meghna rivers.

Sediments from the eroding Himalayas create huge alluvial fans in the plains[11]. The Bengal Basin slopes into the spectacular Bengal Deep Sea Fan, the largest submarine fan in the world and the ultimate destination of the waters and sediments carried by the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna River system.

❄

Expedition to the Tsangpo bend

Harish Kapadia

WE WERE standing at a bend in the river. Flowing fast from the Tibetan plateau, it made a large "S" turn and came rushing towards us. It is a river known by many names: in Tibet, it is the Yarlung Tsangpo, followed by Siang, and Brahmaputra as it enters India. We could see the mouth of the Nugong Asi nala flowing from the snow-capped Dapang peak (5,570 meters) in Tibet merging with the Siang. We had reached a point that explorers had been trying to reach for decades. It was a historical moment—the last piece of an almost century-old puzzle. That the Yarlung-Tsangpo and Brahmaputra were one river!

It took almost a century of exploration to solve this question. One school of thought believed that the river traversed further east till it merged with the Salween river and turned south into Burma. Another school believed that it took a turn to the south much sooner and flowed towards India, either into the Siang valley or the Subansiri valley. Several exploratory trips were made, and many different results were obtained.

The Survey of India deputed the first of its pundit explorers, Nain Singh Rawat, to trace the route of the Tsangpo. These native explorers were trained to survey the area


Liu Rui/China Plus

The Great Bend

while travelling in disguise. By this time, Tibet was closed to outsiders, but in two epic journeys in 1865 and 1873, Singh followed the course of the river to Lhasa and beyond. Reaching Chetang, east of Lhasa, he was forced to turn south after his subterfuge was revealed.

In 1874, the Assam survey was placed under Lieutenant Henry Harman. He measured the flow of various rivers and found that the flow of the Siang was greater than that of the others, proving that the river was most likely the Tsangpo. He dispatched another pundit explorer, Nem Singh, to Tibet in 1878-79, accompanied by Kinthup, a tailor from Darjeeling. They followed the Tsangpo from Chetang onwards, between the gorge of Namcha Barwa and Gyala Peri, and turned south to reach Gyala Sindong before returning. They made a major contribution, taking the exploration further upstream by 460 kilometers.

Harman, then posted in Darjeeling, again deputed Kinthup to travel to Tibet in 1880. Kinthup was instructed to cut 500 logs, make a marking on them and throw them into the Tsangpo river. If the logs emerged in the plains of Assam it would conclusively prove that the river turned south to enter Assam. As Kinthup was illiterate, a Chinese lama accompanied him. From Darjeeling, they went to Lhasa and followed the course of the Tsangpo to Chetang and Gyala Sindong. Around 24 kilometers later, they reached Pemakochung village, where the Tsangpo fell 150 feet in a waterfall which came to be known as the “rainbow falls".

Lieutenant Henry Harman measured the flow of various rivers and found that the flow of the Siang was greater than that of the others, proving that the river was most likely the Tsangpo

Unfortunately, Kinthup was sold into slavery at a monastery, from where he escaped two years later, but was captured again at Marpung, 56 kilometers downstream of the river. He was, however, allowed to go on a pilgrimage. He crossed the Tsangpo to the opposite bank, cut and marked 500 logs with special markings and threw them into the river.

Kinthup sent a letter to Harman about this, unaware that the Englishman had already left India, the letter remained unopened, and there was no one to check on those logs even if they reached Assam. He followed the Tsangpo downstream as far as Onlet, a small village near the Indian border. He could see the haze of the Assam plains; he was about 64 kilometers in a straight line from the border. He concluded that the Tsangpo did indeed flow into the Brahmaputra.

Kinthup returned to Darjeeling in 1884 and resumed tailoring. Two years later, he was debriefed by the Survey of India, but no one believed him. It was only in 1913, following a report by Bailey, that Kinthup's description was acknowledged as remarkably accurate. Aerial photography and satellite imagery have now confirmed beyond doubt that the Tsangpo enters India, is called the Siang, and forms a major tributary of the Brahmaputra.

View of Siang as it leaves the mountains and hits the plains for the first time

After the journey of Kinthup, no further physical explorations were undertaken, but the journey of the river was known through technology. In the year 2003 a party of Indian explorers including myself, trekked from the south, coming from the plains of Assam to reach the entry point of the river into India and named it, the “S” bend, completing the physical exploration of the Tsangpo. Standing there and completing a historic exploration was the elixir of my trekking life.

The Tsangpo bend expedition from 16 November to 5 December 2004 was organised with two main objectives: firstly, to see and photograph the bend where Tsangpo enters India and secondly to see if Namcha Barwa, the massif, around which the river takes a right angle southwards to reach Guyor La could be visualised from the Upper Siang valley. The expedition comprised of Motup Chewang (adventure tour professional, Ladakh), Wing Commander V K Sashindran (Assistant Professor, Armed Forces Medical College, Pune), with Lt. Rippon Bora (17 Kumaon, Indian Army) and myself.

❄

THE ORIGIN OF THE YARLUNG TSANGPO RIVER

Xiawei Liao

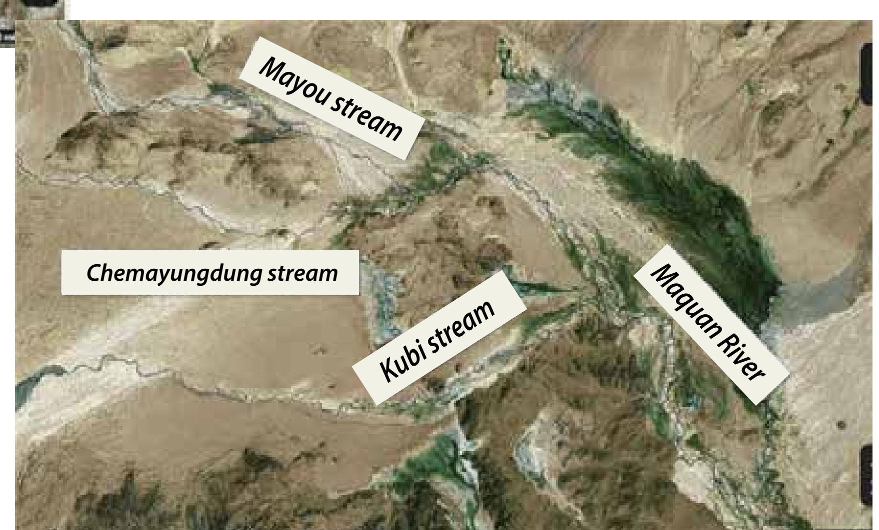
From 2007 to 2010, Chinese Academy of Sciences and the National Geomatics Center of China under the National Administration of Surveying, Mapping and Geo-information formed joint expedition teams to conduct field investigations in the headwater areas of the Yarlung-Tsangpo River in Tibet Autonomous Region of China. The field investigations showed that the Yarlung-Tsangpo River originates from the Angsi Glacier (82°03′20″E, 30°22′06″N), located on the northern side of the Himalayas and southeast of Mount Kailash and Lake Manasarovar in the Burang County in Tibet. The altitude of the origin is 5319.7 meters[45].

Based on the identification of the origin the river length is 3,848 kilometers and the drainage area is 712,035 square kilometers.

(Left) The headwater region of the Yarlung-Tsangpo River

Before the expedition, the origin of the Yarlung-Tsangpo River was thought to be the Chemayungdung Glacier (Figure 2), according to what was proposed by the Indian geographer Swami Pranavananda in the 1930s based on traditional Tibetan information.

(Below) The upstream of the Yarlung-Tsangpo River



The Chemayungdung Stream converges with the Mayou Stream from the north and Kubi stream from the south (Figure 3) and becomes Maquan River (meaning the horse river in Tibetan), the upper stream of the Yarlung Tsangpo.

Against the global context of climate change, glacier retreating has raised growing concerns. Liu and Xiao (2011) analyzed topographic data of the Chemayungdung Glacier from 1974 to 2010 and concluded that the glacier area has decreased by 5.02% and the glacier terminal has retreated 768 meters at a rate of 21 meters per year. The terminal lake area has increased by 63.7 percent, from 0.7 square kilometers to 1.14 square kilometers. The volume of the lake has increased by about 9.8 million cubic meters.

This may be surprising and counterintuitive. The headwater region of the Yarlung-Tsangpo River actually suffers from serious desertification issues due to the high altitude, dry climate and wind disasters (Figure 4). Desertification has also resulted in serious grassland retreat and conflicts between grassland conservation and animal grazing[46].

(Below) Desertification in the headwater region of the Yarlung-Tsangpo River

Tributaries of the River

IN THE course of its 3,350 kilometers journey, the River receives as many as 22 major tributaries in Tibet, 33 in India[12] (another estimate indicates 50 tributaries in India, 30 of these coming from the north and 20 from the south[13]), and 5 in Bangladesh. Like the main channel, many of the tributaries take on different names at their origin and as they cross the borders or meet with another tributary. In this narrative, the local names of the tributaries as they join the main channel have been used (shown in the Basin Map and Figure 1).

The tributaries of the Yarlung Tsangpo are mostly snow fed, as they originate in snow covered high mountains. As mentioned earlier, in this region the major tributaries are Doxung Zangbo, Nianchu, Lhasa, Nyang, Parlung Zangbo and Yigong Zangbo.

Although the Yarlung Tsangpo flows west to east, the tributaries flow in the opposite direction that is in a westerly direction before joining the main channel, assuming a barbed drainage pattern[14]. The longest tributary is the Lhasa, which joins the River from the north near the city of Lhasa. Another tributary, the Parlung Tsangpo rises in mountain glaciers situated at the eastern margin of the Tibetan Plateau and flows from east to west to join the Yarlung Tsangpo, before it plunges into the Yarlung Tsangpo Grand Canyon. The Siang is joined by Dibang and Lohit about 30 kilometers downstream of Pasighat in north-east India. Both these tributaries originate from the extreme eastern flank of the Himalayas. The Brahmaputra gradually gains in size and becomes more silt laden, as it collects water from scores of tributaries flowing from the Himalayas in the north and from the Patkai hills, North Cachar hills and Shillong plateau to its south. The tributaries of the Brahmaputra valley are of two categories. The north bank tributaries originate in high precipation intensity catchments, have very steep channel gradient, carry a lot of sediment and cause choking of river beds resulting in channel shifting or change in drainage pattern; the tributaries from the south have comparatively lower gradient with deep meandering channels, a lower sediment yield, and are more stable than their northern counterparts. The major tributaries that join the northern bank from east to west are Subansiri, Jia Bareli, Dhansiri and Manas; the tributaries that meet the river on its southern bank are Buridihing, Dhansiri (south), Kopili, Krishnai and Jinjiram[15]. The flow contributions of these tributaries are shown in Table 1. The table shows that Subansiri contributes the highest flow to the main channel.

Table 1: Tributary flow contributions to the Brahmaputra
(Source: based on 1995 data, Mahanta et al, 2014)

Tributary	Average flow in million cubic meter (MCM)/yr
Subansiri	52,705
Lohit	46,964
Dibang	37,818
Jia Bharali	28,844
Burhi Dihing	11,906
Kapili Kalang	9,023
Other tributaries above Pandu	121,938
Brahmaputra at Pandu	494,300

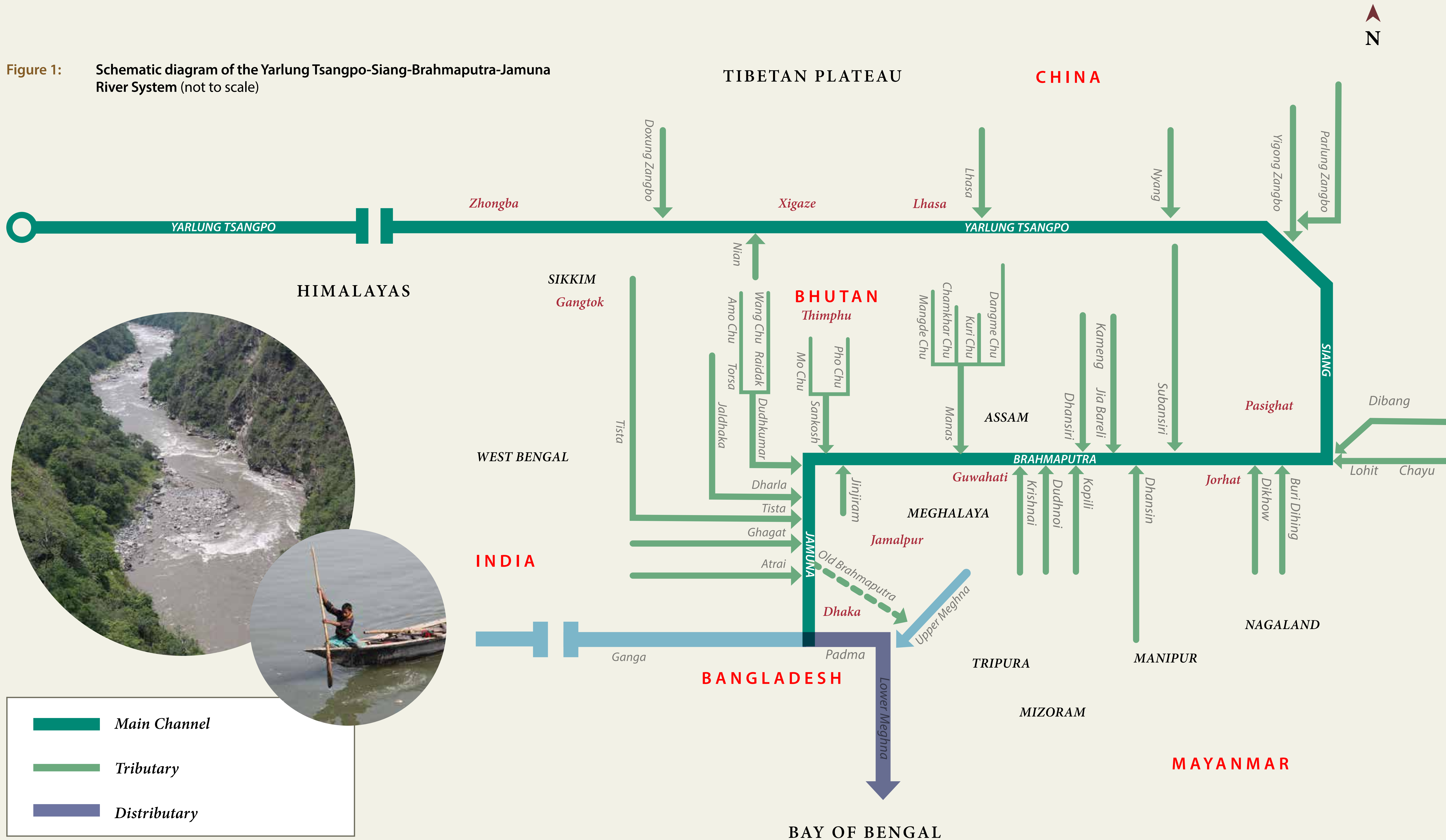
The Dhansiri, Manas, Dudhkumar and Dharla originate in the mountains of Bhutan and contribute substantially to the discharge of the Brahmaputra-Jamuna

The Jamuna, on its southbound course towards the Ganges, is joined by the Dudhkumar, Dharla, Teesta, Ghagot and Karatoya-Atrai rivers on its right bank and the Jinjiram on its left bank. Twenty kilometers south of its entrance, the Old Brahmaputra flows out from the left bank of the Jamuna. Another left bank distributary is the Dhalesawri. The Dhansiri, Manas, Dudhkumar and Dharla originate in the mountains of Bhutan and contribute substantially to the discharge of the Brahmaputra-Jamuna. Many of these tributaries are large rivers in their own right, draining out large catchments while receiving higher-order discharges along their banks. However, only the transboundary tributaries of the River, Lohit, Subansiri, Manas, Dudhkumar, Dharla and Teesta will be detailed in this section.

❄

In the course of its journey, the River receives more than 75 major tributaries. Like the main channel, many of the tributaries take on different names at their origin and as they cross the borders.

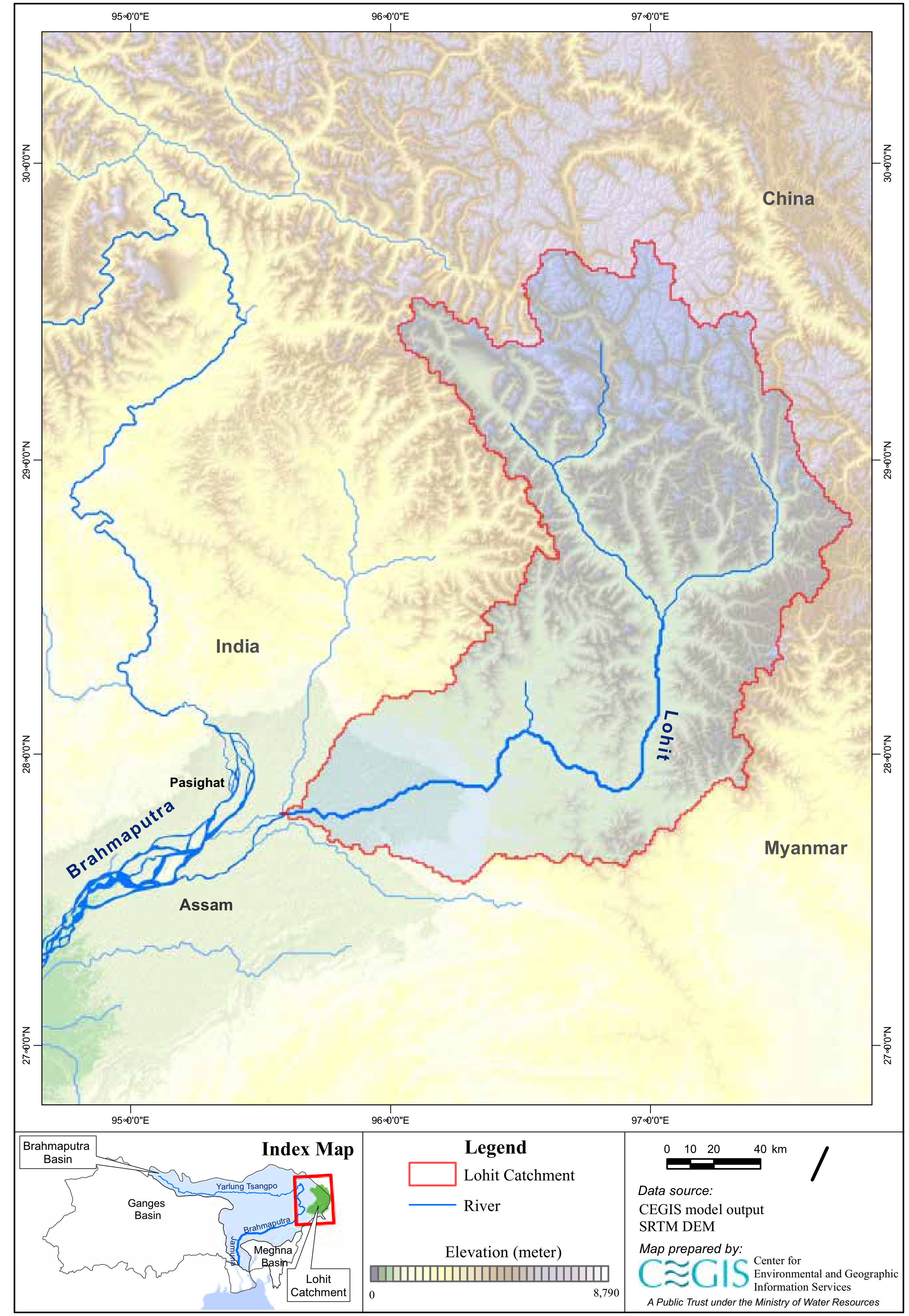
Figure 1: **Schematic diagram of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna River System** (not to scale)



Tributary: Lohit River (Zayul River)

Bushra Nishat

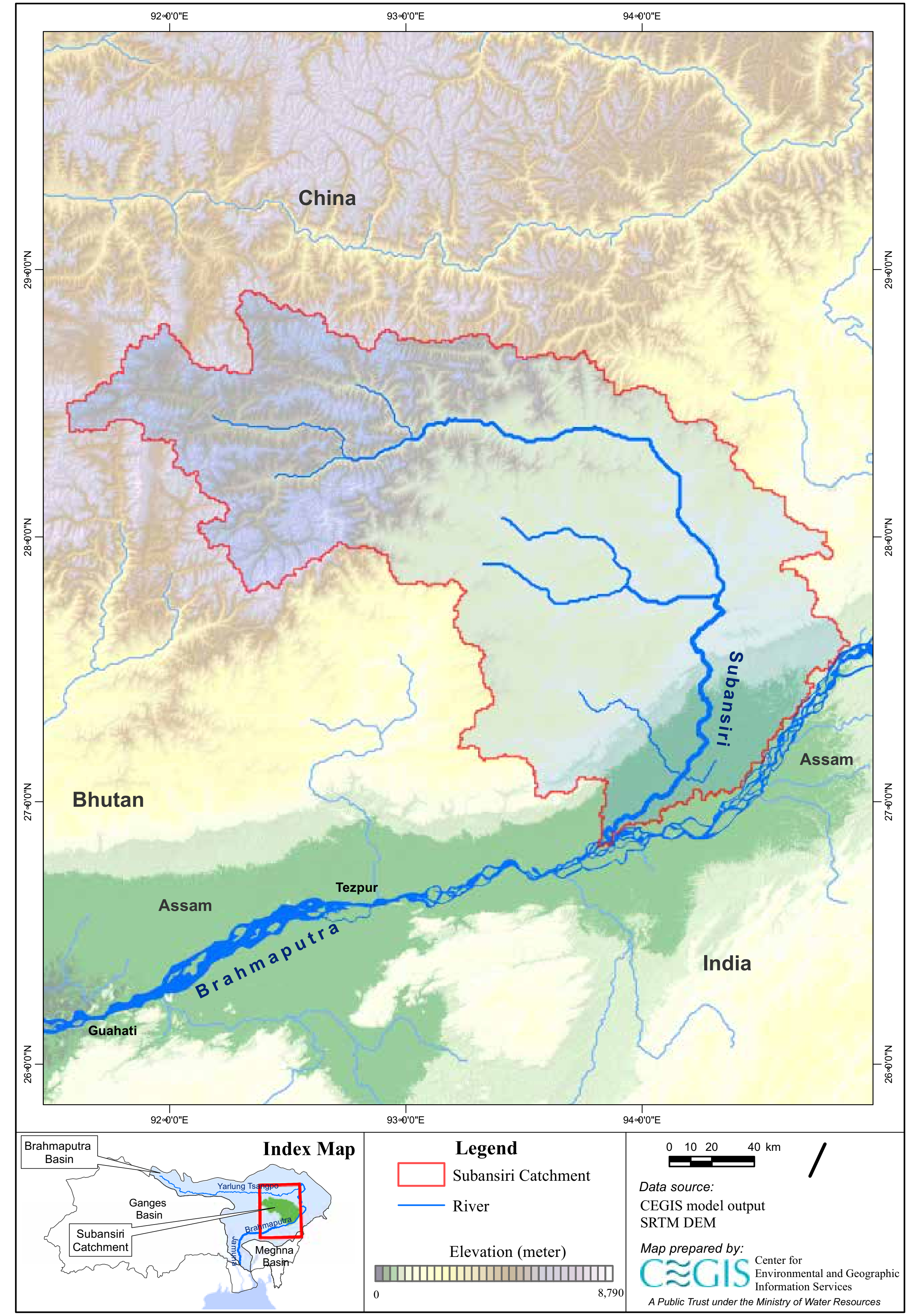
LITERALLY MEANING river of blood, the turbulent Lohit is the eastern most tributary of the Brahmaputra. In ancient times, the Lohit was considered as the main channel of the Brahmaputra. According to folklore, the Brahmaputra originated from the Brahmakunda or Parshuram Kunda, a holy site currently nestled on the lower reaches of Lohit, at the foothills of the Mishimi Hills. The river originates from the Kangri Garpo mountain range of Eastern Tibet as the Zayul and then enters India through the northeastern tip of the country, flows through the Mishmi Hills and descends to join the Siang and Dibang at the head of the Brahmaputra valley. On its travels, the Lohit is joined by numerous tributaries; all these streams are perennially snowfed rivers[17]. A very small part (less than 1 percent) of the Lohit catchment falls in Myanmar.



Tributary: Subansiri River

Bushra Nishat

THE SUBANSIRI is the largest, longest and most important tributary of the Brahmaputra, and contributes around 12 percent of the annual flow of the Brahmaputra. The Subansiri is 442 kilometers long, with a drainage basin covering 32,640 square kilometers in China and India. The Subansiri River originates in the Himalayas, in China at an elevation of 5,591 meters above sea level. It flows east and southeast into India, then south to the Assam Valley, where it joins the Brahmaputra on its northern bank. Many tributaries such as Kamala, Kurung and Ranga join the Subansiri as it descends into the Brahmaputra valley[18]. Subansiri meaning the flow of gold in Assamese was a potential site for the valuable mineral. Religious Epics record that, the Kings of Brahmaputra valley offered Yudhistira, son of the Hindu God of justice and death, a gift of gold shipped on elephant back. Legends claim, this gold was carried by the water and washed since ancient times by the local tribes called Sonowals[19].



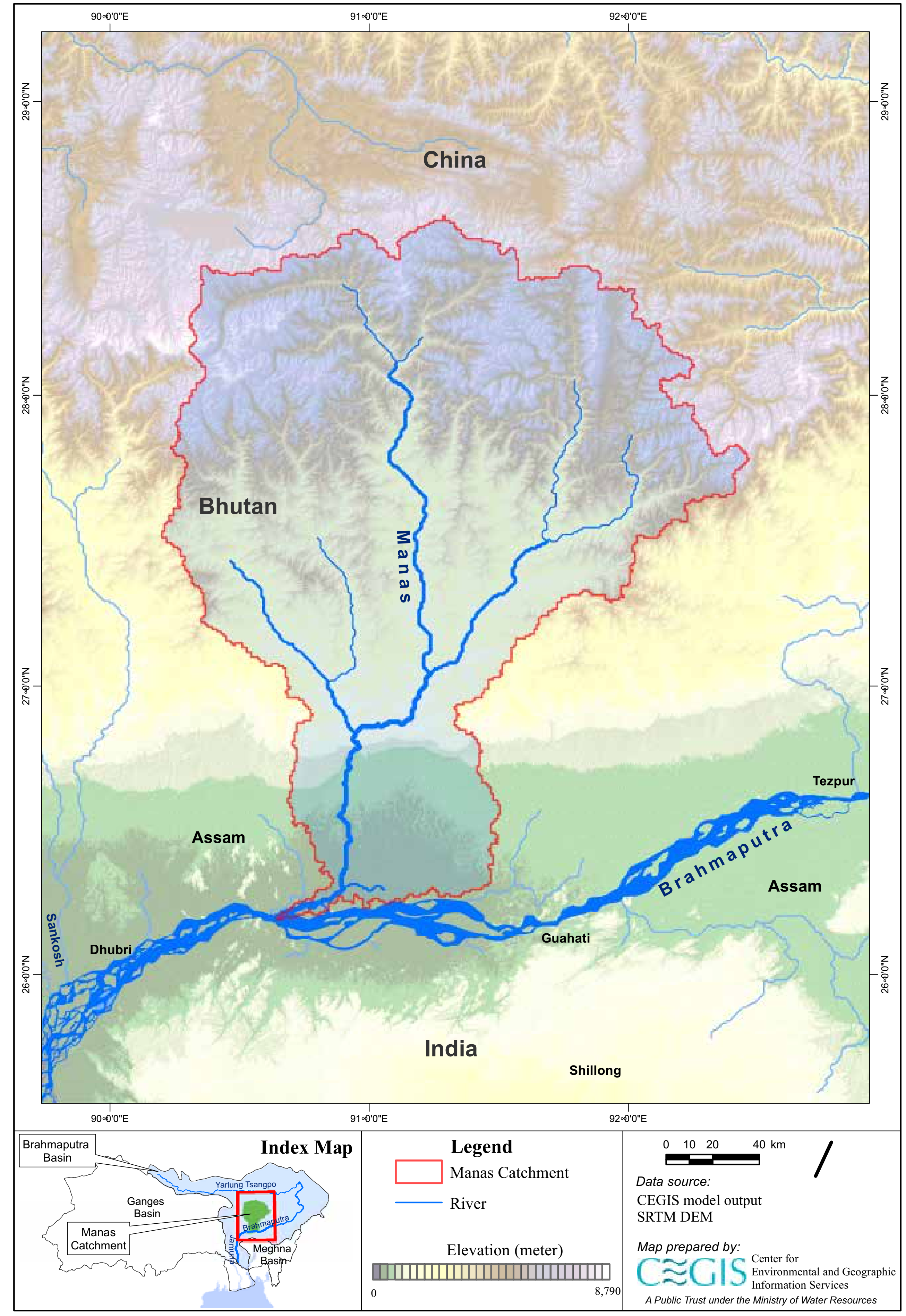
June 2020

Tributary: Manas River

Md Monowar-ul-Haq

THE MANAS is the largest river system of Bhutan, which drains almost all the catchments of the central and eastern regions of the country. It comprises of four major sub-basins, namely Mangde Chhu and Chamkhar Chhu; Kuri Chhu, which originates from Tibet; and Dangmechhu, formed by joining two main tributaries Kholongchhu that originates from the northeastern part of the country and Gongri that originates from Tibet and flows into India before entering Bhutan. Mangde Chhu and Chamkhar Chhu both originate close to Gangkhar Puensum which has a height of 7,570 meters above sea level, is the highest peak of Bhutan and one of the highest unclimbed mountains in the world. The Manas basin covers 8,457 square kilometeres, which represents 22 percent of the total area of Bhutan[20]. The catchment is mostly covered by steep mountainous terrain, rising within a space of 140 kilometers from an elevation of about 100 meters near the Indian border to the great Himalayan peaks at over 7,500 meters along the main Himalayan range bordering Bhutan and Tibet. The huge elevation range and varied climatic conditions are reflected in the great ecological diversity and rich fauna and flora in the river catchment[21].

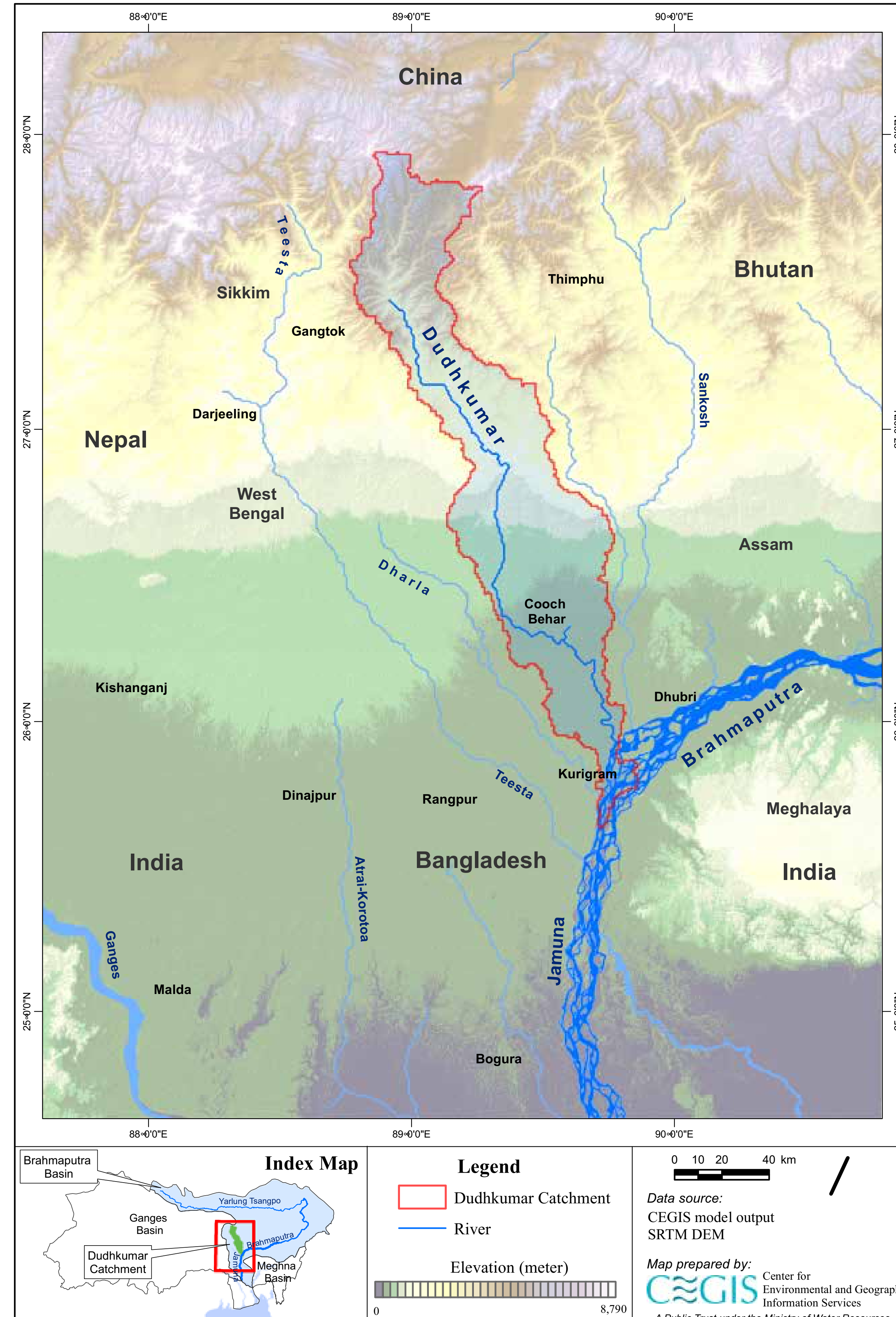
The climate is extremely varied, ranging from hot and humid subtropical conditions in the south to cold and dry alpine conditions in the north. From May to October, the southwest monsoon brings heavy rainfall, more than 6,000 millimeters to the southern part and there is a pronounced dry season in winter[22]. The difference between maximum and minimum river flow in monsoon and the dry months is said to be as much as 20 times. The Manas merges with the Brahmaputra in Duars[23] of India, has a recorded maximum discharge of 7,641 cubic meters and contributes 5.48 percent of the total flows of the Brahmaputra[24].



Tributary: Dudhkumar River/ Torsa-Raidak River system

Md Monowar-ul-Haq

THE TWIN streams of Torsa and Raidak draw their source-waters from high glacial valleys that fringe western Bhutan and the Tibetan plateau and merge in West Bengal, India as the Dudhkumar, which flows through northeastern Bangladesh as a major tributary to join the Jamuna. In Bhutan the Torsa and Raidak are known as the Amuchhu and Wang Chhu respectively. Just before the Torsa-Raidak confluence, one Raidak distributary combines with Sankosh, another Indian tributary to flow into the Brahmaputra near the Assam-Bengal border. The Raidak thus contributes to the Brahmaputra through two river systems, one branch of which is gaining prominence as the other shrinks. However, till the downstream flows of the Torsa and Raidak unite, they are widely seen as separate rivers in their upper, middle and lower segments. Therefore, a real sense of their regional importance is better gained if they are viewed initially as distinct systems[25].

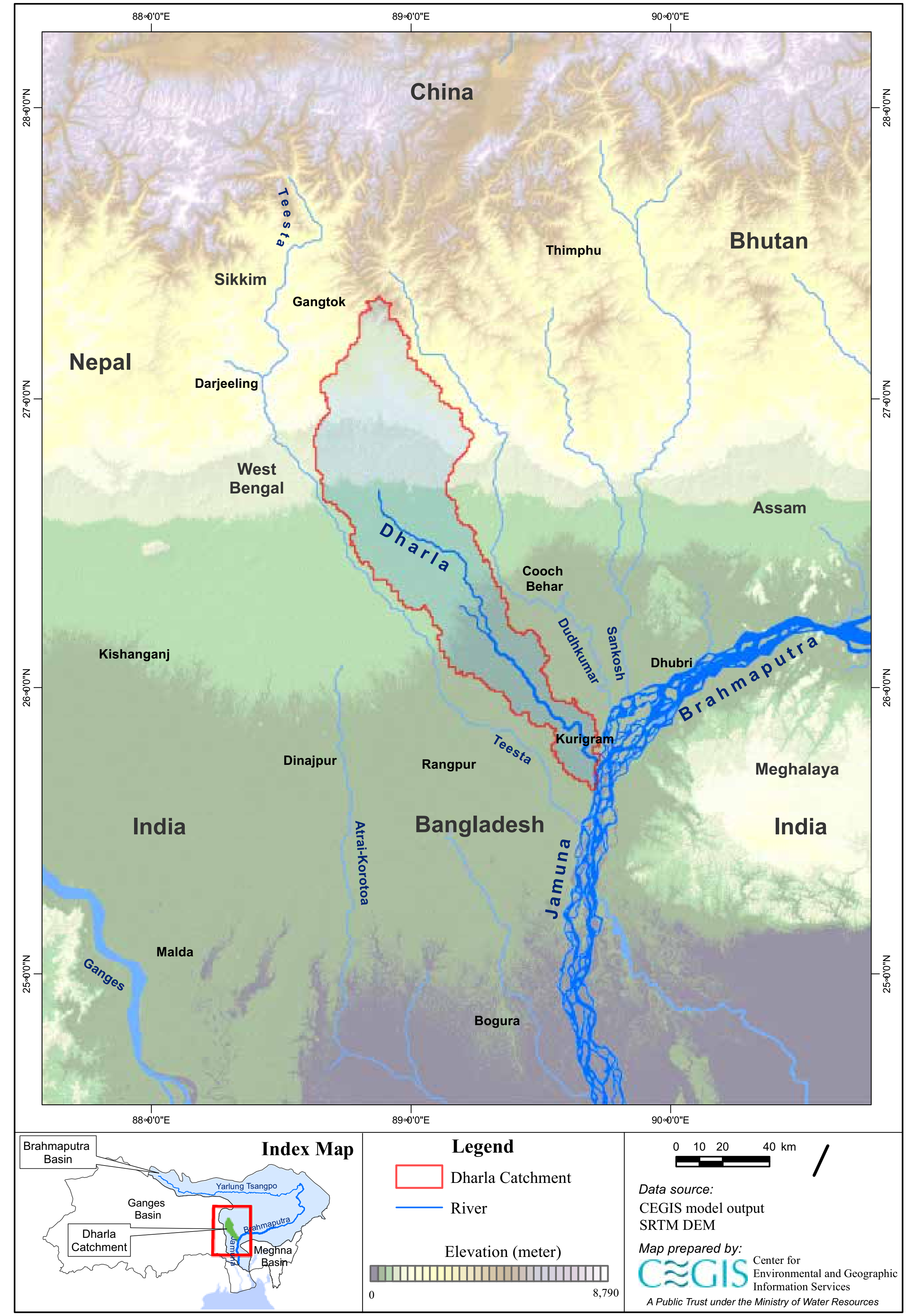


June 2020

Tributary: Dharla River/Jaldhaka River

Bushra Nishat

FROM ITS source and most part of its upstream, this tributary emerges as Jaldhaka from the eastern part of Sikkim, the southwestern highlands of Bhutan and the Darjeeling hills of West Bengal in India. Flowing east of Teesta, it gathers waters from several mountain streams as it descends on the low lying Duars of northern Bengal. As it flows downstream, the Jaldhaka, also known as Mansai in some areas of Jalpaiguri, assumes a new name Dharla as it crosses the international border and joins the Jamuna north of the Teesta-Jamuna confluence. The Dharla is completely rainfed. With a large and well-developed higher-order catchment, it receives major tributary rivers along both its banks. These include the Jaldhaka that separates India from Bhutan, as well as the various segments, Mansai, Jaldhaka, Singimari, that feed into the Jaldhaka downstream. This variety of names also identifies the Jaldhaka as another transboundary river that has swung widely over its floodplains in the past[26].



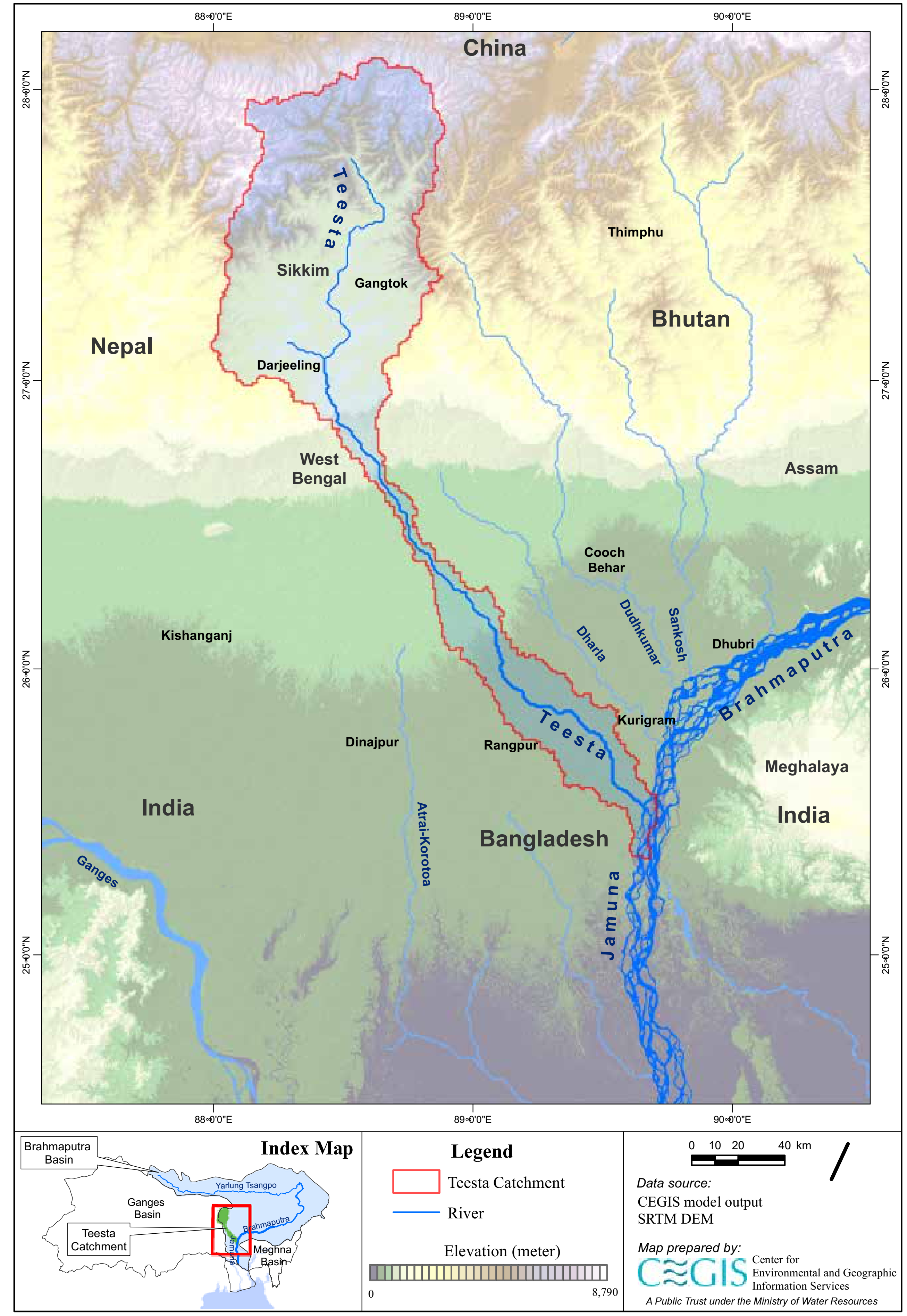
Tributary: Teesta River

Malik Fida Abdullah Khan

THE TEESTA originates high in the Himalaya at an elevation of 5,330 meters above sea level from the Cholamo Lake and crosses Sikkim and West Bengal states of India before joining the Jamuna in Bangladesh. This river is the main tributary of the Jamuna and a river of high importance in Sikkim, northern part of West Bengal and northwest Bangladesh. In the northern state of Sikkim of India, the emerald green waters of the Teesta dominate the landscape of the mountains and valleys. As the river winds its way through the Himalayan temperate and tropical valleys it is fed by smaller rivers which arise from Thangu, Yumthang and Donkia-La ranges. The main tributaries being the snow and rainfed – Lachen and Lachung, Rangeet and the Rongni-chu rivers[27].

Historians believe the name Teesta comes from the Bengali word Trisrota (having three torrents) as once this river split up into three distributaries, the Punarbhaba, the Karatoya and the Atrai. This tendency to shift course is displayed by most mountain-sourced rivers of this region, the Teesta is the largest among these to have periodically undergone such shifts. Each swing of the river has irretrievably transformed the economic life and activities of the eco-region through which the Teesta flows[28].

The rain and snow fed river is perennial but flow in the dry season goes down drastically. The average annual rainfall varies from 1,200 millimeters to 2,500 millimeters in the Teesta basin[29].



CLIMATE OF THE BASIN

Fanyu Zhao and Di Long

THE LOCATION, complex topography and tremendous height of the Himalayas impedes the passage of cold continental air from the north into the Brahmaputra valley and Jamuna floodplains in winter and also forces the rain-bearing summer monsoon from the Bay of Bengal to limit moisture content before crossing the range northward. The result is heavy rain in lowlands and snow at higher elevations on the southern part of the basin but arid conditions in the Tibetan Plateau[30]. The Himalayas thus divides the entire basin into two distinct climatic zones:

(1) **the mountain climate**, characterized as cold and dry, dominates the northern part of the basin; and (2) **the tropical monsoon climate**, characterized as warm and humid, dominates the southern part.
However, based on climate and topography there are three distinctive physiographic zones, the Tibetan Plateau, the Himalayan Belt and the lowlying flood plains[31].

The Himalayas thus divides the entire basin into two distinct climatic zones: the mountain climate and the tropical monsoon climate

Temperatures in the three physiographic zones

Average temperature and precipitation in the basin vary in the three physiographic zones. Typically, December and January are the coldest months, and May to August are the warmest months of each year. The mean annual precipitation in the basin is about 1,350 millimeters[32], of which 60 to 70 percent occurs during the summer monsoon months (June to September)[33], 20 to 25 percent in the pre-monsoon months from March through May.

The Tibetan Plateau is coldest with average temperatures ranging from −10 °C in winter to 7 °C in summer. Winter temperatures in the Himalayan Belt fluctuate around 2 °C, whereas summer temperatures are approximately 15 °C on average. The low-lying flood plains are the warmest among the three zones, with mean winter temperatures around 17 °C and mean summer temperatures about 27 °C. For all zones the seasonal temperature variation is largest in winter but smallest in summer[34].

Precipitation in the three physiographic zones

The dry Tibetan Plateau has a mean annual precipitation of 734 millimeters, however, around the Yarlung Tsangpo Grand Canyon, channels of moisture and precipitation extend northwards, which translates into significant rainfall, around 2,000 millimeters or less per year north of the Himalayan front in the syntax region[35]. Snowpack of the Tibetan Plateau also plays a crucial role in the variation in inter-annual precipitation. Upper-tropospheric air temperatures above the Plateau are amongst the warmest on the planet as a result of the heating of the elevated land with altitudes of over 3,500 meters above sea level. The tropospheric temperature gradient between the Tibetan Plateau and the Indian Ocean is essential for the occurrence of the Indian monsoon. The snow depth on the Tibetan Plateau affects the land surface thermodynamics and

reduces this thermal gradient[36].

The Himalayan Belt is situated in the periphery of the extra-tropical circulation and tropical monsoon circulation in the north and south respectively. Southwesterly monsoon currents channel moist air toward the eastern Himalayas, where the moisture rising over the steep terrain cools and condenses to fall as rain or snow. Annual average precipitation varies between 1,000 millimeters and 1,600 millimeters in the north to higher than 4,000 millimeters in the south at the lower reaches of the mountain ranges[37].

The Brahmaputra floodplains are the wettest part of the basin with an average precipitation of 3,500 to 4,000 millimeters. Within Bangladesh, the annual rainfall within the Jamuna floodplains varies between 1,500 millimeters and 3,000 millimeters[38].

Glaciers of the Basin

Due to the high altitude and low temperature, glaciers are widely distributed in the basin, with an area of about 9,513 square kilometers[39]. These glaciers are mainly distributed in the high altitude areas of the Himalayan mountain ranges. In the eastern Nyainqentanglha range, the glaciers are extremely developed, mainly affected by the Indian monsoon, with a low elevation (minimum 2,400 meters), and glacier tongues generally extend into forests. The impact of climate change on glaciers is becoming apparent with the majority of glaciers shrinking. Rising temperatures is one of the major causes of snow-melting in the Yarlung Tsangpo catchment. The increased rates of snow and glacial melt are likely to increase summer flows for a few decades and accelerate glacial lake expansion[40].

Climate change in the Basin

Over the past decades and across the basin, temperatures are changing over time and showing mixed trends across seasons and in different areas of the basin. Overall, mean winter minimum temperatures show increasing trends, and nighttime temperature shows a highly significant warming trend for winter as well as summer. There has been a significant rise of 0.5 °C in mean minimum winter temperature across the basin. As for precipitation, no specific trend of change in the amount of rainfall has been observed between the baseline period of 1951–1980 and 1981–2007. Extreme rainfall appears to be decreasing in the north but increasing over eastern portions of the basin. Rainfall intensity has increased slightly over eastern portions of the basin[41]. Therefore, there could be more disastrous problems like flood frequency and lake outburst.

Glacial reserves combined with the extremely dynamic monsoon regime interacting in a unique physiographic setting and active seismo-tectonic geological base have moulded the river into one of the world's most massive fluvial systems

HYDROLOGY

Glacial reserves combined with the extremely dynamic monsoon regime interacting in a unique physiographic setting and active seismo-tectonic geological base have moulded the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna into one of the world's most massive fluvial systems. The inter annual discharge and repetitive patterns of rise and fall of flow correspond to the seasonal variation of monsoon precipitation and freeze-thaw cycle of the glaciers and snowpack in the basin. The seasonal variation in flow is thus highly skewed with around 70 to 80 percent of the flow occurring during monsoon and very small flow during dry season[42]. Floods inundate the landscape during the summer monsoon every year as rainfall and snowmelt from the mountains cause the rivers to spill over their banks. These inundations frequently develop into devastating floods, especially in India and Bangladesh. The average annual runoff of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna River at Majuli and Pandu in India is 278 and 509 billion cubic meters[43] respectively, and at Bahadurabad in Bangladesh the flow becomes 660 billion cubic meters[44].

This section describes the network of the main channel, tributaries and drainage outlets, the hydrology and floods of the River.

Hydrology of the River System

Md Monowar-ul-Haq, Malik Fida Abdullah Khan, Tanvir Ahmed

THE WATER yield of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna basin is one of the highest in the world; the drainage area is the fourteenth largest in the world, yet, in terms of flow the River carries the fifth largest discharge[47]. It should be noted that the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna catchment is largely ungauged; moreover, topography, accessibility and to a large extent, economic considerations restrict the routine data collection which can consequently limit the accuracy of the data owing to the fact that the river through its course, traverses some of the steepest jagged ravines and dense temperate and tropical forest landscapes[48].

The water yield of the river basin is one of the highest in the world; the drainage area is the fourteenth largest in the world, yet, in terms of flow the River carries the fifth largest discharge

Figure 5 illustrates the catchment-wise flow contributions for the River system. The estimations of flow are based on basin level hydrological modelling using the ArcSWAT model tool based on the Soil & Water Assessment Tool (SWAT) with precipitation data for the period 1981 to 2012[49]. River, tributaries and sub-basin delineation has been principally based on georeferenced Digital Elevation Models. The delineated Brahmaputra Basin was sub-divided into 223 watersheds for flow calculations. For weather data (precipitation, temperature, relative humidity etc.), a combination of both local (Bangladesh portion of GBM) and global (transboundary portion of GBM) sourced data have been used. The model has been calibrated and validated against monthly discharge data at Bahadurabad inside Bangladesh and simulated for a period between 1981 and 2012 and annual average flow was estimated for each catchment to assess the percentage of catchment contribution.

Figure 5: Sub-catchment flow contributions for Yarlung Tsangpo-Brahmaputra-Jamuna Basin

Source: Analysis by Center for Environmental and Geographic Information Services (CEGIS) based on Shuttle Radar Topographic Mission (SRTM) 90 meter Digital Elevation Data of 2016 (resampled to 900 meter from 90 meter) and the Bangladesh National 300 meter resolution (resampled to 200 meter) Digital Elevation Model[50]

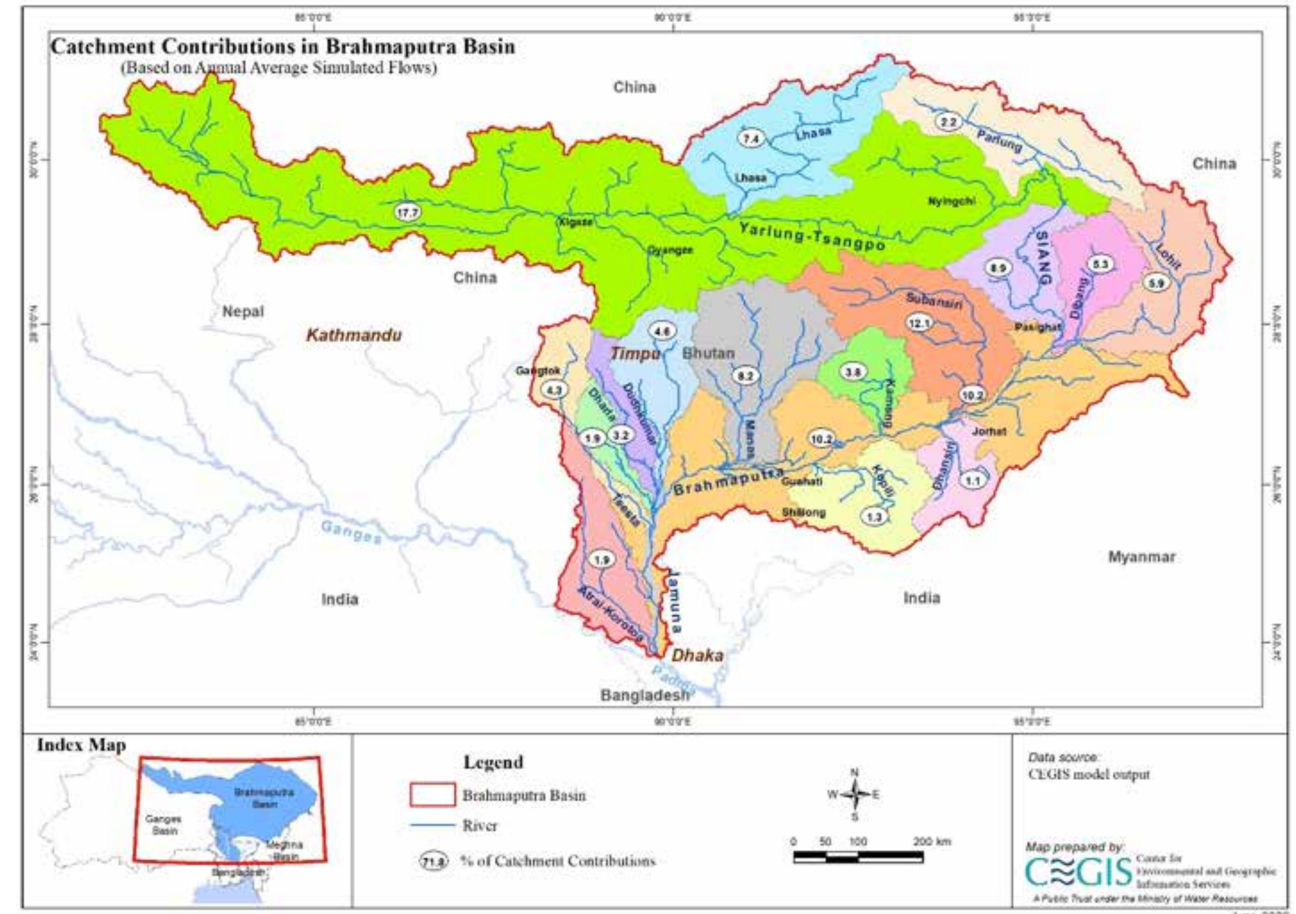
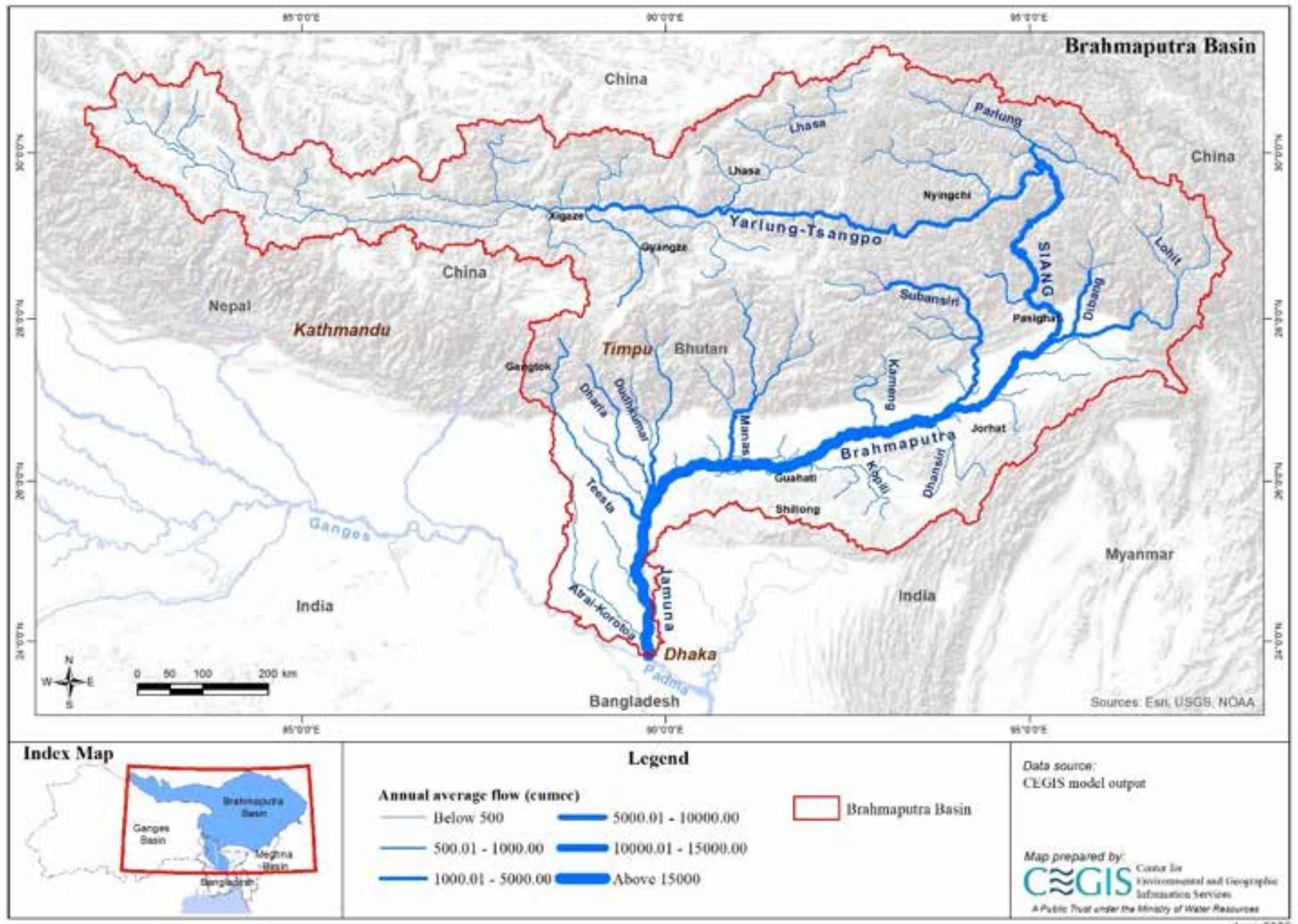


Figure 5 shows the Yarlung Tsangpo is the largest of the catchments which covers nearly half of the entire basin of the River system, but with less than one-fifth (17.7 percent) of the annual flow indicating relatively less precipitation from within the upper catchment bounds[51]. The Figure shows that the Yarlung Tsangpo has been further subdivided into three sub-basins for easier calibration. The Brahmaputra sub-catchments which are mainly within India and Bhutan contribute substantially to the flow as these regions see some of the highest rainfall in the world. The six sub-catchments totaling to roughly one-third (34 percent) of the entire basin contribute almost half (47.7 percent) of the total basin flow. The combined flows of Siang, Dibang and Lohit contribute 20.2 percent of the total Brahmaputra flow[52]. By the time the River enters Bangladesh, it already carries almost the entirety of its total flow (93.7 percent). Only 9 percent of the basin is situated in Bangladesh, and this portion experiences relatively low rainfall, so contribution to Jamuna flow from Bangladesh is also compartitively low.

Figure 6 illustrates flow river reach-wise distribution as displayed as proportionate width. It depicts the gradual increase in river discharge as it gains flow via tributary sub-catchments.

Figure 6: Reach-wise flow distribution proportion to flow width for Yarlung Tsangpo-Siang-Brahmaputra-Jamuna System



Hydrology of Yarlung Tsangpo River Basin

Fuqiang Tian, Ran Xu, Yi Nan

THE YARLUNG Tsangpo is one of the largest rivers originating from the Tibetan Plateau in Southwest China. The mean annual discharge is approximately 20,000 cumec[53]. The climate of the basin is monsoon-driven with an obvious wet season from June to September, which accounts for 60–70 percent of the total annual rainfall. Yarlung Tsangpo basin covers Lhasa, Shannan, Shigatse, Nyingchi and Nagqu, and southern Tibet regions. There are four main hydrological stations located along the main stream, i.e., from upstream to downstream, Lazi, Nugesha, Yangcun and Nuxia hydrological stations. Yarlung Tsangpo River has several tributaries. Information of the six main tributaries is listed in Table 2.

Table 2: Length of channel and area of basin of the six major tributaries of Yarlung Tsangpo

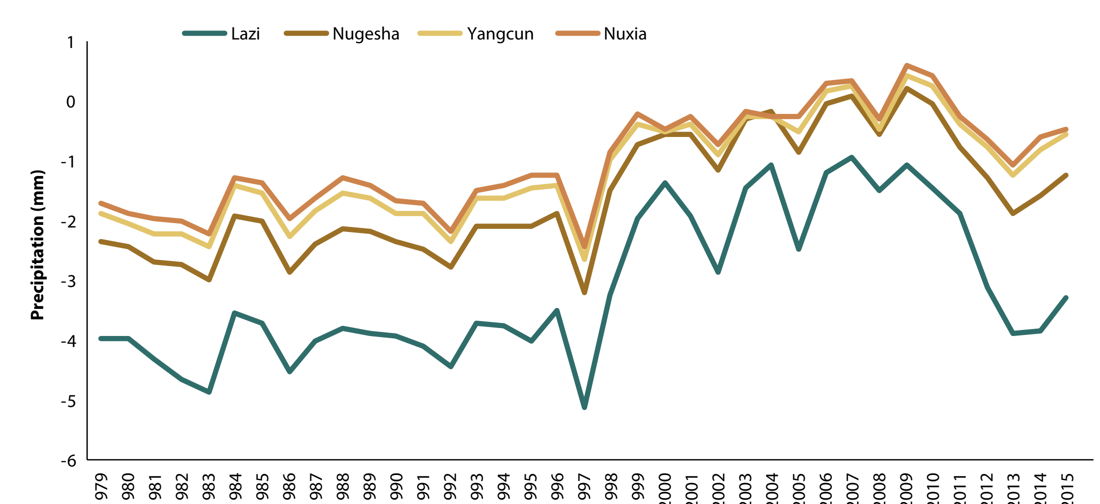
Name	Length (km)	Area (km²)
Doxung Zangbo	303	19697
Nianchu	217	11130
Lhasa	551	32471
Nyang	286	17535
Parlung Zangbo	266	28631
Yigong Zangbo	295	13533

In terms of climate, due to the barrier effect of the high Himalayas and the high altitude of the Tibetan Plateau, the upper and middle sections of the basin, classified as semi-arid climate and cold temperate zone, are extremely cold with little precipitation. The downstream section is humid, rainy and warm and can be classified as mountainous subtropical and tropical climates.

Precipitation in the Yarlung Tsangpo River Basin

The mean annual precipitation of the Yarlung Tsangpo River Basin is 470 millimeters (data from China Meteorological Forcing Data, CMFD). The precipitation shows an increasing trend from the upstream Lazi station to the downstream Nuxia station (Figure 7). The precipitation at Lazi, Nugesha, Yangcun, and Nuxia stations are 410 millimeters, 404 millimeters, 428 millimeters and 470 millimeters, respectively.

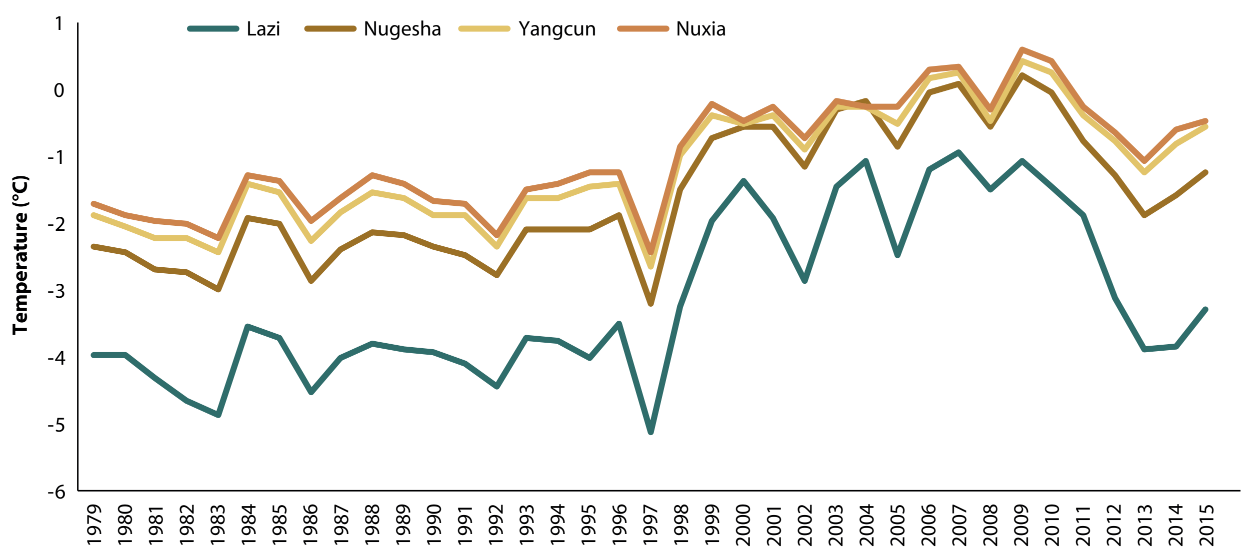
Figure 7. Mean annual precipitation in Yarlung Tsangpo River Basin



Temperature of the Yarlung Tsangpo River Basin

The mean annual temperature of the Yarlung Tsangpo River Basin is -1.01°C (data from CMFD). As shown in Figure 8, the temperature gradually increases as the altitude decreases from upstream to downstream. Mean annual temperature at Lazi, Nugesha, Yangcun, and Nuxiazhan are -3.15°C, -1.59°C, -1.18°C, and -1.01°C, respectively. In terms of temporal pattern, the graph shows a slow increasing trend, which is consistent with global warming.

Figure 8. **Mean annual temperature in Yarlung Tsangpo River Basin**



Hydrology of the Yarlung Tsangpo River Basin

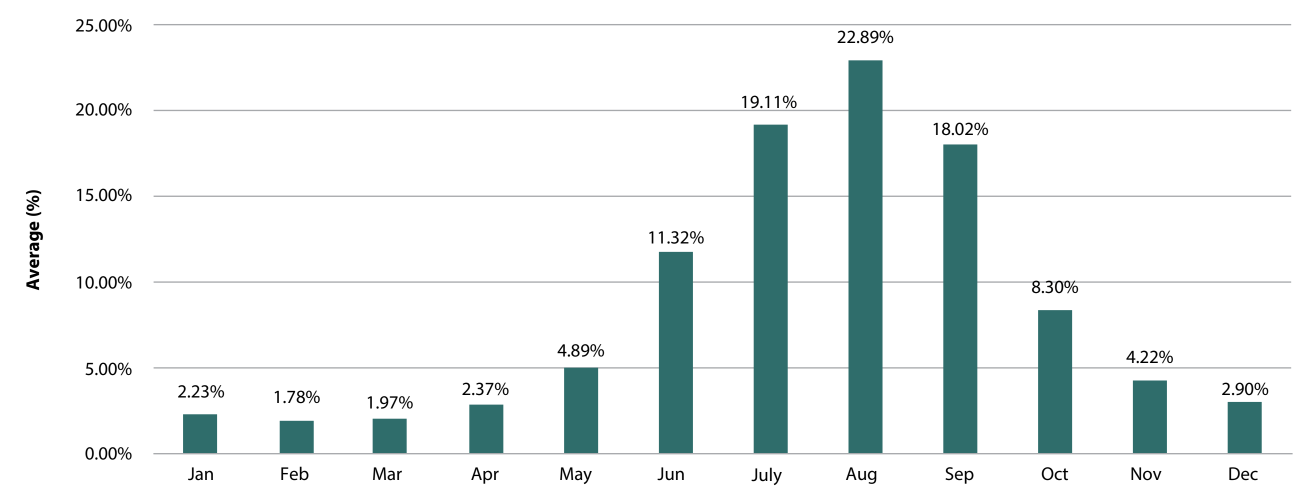
The mean annual runoff depth or water level of the Yarlung Tsangpo River Basin at Nuxia is about 300 millimeters. In terms of spatial pattern, similar to precipitation, the runoff depth increases from upstream to downstream, and the average runoff depth at Lazi, Nugesha, Yangcun, and Nuxia stations are 106 millimeters, 152 millimeters, 184 millimeters, and 292 millimeters, respectively (see Table 3). Due to the effect of monsoon, there is an obvious wet season from June to September, which accounts for more than 70 percent of the runoff (Figure 9).

The runoff of Yarlung Tsangpo River is a mixture of various components. In dry season from October to April of the next year, baseflow dominates the hydrograph. With the increasing temperature, from April to June, snowmelt contributes to the runoff. During the wet season from June to September, the runoff is a mixture of precipitation, snowmelt, glacier melt and baseflow, resulting in a comparatively large discharge[54].

Table 3: **Spatial variation of hydrometeorological elements in Yarlung Tsangpo River Basin**

Name	Mean Annual Precipitation (mm)	Mean Annual Temperature (°C)	Potential Evapotranspiration (mm)	Mean Annual Actual Evapotranspiration (mm)	Runoff Depth (mm)
Nuxia	470	-1.01	2043	195	292
Yangcun	428	-1.18	2104	223	184
Nugesha	404	-1.59	2129	253	152
Lazi	410	-3.15	2012	225	106

Figure 9: **Average seasonal cycles of streamflow at Nuxia station from 1980 to 2012**



Hydrometeorology of Siang-Brahmaputra River Basin

Bushra Nishat

THE SIANG and Brahmaputra along with their network of tributaries dominates the landscape and controls the geomorphic regime of the entire region, especially the Brahmaputra Valley. This is the middle reach and the strongest segment in terms of discharge for the entire River system. Almost 80 percent of this flow occurs in the monsoon season between June and September which corresponds to high monsoon rainfall, especially in the upper reaches of the tributaries. The tributaries have been detailed in a separate section, so in this section the hydro-meteorological conditions of the main channel of the Siang and Brahmaputra is being described.

Climate in the Siang-Brahmaputra River Basin

The climate of this part of the basin is humid sub-tropical characterized by high rainfall and humidity. The physiographic configuration, enormous water bodies and upper air circulation has shaped the climate of this region. The valley is bounded by high mountainous formations and table land in the north, northeast and south; and is wide open in the southwest. The valley thus predominantly receives southwest tropical monsoons during April through October through two inlets, through the southwest and also through hill gaps in the eastern boundary[55]. The monsoon rain accounts for 70 to 80 percent of the annual rainfall with an average between 2,500 and 3,200 millimeters. However, spatial distribution of monsoon rainfall is influenced by orography and varies from 1,200 millimeters in the eastern part to over 6,000 millimeters in the southern slopes of the Himalayas[56]. The higher mountain areas in the north experience snowfall in the winter.

The smaller tributaries are mostly fed by rain and spring water, but the major tributaries orginate from high precipitation areas and in combination with snow and glacier melt contribute large flows to the main channel

The region experiences four distinct seasons, the relatively dry, cool winter from December through February; the dry, hot pre-monsoon season from March through May; the southwest monsoon from June through September when the predominating southwest maritime winds bring rains; and the retreating monsoon of October and November[57]. Post winter, a wide thermal gap is created between the valley and surrounding mountains, this thermal fluctuation and the moisture from the Brahmaputra and its tributaries creates dense fogs, especially in the morning hours[58]. The pre-monsoon season is characterized by a gradual rise in temperature, disappearance of fog, occasional thunderstorms, cool mornings and hot afternoon winds. The hottest month for most of the basin is May when temperatures can rise as high as 40°C, and winter becomes extremely cold as freezing winds from the north depress temperatures in the valley.

Hydrology of the Siang-Brahmaputra River Basin

The Siang-Brahmaputra and their major tributaries show a seasonal variation in discharge pattern, which corresponds to a tropical monsoon climate. The smaller tributaries are mostly fed by rain and spring water, but the major tributaries orginate from high precipitation areas and in combination with snow and glacier melt contribute large flows to the main channel. Since peaking characteristics of flood flows are different in different tributaries, due to catchment physiography and time lag in rainfall, there is a time lag in tributary floods draining into the river. As a result, the flood hydrograph for the Brahmaputra often shows multiple peaks as can be seen from Figure 10.

Figure 10. Hydrograph of Brahmaputra
(Source: Mahanta et al 2014[59])

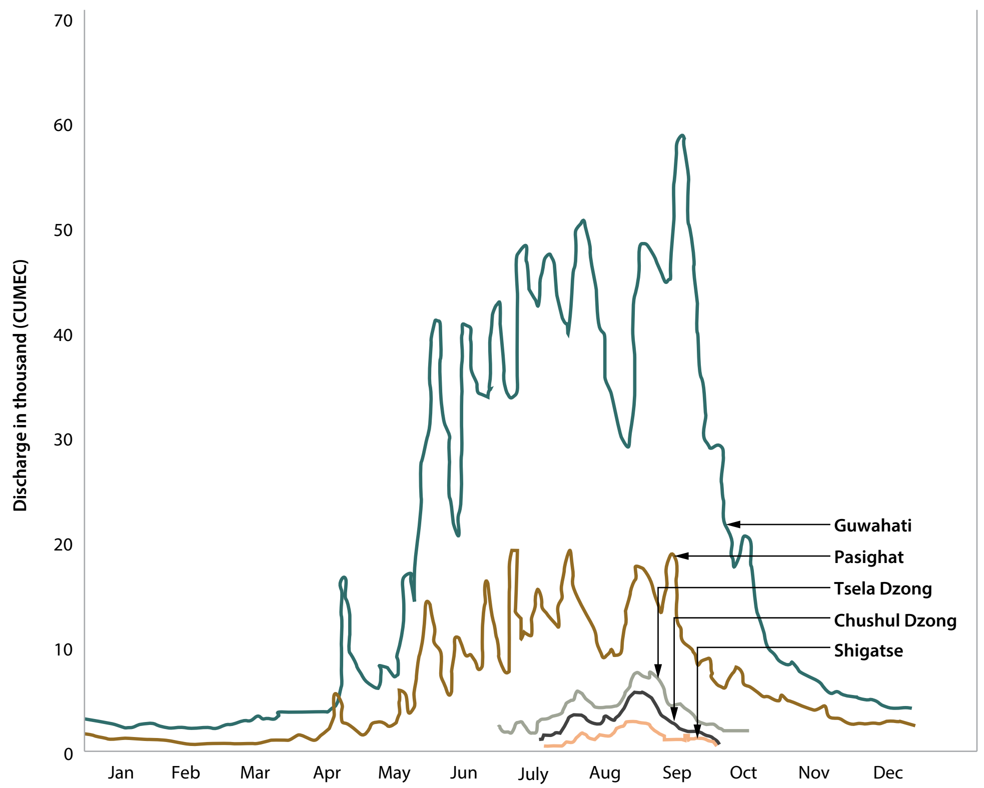
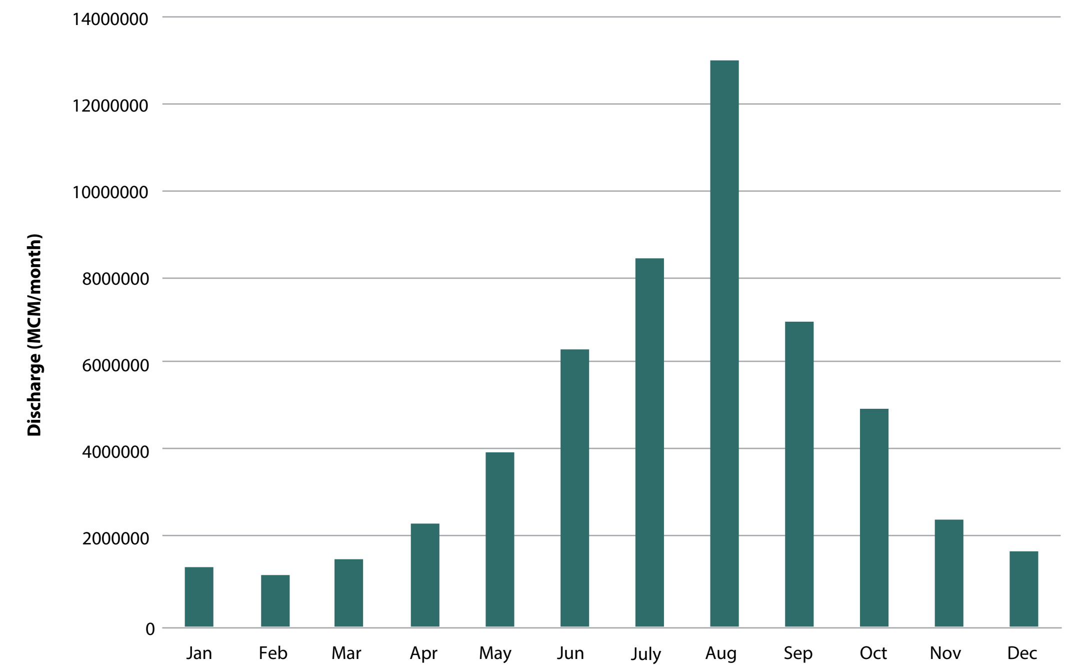


Table 4 shows the different flows of the Siang-Brahmaputra at different locations of the basin at Pasighat, Majuli, Pandu and Pancharatna. It shows that the flow of the main channel increases substantially and almost doubles by the time the River reaches Bangladesh. As seen from Figures 10 and 11, this increase is more prominent in the monsoon[60].

Table 4: Mean annual flows at various locations on the Brahmaputra
(Source: Mahanta et al 2014[61])

Location	Mean Flow (MCM/yr)
Bechamara, Majuli	278,447
Bhurbandha, Bhurgaon	365,550
Pancharatna, Goalpara	509,435
Pandu, Guwahati	526,092

Figure 11. Average seasonal cycles of streamflow at Pandu
(Based on Mahanta et al 2014[62])



The Brahmaputra channel is governed by the peak and dry period discharge during which the channel bed undergoes tremendous adjustment, which in turn affects the flow regime of the river. While the Siang-Brahmaputra is considered a water abundant basin and the main channel and tributaries are perennial in nature, flows reduce considerably between October and May (shown in Figure 11). Since all tributaries pass through alluvial plains, underground seepage is quite high, especially during flood events, providing a substantial base flow for the rivers during dry season[63].

With a catchment area of 47,000 square kilometers, the four river basins of Bhutan cover around 9% of Brahmaputra basin

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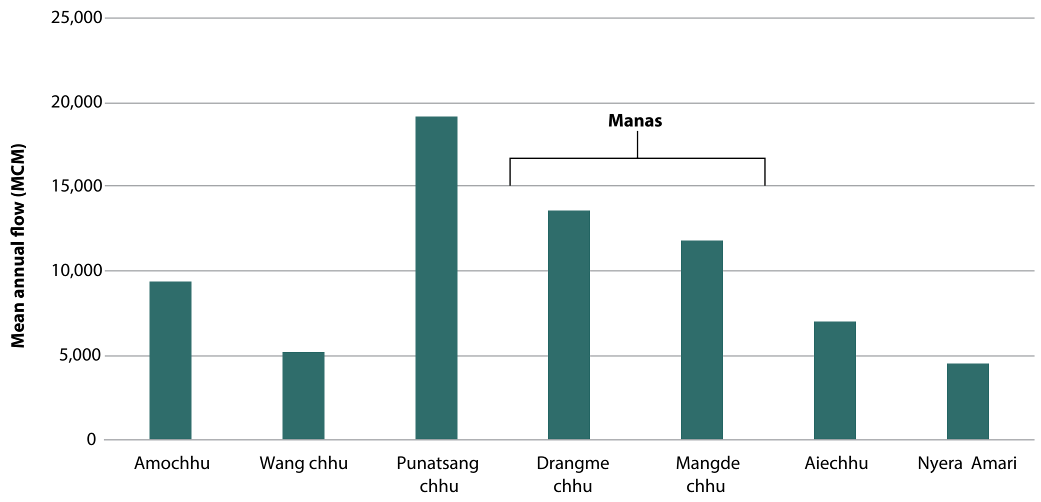
Hydrometeorology of tributaries flowing through Bhutan

Ahmmed Zulfiqar Rahaman

BHUTAN HAS four[64] major river basins viz Amohchu, Wangchhu, Punatsangchhu, and Manas with a catchment area of around 47,000 square kilometers, which covers around 9 percent of Brahmaputra basin[65]. The Manas is the largest river basin with the highest flow, which drains almost all the catchments of central and eastern Bhutan. The basin is around 15,837[66] square kilometers inside Bhutan and covers around 41 percent of the country's territory.

Figure 12: Mean annual flow of rivers of Bhutan
(Source: National Environment Commission (NEC), 2016)[67]



These rivers are mostly fed by rainfall and supplemented by glaciers (2 percent to 12 percent)[68] and snowmelt, which attributes an estimated 70,576 million cubic meters flow from Bhutan into the Brahmaputra-Jamuna river and corresponds to around 12 percent of the flow of Jamuna at Bahadurabad Water and Discharge Guaging Station[69].

The rivers of Bhutan generally have steep gradients in the scale of 1:1140[70] on an average, and narrow steep-sided valleys, which occasionally open up to give small areas of flat land for human settlement and cultivation[71]. They carry large volumes of flow and sediment during the monsoon season and significant snowmelt at the end of the dry season. Average annual suspended load of the Manas River is 2,1660 tonnes and the annual sediment yield is 1,581 tonnes per square kilometer per year[72].

Hydrology of Jamuna River Basin

Md Monowar-ul-Haq and Malik Fida Abdullah Khan

THE BRAHMAPUTRA enters Bangladesh east of Bhabanipur (Assam, India) and northeast of Kurigram district and the river is now called the Jamuna. The Jamuna has an annual average discharge of around 667 billion cubic meters as measured at Bahadurabad Water and Discharge Guaging Station. Over 75 percent of the discharge of the Jamuna river is generated from rainfall and snowmelt from upstream countries, as a result, the flow pattern is not strongly related to local precipitation.

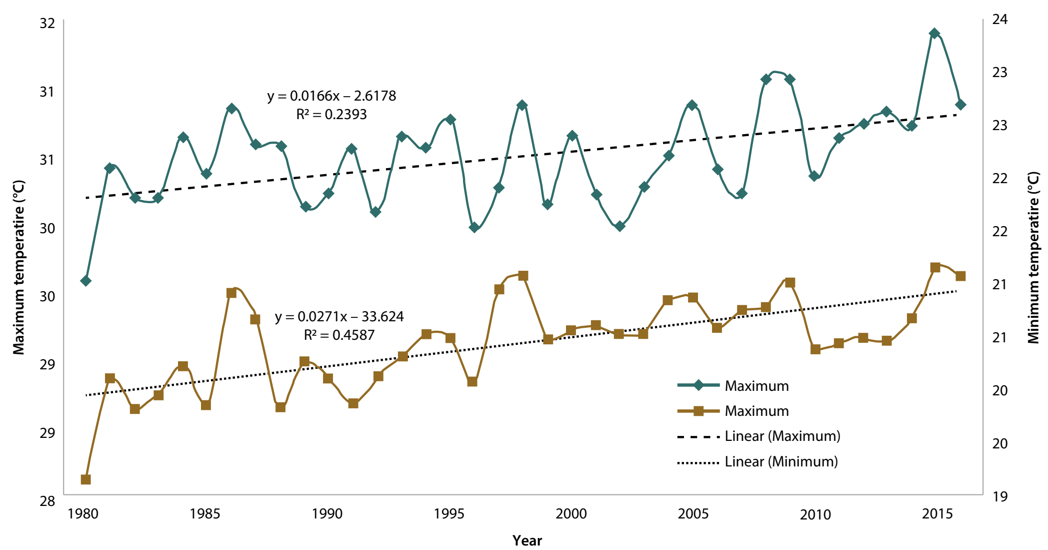
Climate

The Jamuna basin lies in the northwest part of Bangladesh where the climate is sub-tropical in nature with three seasons namely summer/pre-monsoon from March to May, monsoon between June to September, and winter season from October to February. Lower rainfall makes this area atmospherically drier than the rest of the country. The rainy season is hot and humid with about 70 percent to 80 percent of the annual rainfall. The winter is predominately cool and dry.

Maximum temperature occurs in the month of April and minimum temperature in January. Monthly maximum temperature varies from 25°C to 35°C.The average temperature during monsoon is about 34°C[73]. Figure 13 presents a temperature trend analysis for the Jamuna Basin within Bangladesh. Plots are generated for both maximum and minimum temperature values using data for the years 1981-2017. Trends indicate an increase for both maximum and minimum temperatures.

Figure 13: Temperature trend analysis for Jamuna Basin

(Data source: National Water Resources Database, Bangladesh. Analysis by Centre for Environmental and Geographic Information Services (CEGIS))



Average annual rainfall in this region is around 1,900 millimeters which is below the average of Bangladesh, which is around 2,300 mm[74]. Trend analysis of precipitation in the Jamuna basin is shown in Figure 13. Rainfall data for the plot was prepared using the average data for the years 1948-2017 and is compared with the discharge for Jamuna river at Bahadurabad.

Between 1953 and 2016 the Brahmaputra valley experienced major floods on thirty-nine occasions, affecting over a million people

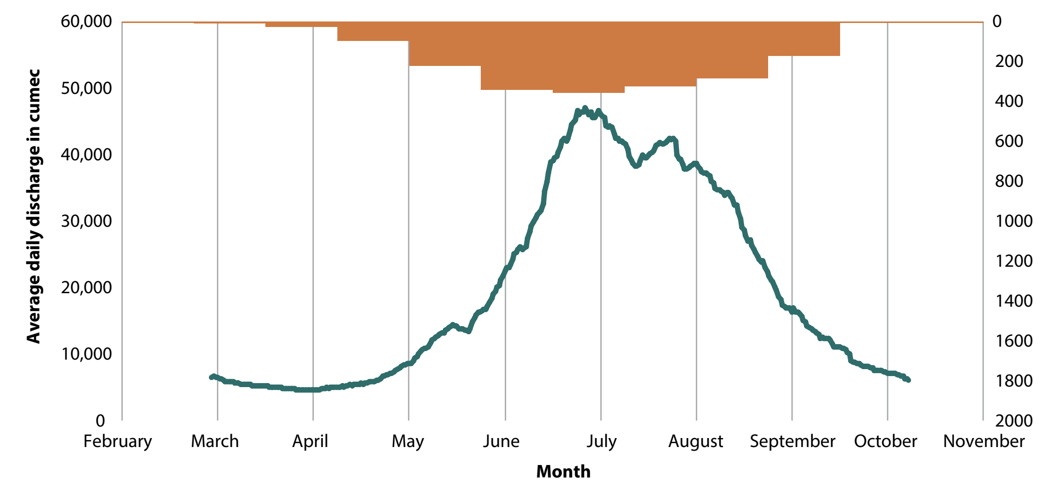
Hydrology

The Jamuna usually peaks in July when the average maximum discharge is about 60,000 cumec and flow reduces in the dry season with average lowest in February at 4,700 cumec[75]. Around 70 percent of total average annual flow is discharged during monsoon.

Figure 14 presents the flood hydrograph for Jamuna at Bahadurabad with data between 1999 to 2019 with monthly average values. The flow hydrograph represents the typical bi-modal nature as observed for Brahmaputra with back-to-back peaks occurring in between July-August and August-September. Onset of these peaks are from the beginning of the monsoon season.

Figure 14: Flood Hydrograph for Jamuna River at Bahadurabad

(Data source: National Water Resources Database, Bangladesh. Analysis by Centre for Environmental and Geographic Information Services (CEGIS)



As mentioned earlier, around 55 percent of the discharge at Lower Meghna is contributed by the Jamuna. Dry season contribution of Jamuna to the Bay of Bengal is even more significant as this river alone discharges around 70 percent of the average Ganges-Brahmaputra-Meghna flow for the month of December, January and February to the Bay of Bengal. During monsoon, the freshwater boundary lies close to the coast, but as the rains die down after monsoon and the flows decline, the saline front advances, penetrating further and further landward over the dry months. The flows of the Jamuna strongly affect the salinity of the Meghna estuary and neighbouring coastal areas by pushing back the coastal salinity line.

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Historical and Future Climate and Hydrology

Arun B Shrestha and Nisha Wagle

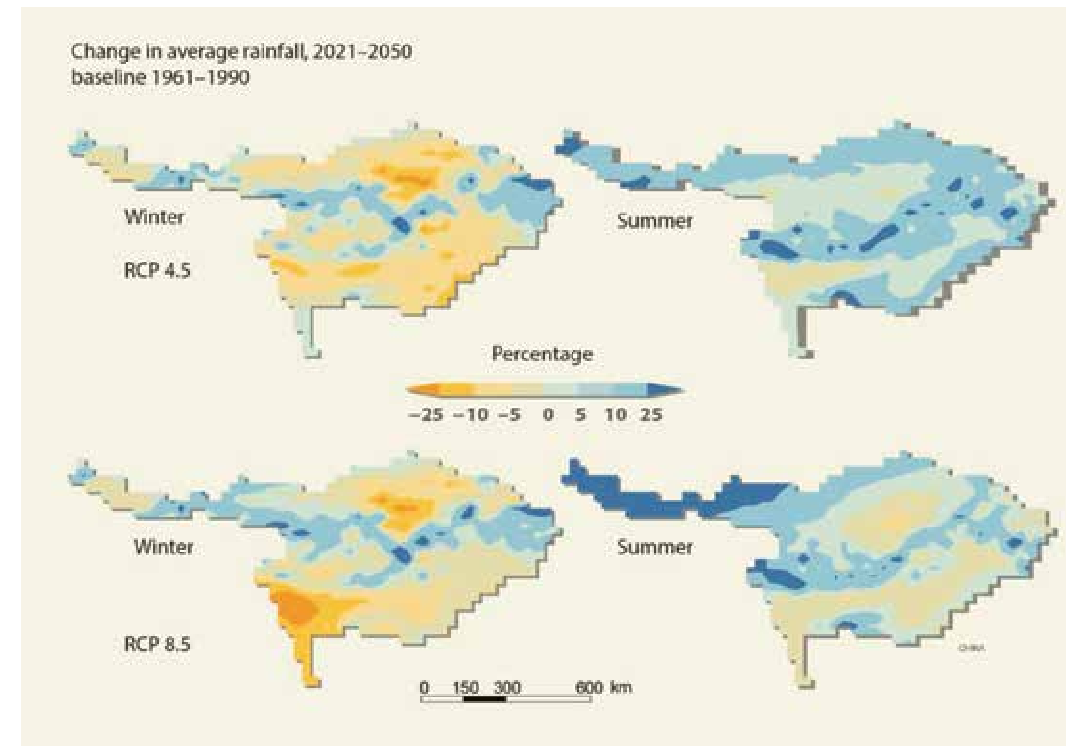
Precipitation: Historical and Projected

The average annual precipitation in the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna basin is just over 1,100 mm, 70 percent of which is received in the monsoon (June-October). The lower basin receives almost three times more rainfall than the upper basin[76]. Majority of the studies do not report significant trends in the rainfall in the basin. For example, Shrestha et al. found no significant trends in the past rainfall records (1951-1980 and 1981-2007) but found slight increase in average and extreme rainfall in the eastern basin[77]. Immerzeel also reported no clear trend from 100 year (1900-2002) monthly precipitation data and suggested that annual precipitation was determined by the monsoon[78]. Flügel et al., reported slight increase in annual and seasonal precipitation from 1961-2005, but with no statistical significance[79]. In contrast, Apurv et al. report increasing trend in summer monsoon during 1990-2000[80].

Unlike in the past, precipitation is projected to increase in the future, including the extremes but with strong spatial and seasonal differences. Shrestha et al.[81] suggest an increase of about 10 percent (from both RCP 4.5[82] and RCP 8.5[83]) in the monsoon season in the mid-century (2050) when compared with 1961-1990, while winter precipitation in the southwest and central northern part are projected to decrease (Figure 15). Likewise, Pervez & Henebey[84] reported seasonal variation in future precipitation with increase in monsoon, post-monsoon and decrease in pre-monsoon, and also suggested monsoon shift from July

to August in comparison with 1988-2010. Wijngaard et al.,[85] projected increase in annual (upto 56 percent) and extremes (P99 upto 104 percent) towards the end of 21st century as compared to 1981-2010. Lutz et al.,[86] also projected increase in both annual and extreme precipitation when compared with 1981-2010 with small decrease in monsoon precipitation in the eastern part for 1.5°C global temperature scenario. Lutz et al.,[87] projected increases in precipitation in 2050 when compared with 1998-2007, in a range between 12 percent and 18 percent under two emission scenarios (RCP 4.5 and RCP 8.5).

Figure 15: Change in future precipitation (2021-2050), when compared with the base period (1961-1990) *(Source: Shrestha et al., 2015)*[88]



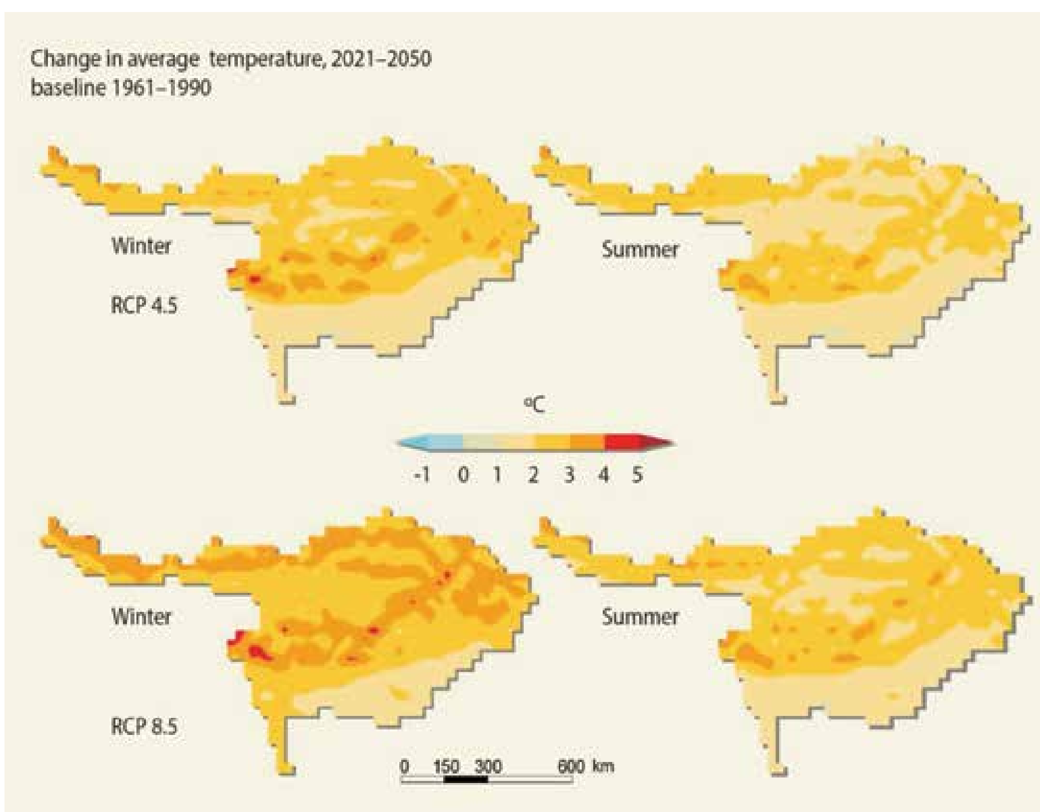
The basin has experienced a general warming trend in the past, but with seasonal and spatial differences with higher warming observed in winter season

Temperature: Historical and Projected

The basin has experienced a general warming trend in the past, but with seasonal and spatial differences with higher warming observed in winter season. Overall, winter minimum (+0.5°C), pre and post monsoon (+0.3°C and +0.4°C), and night-time temperature (both winter and summer) are seen to increase between 1951-1980 and 1981-2007, while the change in summer temperature is not significant. Moreover, extremes (highest maximum) are increasing over the northern parts (Tibetan Plateau), but decreasing east and southwards, and extreme minimum temperatures are decreasing in the center of the basin[89]. Immerzeel[90], reported warming at an average rate of 0.6°C per decade between 1900 and 2002, with 10 percent of the warmest years occurring between 1995 and 2002. Increase in both average annual (+0.28°C per decade) and seasonal temperature (highest in winter: 0.37°C per decade) during the period 1961-2005 with 95 percent significant level was reported by Flügel et al.[91].

The warming is projected to continue and intensify in the future with some indications of elevation dependent warming and more prominent warming in the Tibetan Plateau. Annual temperature is projected to increase in the range of 1-3°C by mid-century (2050) under RCP4.5 and RCP 8.5, with the northern part of the basin projected to warm more prominently. Higher increases are projected for winter temperatures over a major portion of the basin with some areas projected to warm more than by 3°C for RCP8.5 as compared to 1961-1990 (Figure 16; Shrestha et al.,[92]). Immerzeel[93] also projected increase in average temperature from 2000-2100 by up to 3.5°C under B2 scenario (SRES[94] scenarios)[95] as compared to 1961-1990, with highest increase in the Tibetan Plateau. Similar result was obtained by Dobler et al.[96], where increase in annual temperature by 5°C (A1B scenario) and 4°C (B1 scenario) until 2100 as compared to 1971-2000 was projected, and also reported more warming in higher altitude and highest increase in maximum temperature. Wijngaard et al.,[97] also projected increase in average annual temperature towards the end of 21st century in the range of 0.7°C to 5°C for both RCP4.5 and RCP8.5, when compared with 1981-2010. Likewise, recently Lutz et al.,[98] also projected increase in average temperature, higher in the Tibetan Plateau under 1.5°C and 2°C global average warming scenario, when compared with 1981-2010.

Figure 16: Change in future average temperature (2021-2050), when compared with the base period (1961-1990)[99]
(Source: Shrestha et al., 2015)



Hydrology

The basin is rainfall dominated with glacier and snow contribution of about 25 percent[100]. Under changing climatic condition, the snow and glacier melt water will reduce, while the rainfall-runoff will increase[101]. The climate change will have significant impact on the hydrological cycle[102], and likely lead to more severe and extreme flooding events[103]. Shrestha et al.,[104] projected an increase in runoff in the range of 0-13 percent up to 2050, with no significant seasonal shift. Lutz et al., [105]also projected year-round increase in flow for 2041-2050 under RCP 4.5 and RCP 8.5.

Gaini et al., [106]analyzed both extreme low and high flows and indicated that extreme low flow conditions are less likely to occur, while projected strong increase in peak flow, which is in line with steep increase in monsoon precipitation. Likewise, Immerzeel, [107]also projected increase in average monthly discharge in the range of 20-30 percent under A2 and B2 scenario as compared to 1956-1993, with seasonal variation. The winter discharge showed slight positive change, autumn and spring showed intermediate increase, and monsoon discharge showed the highest increase from 2005 to 2100. Lutz et al.,[108] also projected consistent increase in runoff at least up to 2050, primarily due to increased precipitation and melt runoff, and will likely increase the extremes as compared to 1998-2007. The recent study conducted by Lutz et al.,[109] is consistent with the findings reporting increase in precipitation, and extreme events. Ghosh & Dutta[110], projected increase in peak discharge for all the major tributaries and monsoon and pre-monsoon flood-waves under A2 scenario, which is more pronounced in the downstream area. Wijngaard et al.,[111], also projected increase in mean discharge in both near future (2035-2064) and far future (2075-2100), up to 49 percent at the end of century, along with increase in high flow condition, as compared with 1981-2100.

Under changing climatic condition, the snow and glacier melt water will reduce, while the rainfall-runoff will increase. The climate change will have significant impact on the hydrological cycle

On the other hand, Immerzeel et al., [112]projected decrease in mean water supply in the upstream by 19.6 percent for 2046-2065 as compared with 2000-2007, which is partly compensated by increase in mean rainfall. Prasch et al. [113]predicted reduction in water availability from 2011 to 2080, due to decrease in glacier melt after 2040.

The hydrology of Brahmaputra basin is a complex interplay between temperature and precipitation. Increased temperature, particularly in the high elevation and Tibetan Plateau and resulting melting of cryosphere is likely to cause decrease in the water availability in the upstream part. In the downstream, the meltwater reduction is compensated by precipitation. Therefore, overall, studies show increase in future discharge, due to increased precipitation together with increased occurrences of the extreme flows[114]. There is still uncertainty in future projections of climatic parameters and its impact on the hydrology[115], but a no regret strategy for basin planners would be to prepare for reduced water availability in the upstream and increased floods in the downstream.

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UNDERSTANDING FLOODS

The Brahmaputra and Jamuna sections of the River system are prone to heavy annual flooding during the monsoon season. The Brahmaputra flows through the state of Assam in the northeastern part of India which is a high rainfall area. Currently, 5,000 kilometers of embankments stand along the Brahmaputra river and its tributaries to manage floods but often fail to withstand the increased pressure during heavy rainfall leading to breaches and flooding in the adjoining lowlands. In Bangladesh, the hydrology and inundation cycles of almost 40 percent of the flood plains are influenced by the Jamuna.

Floods in the Brahmaputra river[116]

S.S. Nandargi

FLOODS IN the Brahmaputra Valley of Assam are caused by a combination of several natural and anthropogenic factors such as unique geographic features of the region, highly potent monsoon rainfall region, easily erodible geological formations in the upper catchments, recurrent and high seismic activities, numerous landslides in the hilly areas of the Valley, accelerated rates of basin erosion, massive deforestation, intense land use practices, increasing population growth especially in the flood plain areas and temporary measures of flood controls.

The two heaviest rainfall stations of India, viz. Cherrapunji and Mawsynram, are located just to the south of the Brahmaputra basin

In India, the southwest monsoon occuring between mid-May and mid-October is responsible for causing 65 percent of the annual rainfall over the Brahmaputra basin, generating 70 percent flow of the Brahmaputra river. The other cause of heavy rainfall is the 'Break monsoon' which occurs when the monsoon trough moves towards the foothills of the Himalayas. In addition, cyclonic circulations like low pressure areas, depressions and storms when they move in a northerly or northeasterly direction, cause very heavy rainfall over Assam region. The two heaviest rainfall stations of India, viz. Cherrapunji and Mawsynram, are located just to the south of the Brahmaputra basin. One-day extreme point rainfall over the basin varies from about 40 centimeters to 90 centimeters. Most of the runoff of this river is contributed by heavy rainfall of 510 centimeters to 640 centimeters in the Abor and Mishmi hills in Siang basin and 250 to 510 centimeters in the Brahmaputra plains.

According to the Rashtriya Badh Ayog (RBA), or National Flood Commission, the total flood-prone area in Assam is about 32 lakh hectares which comprises nearly 9.4 percent of the country's total area. Therefore, the Brahmaputra Valley in Assam represents an acutely flood-prone region of the country causing devastating floods almost every year with tremendous loss and damage to public property, infrastructure and environment. The annual loss due to flooding in Brahmaputra basin is also observed to be increasing since 1953.

Eklavya Prasad

Flood analysis shows that thirteen sites on eleven tributaries and three sites on the main Brahmaputra river experienced flood deviation more than 2.0 meters above their respective danger levels in a period of 33 years. The highest flood deviation recorded by different measurement sites above their respective danger levels (D. Ls) at these rivers (Table 6) showed that northern tributaries, Jaibareilly and Manas recorded highest flood deviation of more than 10.0 meters in the last 25 years.

Table 6: Most severe floods in the Brahmaputra basin in northeast India when flood levels were 5 m and more above their respective Danger Levels D.Ls. (updated up to 2019)

River	Gauge/ Discharge Site	State	Deviation of Highest flood from DL (m)	Date & year of occurrence
Kushiyara	Karimganj	Assam and neighbouring states	5.37	24.09.2010
Barak	Lakhipur		6.05	12.09.1979
Manas	N.H. Crossing		11.03	13.07.1984
Kopili	Kampur		8.30	13.08.2002
Jaibareilly	N.T.Rd. Crossing		12.22	22.09.2010

However, detailed flood frequency analysis at individual gauge/discharge sites of the main Brahmaputra river, its northern and southern tributaries of recent past indicate that there is decrease in frequency of floods in the main river and its northern tributaries as compared to its southern tributaries but there is increase in the intensity of floods in the Assam valley and surrounding region. This is mostly because of man-made interventions or obstructions made to the free flow of water such as bridges, or for agriculture purposes, to meet the increasing population demands.

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Brahmaputra, floods and people

Eklavya Prasad

Between 1953 and 2016 the Brahmaputra valley experienced major floods on thirty-nine occasions when more than one million people were affected

THE BRAHMAPUTRA Valley, home to 85 percent of Assam's population, is one of the most hazard-prone regions of the country, with more than 40 percent of its land (3.2 million hectares) susceptible to flood damage. This is 9.4 percent of the country's total flood-prone area. About seven per cent of land in the state's 17 riverine districts has been lost because of river erosion over the past years.[117] Between 1953 and 2016 the Brahmaputra valley experienced major floods on thirty-nine occasions when more than one million people were affected.

A total of 51.564 million hectares land area was affected by cumulative flood damage induced by the Brahmaputra and its tributaries between 1953 and 2016, of which the maximum was 3.820 million hectares during the 1988 floods. As per the figures, the value of damaged crops from 1953 till 2016 is approximately Rs 24.07 billion (approximately 40 million USD) whereas 25.351 million hectares of agricultural land was damaged. The cost of total damages (crops, houses, and public utilities) during this period is estimated at Rs 78.97 billion (approximately 1 billion USD).

Assam's proneness to high, extreme precipitation, frequent earthquakes, landslide hazards, and sediments from the upper catchments increases the possibility and intensity of floods in the region. Apart from the geo-climatic setting, human activities like deforestation, accelerated change in land use, filling up of low lying areas for the construction of buildings, urban development and temporary flood control measures are some changes which contribute to the overall vulnerability of the Brahmaputra valley to floods. Sudden and excessive release of water from dams also lead to flooding, a mega-disaster because of the huge loss of life and property associated with it. The reliability and effectiveness of the embankments from the Brahmaputra flooding are generally insufficient because of structural deterioration and ongoing riverbank erosion.[118]

Eklavya Prasad

The eighteen districts along the main Brahmaputra stem encounter different kinds of floods with multi-layered complexities involving social, cultural, and economic dimensions which lead to differential impacts. Therefore, typologizing floods in the Brahmaputra valley on the basis of spatial location and character of flood hazard, will help define the area specific vulnerabilities which will further help in preparedness and minimization of losses through addressing area specific prerequisites, rather than adopting a generalist approach.

In Brahmaputra valley there are multiple flood typologies, but the one that is widespread and impacts the poorest are: riverine flood with riverbank erosion on the river side, between the embankments of the same river; riverine flood with riverbank erosion adjacent to the river without the embankments; riverine flood with riverbank erosion adjacent to the embankments on the riverside; flash floods with riverbank erosion on the riverside between the embankments of the same river and flash floods with riverbank erosion adjacent to the river without embankments.

Riverbank erosion is a natural phenomenon that results in the removal of material from the banks of a river. Most of the rivers in the Ganga-Brahmaputra basin are essentially braided alluvial channels that cause erosion through a combination of three different processes. The pre-weakening process involves repeated cycles of wetting and drying of the bank, which prepares it for erosion. While the phenomenon is natural, the impact it has is disastrous on the life and livelihoods of the riparian community who are settled on or close to the unstable banks of these channels. The resettlement is often an involuntary decision as the land gets eroded. Given the impoverished state of the riparian population, the resettlement happens close to the river, since land prices increase as one moves farther away from the river.[119]

Floods are diverse, multi-layered and must be attended to as per its location, reason, severity and diversity

Development induced displacements tend to displace people once, the families affected by bank erosion are subjected to multiple displacement. It is estimated that annually nearly 8,000 hectares of land is lost to erosion. The intensity of the problem can be gauged from the fact that the total land lost due to bank erosion caused by the Brahmaputra River in Assam alone has ranged between 72.5 square kilometers per year and 80 square kilometers per year between 1997 and 2007-2008.[120] Hazards like riverbank erosion that continuously affect the poorest and the most impoverished sections of the community residing in the Brahmaputra flood plains, has to be considered as a typology of floods, to demystify floods as homogenous entity. Floods are diverse, multi-layered and must be attended to as per its location, reason, severity and diversity. Therefore, there is a need to re-examine the flood management plans and strategies in the changing times.

Floods of the Jamuna Basin

Malik Fida Abdullah Khan

EACH YEAR in Bangladesh about 26,000 square kilometers, that is around 18 percent of the country is flooded[121]. During severe floods, the affected area may exceed to 55 percent of the total area of the country. In the event of catastrophic floods, it has been anticipated that about two-thirds of the country can get affected[122].

The hydrology and inundation cycles of almost 40 percent of the flood plains in Bangladesh are influenced by the Jamuna. Major extreme flood events contributed by Jamuna inundates between 18,000 square kilometers 23,000 square kilometers area in the surrounding flood plains on an average, which is equivalent to 12 percent to 16 percent of the total country area. However, impacts of those floods are even higher when combined with peak discharge of Ganges and Meghna. Table 7 summarizes extent of flooding during major flood years for the Jamuna and corresponding impacts on the entire country when combined with Ganges and Meghna flows.

Table 7: Notable flood disasters in Jamuna floodplains and their impacts

(Source: Analysis by Centre for Environmental and Geographic Information Services (CEGIS) based on satellite images, Hossain, 2006[124] and Reliefweb, 2017[125]

Year	Flooded area (sq km) in Jamuna floodplains[123]	Countrywide impacts due to floods (from Jamuna, Ganges and Meghna)
1954	23,132 (16% of the country area)	Affected 55% of the country.
1988	23,200 (16% of the country area)	Inundated 61% of country, estimated damage US$ 1.2 billion, more than 45 million homeless, between 2000-6500 deaths.
1998	21,232 (14% of the country area)	1100 deaths inundated nearly 100000 km^2, rendered 30 million people homeless, damaged 500000 homes, heavy loss to infrastructure, estimated damage US$ 2.8 billion.
2000	10,601 (7% of the country area)	Estimation unavailable
2002	16,395 (11% of the country area)	Estimation unavailable
2003	13,027 (9% of the country area)	Estimation unavailable
2004	17,477 (12% of the country area)	Inundation 38%, damage US$ 6.6 billion, deaths 700, affected people nearly 3.8 million.
2007	14,068 (10% of the country area)	8 million people displaced; 2000 people died from drowning and water borne diseases. Estimated damage US$1billion, Dhaka was badly affected.
2017	Estimation unavailable	July floods affected about 1.6 million people, damaged over 100000 houses and 40000 hectares of cropped lands were inundated. August floods affected 31 districts, and about 16000 ha were fully lost and 560000 ha of standing crops were partially damaged.

The floods of 2007 and 2017 mostly affected the northern districts due to high water level and discharge in the Brahmaputra. In 2007, many countries in South Asia experienced floods, thus all the rivers, especially the Brahmaputra and Ganges peaked at the same time. In 2017, the northern districts faced severe floods in July and August (there were also flash floods in the northeast part of the country in March-April). These floods impacted standing crops. Prices of rice, the country's main staple, reached record high levels in September, mostly reflecting flood-induced crop losses in 2017.

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Plethora of Pains: Living with floods and erosion

Imtiaz Ahmed

EVERY YEAR during the monsoon season, floods arrive in the Jamuna river basin. Riverbank erosion is also an annual phenomenon. Flooding and erosion have become a part of the lives of the people living on the banks and the *chars*[126] or riverine islands of the Jamuna. In Bangladesh, flooding begins from the middle of July and continues till September.

The Bengali language distinguishes between the normal floods of the rainy season, which are locally known as *barsha*, and the more harmful floods of abnormal depth and timing, which are termed *bonna*. The *barsha*, which occurs more frequently than *bonna*, is often deemed a necessity for survival, especially to farmers[127].

Flooding and erosion have become a part of the lives of the people living on the banks and the chars *or riverine islands of the Jamuna*

Huge tracts of paddy and other crops, ponds and fish enclosures go under water, livestock is also damaged, crippling already poor rural communities. Stranded in waterlogged areas, people lose their livelihoods, with little access to food and drinking water. In the wake of floods, outbreak of water-borne diseases such as diarrhoea, skin diseases, dysentery and cholera cause immense suffering and even loss of lives. Roads, railways and key infrastructures are damaged, communication system is disrupted, homesteads, schools, hospitals are also submerged in flood waters. In the period between 10 July and 24 July 2019 alone, torrential rains damaged more than 580,000 houses forcing an estimated 307,000 people from their homes across Bangladesh. Public health officials confirmed 14,781 flood induced medical cases in northern Bangladesh[128].

Although in Bangladesh, more than 10,000 kilometers of embankments have been constructed throughout the country[129], embankments are often overtopped or breached. The people living in the region, having suffered from the *bonna* or 'big floods' in their own lifetime more than once, have learned to 'live with floods'. This is manifested not only in the coping mechanisms, for instance, in containing diarrhoea and other water-borne diseases, but also in agricultural practices and the construction of secured infrastructures in flood prone areas. The people residing in the vicinity of these rivers have learned to grow flood-tolerant crops, live in portable houses, store food, household items and crops on a platform in the main living room and plant flood tolerant vegetation such as bamboo and banana. Flood resistant houses constructed on a two-foot-high concrete plinth with walls made from jute panels helps to reduce loss from damage to property[130].

People in this region are resilient, and over the years have adapted with coping mechanisms

Erosion caused from the flooding and receding of the waters of the Jamuna results in huge loss of land and property every year. Embankments collapse from erosion, causing flood inundation in previously flood protected lands. Huge number of people become homeless for uncertain periods due to erosion[131]. People in this region are resilient, and over the years have adapted with coping mechanisms. People in *char* areas (riverine islands), where erosion occurs the most, live in portable houses; the house and assets can be easily relocated to safer places. Many people have to eventually leave their lands and migrate to nearby districts and urban areas[132].

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Community based flood early warning system

Neera Shrestha Pradhan and Partha J Das

"That one hour of early flood warning makes all the difference to ensure that my investments are safe, and livelihood ensured"- Osman Ali, Barsola 2 village, Assam, India

DEVASTATING FLOODS inundate large areas of the Brahmaputra River Basin every year crossing national and inter-state borders resulting in loss of lives and livelihoods, and displacing millions of people in India. Though early warning systems have been developed in many parts of the world to provide flood information, there are gaps – identified by the Hyogo Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) Special Report on Extreme Events and Disasters (SREX 2012) – in getting this information to communities that are most vulnerable. In the absence of reliable and timely early warning of flooding, damage and loss to private and public property, economy, lives and livelihoods have increased, making people more vulnerable worldwide.

A community-based flood early warning system (CBFEWS) was envisioned and executed by ICIMOD jointly with the District Disaster Management Authority (DDMA) in Dhemaji and Lakhimpur, and Aaranyak- an NGO partner in Assam, India, to provide near real time flood information to prepare the vulnerable communities for the upcoming flood risk during 2010-2016. CBFEWS is an integrated system of tools and plans in which upstream communities, upon detecting flood risk, disseminate the information to vulnerable downstream communities through mobile phones for preparedness and response using local resources and capacities.

The first version of CBFEWS was tested and used during 2010-2012 on the Jiadhal river of Dhemaji District in Assam. In 2013, five units of an advanced version of the CBFEWS were installed in the Jiadhal (Dhimaji district) and Singora (Lakhimpur district) rivers in Assam with active involvement and ownership of local people and DDMA reaching out to 45 vulnerable communities downstream to provide flood early warning. With an investment of approximately USD 1,000 per instrument, the information disseminated by CBFEWS was able to save assets worth USD 3,300 in the flood of 5 September 2013 in the Dihiri village of Dhemaji. Dhemaji DDMA officer explained, "After receiving a warning, we deployed the National Disaster Response Force to the affected downstream areas of the Jiadhal River, which helped the district administration prevent a disaster situation". The communities, who had to stay awake all through the night to monitor rivers and floods earlier, expressed their happiness as they were able to have "sound sleep at night" after the installation of CBFEWS.

Providing the life-saving information to the villagers, a woman caretaker of the system stated, "I feel empowered and important because even the Gaon-Burha (Village Head Man) of the village comes to me to ask about the flood situation".

The project's impact was acknowledged by the UNFCCC by awarding it the Momentum for Change 2014 Lighthouse Activity Award as a shining example of innovative use of Information and Communication Technology for Disaster Risk Reduction and Climate Change Adaptation. Encouraged by the impact on the ground, the DDMA of Lakhimpur District replicated the CBFEWS in Ranganadi river in 2016. The Government of Assam, Flood and River Erosion Management Agency of Assam discussed the upscaling of CBFEWS in Assam and mentioned, "We have been informed that the only Early Warning System (EWS) established in Assam has proved to be successful in generating and disseminating flood signals that not only helped people to save their assets but also supported District Disaster Management Authorities to deploy flood rescue teams to the vulnerable sites".

The river displays a variety of channel patterns on its journey towards the sea, at times meandering, but mostly in braided form

Inspired by the success achieved in Assam, CBFEWS instrument was improved from wireless to telemetry based EWS and scaled up in different tributaries in Nepal, India, Pakistan and Afghanistan in the Hindu Kush Himalayan region. From 2020 onwards, CBFEWS is also out scaled in 33 tributaries in Malawi, South Africa jointly with the relevant government line agencies and local partner organization.

❄

MORPHOLOGICAL CHARACTERISTICS OF THE RIVER

The Yarlung Tsangpo-Siang-Brahmaputra-Jamuna displays a variety of channel patterns on its journey towards the sea, at times meandering, but mostly in braided form. The Yarlung Tsangpo consists of alternating sections of wide valleys with braided channels and narrow gorges with single deeply incised channels amid shallow layers of boulders that cover bedrocks. In the Brahmaputra valley and flood plains of Jamuna the River is highly braided, marked by the presence of numerous alluvial channels with lateral bars and islands between meeting and dividing again[133]. This section briefly describes the historical development, planform[134] characteristics and morpho-dynamics of the main channel.

Geological history

Bushra Nishat

THE YARLUNG-Siang-Brahmaputra-Jamuna and its tributaries are morphologically dynamic, and the fluvial patterns have continuously been reshaped by continental tectonics, surface processes and climate feedbacks.

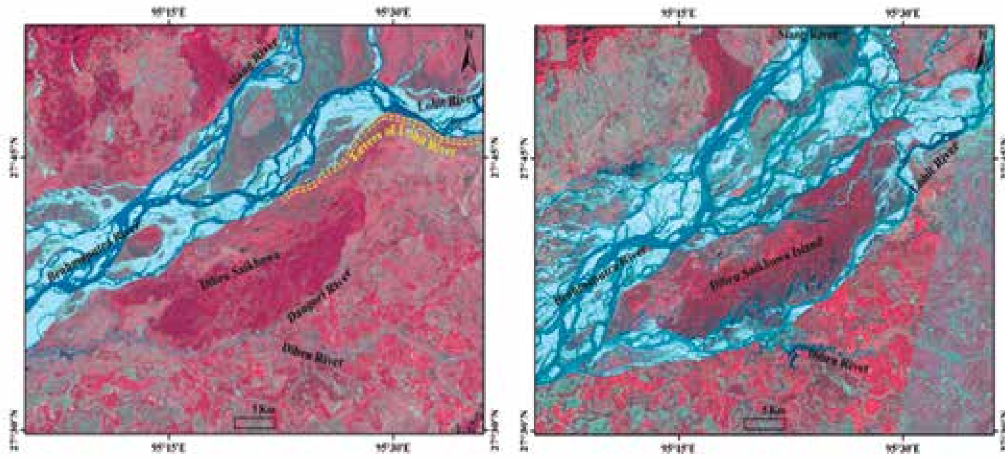
To the south across the flood plains major channel avulsion[135] has taken place within the last 250 years. Historical maps and tell-tale palaeo-channel markers show that the Teesta, the largest tributary of the Jamuna shifted course several times in the past. British geographer Major James Rennel's[136] maps of 1764 and 1777 show Teesta flowing into three branches while travelling through North Bengal and ultimately discharging into the Ganges at several places. Devastating floods and neo-tectonic activities led to a change of direction and the Teesta swung eastward flowing towards the Jamuna around 1787[137]. This sudden eastward shifting combined with the tectonic tilting of the Madhupur Tract triggered avulsion of the Brahmaputra channel. Historical mapping of the last 250 years indicates that the main active channel of the river used to flow through the east of the Madhupur tract and join the Meghna River directly at Bhairab Bazaar in Bangladesh. In the late eighteenth century, the Brahmaputra began to diverge towards a small spill channel known as the Konai-Jenai, shifting gradually southwards to join the Ganges and by 1810, emerged as the Jamuna, leaving the eastward channel which is now known as Old Brahmaputra[138].

Historical maps and tell-tale palaeo-channel markers show that the Teesta, the largest tributary of the Jamuna shifted course several times in the past

The middle reach of the river has also experienced channel migration in more recent times. The Assam earthquake of 1950 and more contemporary processes of erosion and aggradation through bar formation caused bankline migration of the Subansiri, a major tributary of the Brahmaputra. Additionally, abnormal high flood level in 1988, and difference in gradient due to topographic elevations led to avulsion of the Lohit River, a south bank tributary of the Siang. A small channel of the Lohit captured the Dangori river of the Dibru Saikhowa region, and gradually by 1995, the main flows of the Lohit began flowing through the captured channel. This transference in combination with the southward adjustment of the Brahmaputra caused significant shifting of the Lohit-Siang confluence point. But the most noticeable response to this avulsion has been its effect on the Dibru Saikhowa National Park. As can be seen from Figure 17, previously the park area was a part of the left (south) bank of the Brahmaputra river, but in response to the migration of the river, the area has become a *char* or river island in the main channel of the Siang[139].

Figure 17: Landsat image over Dibru Saikhowa. A 15 November 1973; B, 28 November 2000

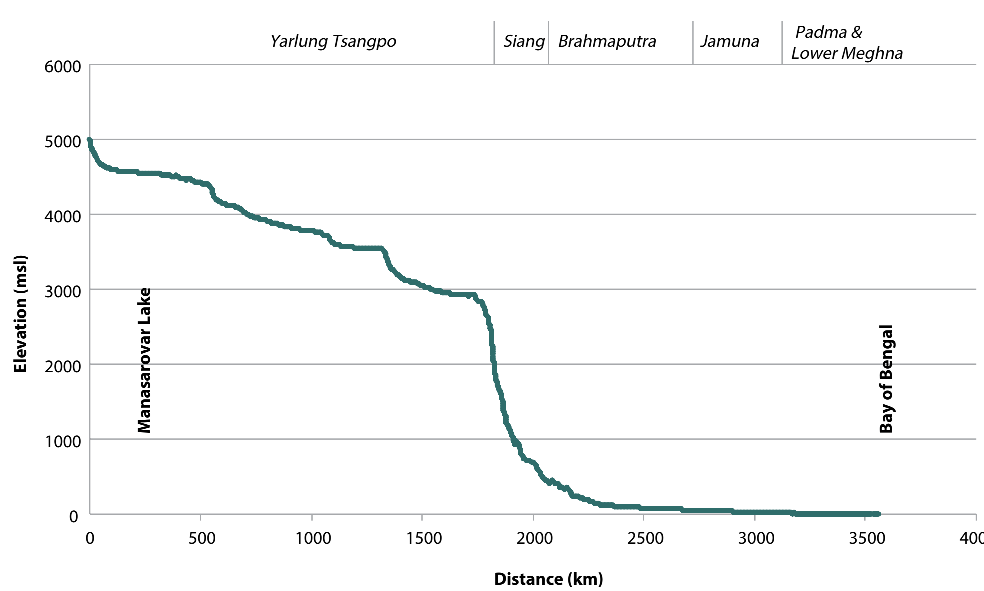
(Source: Borgohain et al 2016)[140]



Longitudinal profile of riverbed

In the upper reaches in Tibet, the river channel displays mild gradient in the wide valleys and large gradient in narrower sections. The gradient of the basin and River channel is as steep as 4.3 meters per kilometer to 16.8 meters per kilometer in the gorge section and the slope decreases suddenly in the Brahamputra valley after the Siang-Lohit confluence. Near Guwahati in Assam, the Brahmaputra is as flat as 0.1 meters per kilometer as can be seen in Figure 18[141]. The low gradient results in high width to depth ratios causing high deposition of sediment and development of a braided channel.

Figure 18: Longitudinal profile of the Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna River *(Based on SRTM 90m DEM)*



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GEOMORPHOLOGICAL CHARACTERISTICS

Yarlung Tsangpo

Sun Jian and Lin Binliang

THE GEOMORPHOLOGICAL characteristics of the Yarlung Tsangpo river is significantly affected by the uplift of the Tibetan Plateau and the movement of geological structures, with a hydrographic network developed on a rock-based gravel bed. Its slope goes steeper, and its undercut goes deeper at the edge of the Tibetan Plateau. In recent decades, the runoff and sediment transport of the river are strongly affected by climate change and the potentially ever-increasing human activities. Local geological structure and lithology, as well as the temperature difference and water erosion, lead to the variety of spatial scales and plane view of the fluvial network.

Geology background

The staggered width of the Yarlung Tsangpo river looks like the shape of a lotus. The canyon sections of the lotus roots are mainly dominated by granite and significant uplift by a lateral fracture in a nearly north-south direction. The glacier-mantled mountains, with an elevation higher than 5,500 meters, is steep along the canyon, and the river mainly has straight or slightly bending patterns. The riverbed here is deeply cut down into the bedrock with little sediment on the riverbed, because of the high riverbed slope and flow velocity. The branches drained into the mainstream also takes the form of deep-cut canyons. Wide valley sections are mainly developed in the large fault zone, where sandstone and mudstone widely distribute. The mountains along both sides of the wide valley have elevations less than 5,500 meters and have gentle slopes. The river's longitudinal slope and flow velocity are small in these reaches, with thick sediment deposition and widely distributed braided rivers. In addition, the shape of the branch estuary in the wide valley sections is mostly trumpet-shaped. In the middle reaches, canyon valleys are restricted by narrow gorges, while the width of the valleys is between 2 and 8 kilometers. Multiple bars in the channel constitute unique complex braided channels of the Yarlung Tsangpo river.

In recent decades, the runoff and sediment transport of the river are strongly affected by climate change and the potentially ever-increasing human activities

The uneven elevation of the Tibetan Plateau in the east-west direction and the sediment deposition over thousands of years have formed lotus-shaped river valleys of the Yarlung Tsangpo River. The river alternately distributes with large-width and shallow-depth lakes. The river reach is characterized by slow flow velocity contributed by a relatively static water environment.

Impacts of climate change and human activities on river geomorphology

Because of the high elevation, the hydro-sediment dynamics, river pattern, the sediment erosion/ deposition of the Yarlung Tsangpo river are basically in a natural state. However, climate change has accelerated the glaciers melting and changed the plateau monsoon over the past few decades. Given the long-term impact of climate change on hydrological elements, it will gradually change the water and sediment flux, the sediment transport capacity, the riverbed morphology and promote river pattern transformation.

The ever-increasing human activities in the river basin will also have potential impacts on the river evolution. For example, over-grazing will lead to grassland degradation and even desertification, which may decrease the flow discharge and increase the sediment flux. The road networks constructions and the mineral resources exploitations produce numerous soil and slag accumulation and expose the bare surface of mountains, which will also increase the sediment flux. Besides, reservoir constructions are the most direct and strongest human activity that influences the evolution of natural rivers. It works in intercepting coarse sediment in the upstream, decreasing the riverbed slope. As a result, sediment in the downstream river reach is reduced and the riverbed is likely scoured by the clean water with lower sediment concentration. These human activities are likely to partially change the flow and sediment transport process of the river channel and bring a series of issues on sediment engineering as well as water-sediment conservation.

The high-elevation terrain and neotectonic movement of the Tibet Plateau play a fundamental role in the geomorphic diversity of the Yarlung Tsangpo river. The plateau uplift is the long-term and large-scale geological background of the Yarlung Tsangpo river's evolvement, especially for the bedrock undercut, headward erosion, and landslide or debris in the riverbank slopes. It is notable that, as a sensitive area for climate change in the Tibetan Plateau, Yarlung Tsangpo river is gradually suffering the water and sediment changes as well as the complex river evolution against the background of global warming. Meanwhile, the human activities such as the hydropower development, road constructions, mineral exploitations and grazing expansion have been increasingly enhanced on the plateau. The changes will break the balance between sediment erosion and deposition in local river reaches, sharply change the alluvial river patterns and accelerate the deep cut of the riverbed, result in the changes in the evolutionary process of the Yarlung Tsangpo River.

Siang-Brahmaputra

Malik Fida Abdullah Khan

SIANG RIVER meanders along its southbound path until it reaches the confluence with Dihang and Lohit Rivers. After the confluence, the main channel of the Brahmaputra becomes braided. The number of major channels in the braided Brahmaputra varies across the segment, with the planform being dominated by a range of vegetated and non-vegetated bars that divide the channel into a hierarchy of channel sizes[142].

Planform characteristics

Planform characteristics of the Brahmaputra River has significant spatial and temporal variability from upstream to downstream reaches, which is caused by tectonic zonation of the river, channel slope and sediment load. Further, the tributaries joining the northern and southern banks of the Brahmaputra vary in terms of river dynamics and sediment load resulting in differences in tectonic regimes. From the recent studies, the average widening over the last 90 years has been estimated at 44 percent; from the average width of 9.74 kilometers in 1915, the channel has widened to the average width of 14.03 kilometers in 2005 and in certain reaches the average widening is as high as 250 percent while the shifting of bankline is not uniform towards both banks[143].

The River is one of the widest rivers in the world. In the plains of Assam, the average width is almost 10 kilometers and some places the width is as high as 18.6 kilometers

The great Assam earthquake of 1950 with an epicenter within the Brahmaputra basin has triggered multiple transformations in planform in the main channel and tributaries of the Siang-Brahmaputra and downstream reaches. This earthquake induced large-scale landslides in the Himalayas, and the loose debris and barren slopes together resulted in 45 billion m^3 of sediment into the river system choking and raising the bed of the Brahmaputra, which was as high as 3 meters in Dibrugarh. As the river became shallower, it became wider to accommodate its regular flow subsequent to 1950[144].

Even in average conditions, the River is one of the widest rivers in the world. The narrowest part of the Yarlung Tsangpo is when it passes through the big bend within the Great Canyon entrenched between the Namcha Barwa and Gyala Peri mountains, which stand only 21 kilometers apart[145]. In the plains of Assam, the average width is almost 10 kilometers and some places the width is as high as 18.6 kilometers, although rock outcrops at several places confine the river width. At Saraighat, a place near Guwahati, Assam the bank-to-bank width narrows down to 1 kilometer[146].

In certain reaches the braiding intensity, which measures the channel multiplicity has also increased. The Brahmaputra River consists of large, deep and active primary channels in combination with smaller and shallower secondary channels. The width and depth of the primary channels as well as the bed profiles vary significantly from place to place with time. During low flow period, the primary channel of the Brahmaputra occasionally splits up into multiple smaller primary and secondary channels and they are part of the main channel having average width of approximately 1 kilometer[147].

Erosion-Accretion

Erosion and accretion have been identified as a major challenge in the northeast region of India[148]. The combined effects of large and highly variable discharge, high silt content, heavy rainfall, and unstable geology have resulted in a very unsteady river channel of Siang-Brahmaputra causing heavy lateral erosion[149]. The river shows a tendency to migrate south as the south bank faces active bank erosion. Erosion is more prominent during recession stages of floods when the water level drops very quickly. The Brahmaputra in the reach from Dibrugarh to Dhubri (near Bangladesh border), between 1990 and 2008, around 1,464 square kilometers land was lost due to riverbank erosion, compared to accretion of 214 square kilometers. Erosion was higher in the south bank (920 square kilometers) compared to north bank (544 square kilometers) while it is vice-versa for accretion. This high amount of erosion along both banks of the river resulted in the deterioration of living standard of people by affecting the people living near the bank as well as loss of infrastructures. The highest erosion occurred in the segment upstream of Dibrugarh until the confluence of Siang-Lohit Rivers[150].

Between 1990 and 2008, around 1,464 square kilometers land was lost due to riverbank erosion, compared to accretion of 214 square kilometers

Sediment Transport

The Brahmaputra flows with a huge load of sediment acquired from the rain-soaked Himalayan tributaries. Estimates of the sediment load of the Brahmaputra River are highly variable, ranging from 270 to 720 million tonnes per year[151]. Similar to discharge, sediment load varies throughout the year, and is highest during monsoon season.

The source of this sediment is the Himalayan region, the distribution of erosion contributing to the sediment flux in the mountain range is heterogeneous. Recent studies show, the eastern syntaxis including the Namche Barwa mountains is a major source of sediments and supplies about 50 percent of the bulk sediment inflow to the Brahmaputra system[152].

❄

Jamuna

Sudipta Kumar Hore

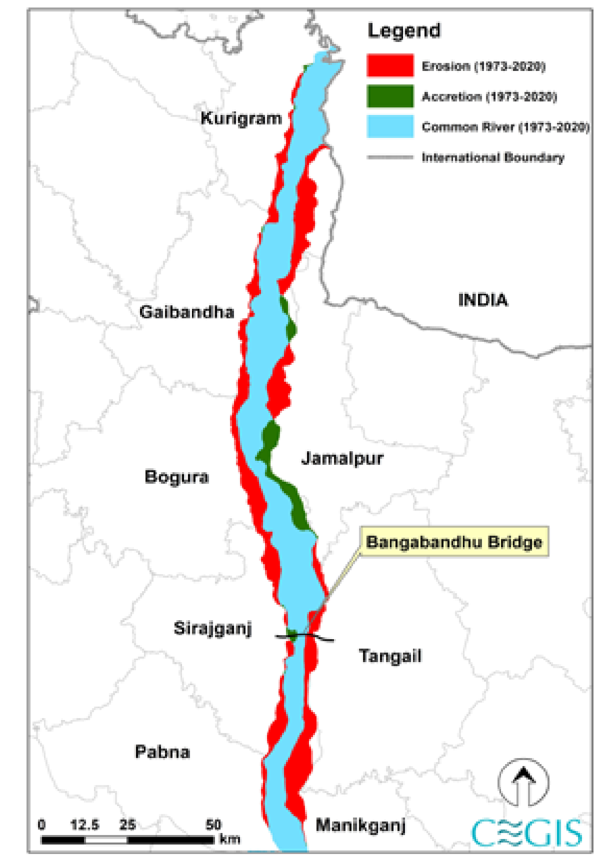
JAMUNA IS a large sand bed braided river. As discussed earlier, the main channel and tributaries of the River have changed courses rerouting drainage patterns frequently in historic and prehistoric times. Geomorphologically this segment of the river is in dynamic equilibrium and migration of channels, shifting of banklines and widening of watercourse are a frequent phenomenon. However, within the last decade the morphological instability of the Jamuna has slowed down.

Planform Characteristics

The Jamuna has multiple channels separated by small bars and *chars*, typically showing two to three channels per cross-section. Migration of channels and shifting of banklines are very frequent. The high variability of discharge, averaging 60,000 cumec during flood and 4,250 cumec during dry period leads to erosion and accretion in the channel respectively.

In Bangladesh the average width of the first order channel increases to almost 12 kilometers and in some places, width can be up to 16 kilometers, especially during monsoon period. Similar to the Brahmaputra, the Assam Earthquake of 1950 has had a massive impact in the planform changes of the Jamuna. Mainly coarse sediment (sand portion) from the earthquake induced landslides played a significant role to alter the morphology in the last 70 years which propagated gradually as sand wave to the Bay of Bengal. This additional input of sediment made the river more dynamic, and energy was dissipated by the process of the erosion and river widening[153]. In most places there is a tendency of the Jamuna to migrate westward. Migration from the center line of the Jamuna took place at about 45 meters per year between 1973 and 2010 as a result of channel shifting and widening[154].

Figure 19: Erosion-Accretion of the Brahmaputra-Jamuna River in the last 46 years *(Analysis based on satellite images)*



Erosion-Accretion

The instability of the Jamuna river coupled with erodible alluvial banks causes heavy bank erosion. Erosion is not similar to a meandering river where erosion takes place in the outer bend at one bank and deposition in the inner bend at the other bank. Erosion occurs in both banks in the Jamuna. It is very difficult to predict the erosion as vulnerable channels shift within one season. Historical analysis shows that erosion has been dominating in the past six decades compared to accretion in the Jamuna. In the Jamuna in the past 46 years (from 1973) total erosion was 928 square kilometers and net accretion was 148 square kilometers (shown in Figure 19). This erosion often takes place in populated areas and erosion is responsible for land loss causing damage to agricultural land and physical infrastructure such as homesteads, embankments and roads. On the other hand, newly accreted area needs time to mature and become productive or create opportunities for inhabitation and economic activities.

The *chars* of the Brahmaputra-Jamuna

Created from sedimentation or avulsion of river channel, river islands or shoals, locally known as *chars* in India and Bangladesh are an important feature of braided rivers. *Char* dynamics are interrelated with the bank erosion processes, widening and narrowing of rivers. While there are river islands of various sizes and shapes in the braided portion of the Yarlung Tsangpo channel, these remain mostly uninhabited and unexploited. In India and Bangladesh, development of *chars* provides opportunities for settlement of people and crop cultivation and for decades, many *chars*, especially mature *chars* have established rural areas including schools, hospitals and other infrastructure. Typically, a new *char* land continuously emerges and submerges and requires at least 10 years of continuous survival before it becomes fit for human habitation. In 2000, approximately 76 percent of the *chars* in the Jamuna were less than nine years old while only 7.2 percent *chars* were mature having existed for 21 years or higher[155]. But there are also very old *chars* such as Majuli, the world's largest riverine island which was formed around 1750.

Analysis of satellite images show that the *char* area in the Brahmaputra channel was 1,460 square kilometers in 2018[156] and in the Jamuna the area was 760 square kilometers in 2016. Widening of the river caused increasing trend of the *char* area. However, the widening process has slowed down recently. This does not mean the formation of *chars* will stop. Rather loss of *char* in one area may compensate in another area within the riverbank.

The Ganga-Brahmaputra-Meghna delta is the largest in the world.

Sediment Transport

Although estimates vary, on average the Brahmaputra-Jamuna carries an amount of about 607 million tons of sediment every year which is the third highest sediment transport river in the world after Amazon and Huang Ho Rivers[157]. However, the combined suspended sediment load of the Ganges-Brahmaputra-Meghna (GBM) region is around 1,050 million tons per year, the second largest sediment load in the world. Almost 60 percent of this sediment load originates in the Brahmaputra basin. The sediment carried by the Jamuna originates in the Himalayas with nominal contribution by the tributaries in Bangladesh and the Jamuna[158].

Around 55 percent of this load is deposited in the rivers, floodplains and deltas, accretion is most rapid in the river braid belt and adjacent floodplain[159]. Annual precipitation and associated runoff rework accumulated sediments in adjacent floodplain surfaces and transport remobilized deposits to local catchments distant from the river. The remaining sediment is circulated in the bay and acts as a source of alluvial delta development across the Bay of Bengal. This process is important for land building in the coastal region of Bangladesh and East India.

Sediment transported through Brahmaputra-Jamuna and deposited to the Bay of Bengal over thousands of years had a significant role in the development of the Bengal Delta[160]. More recently, a large amount of accretion due to the Assam earthquake resulted in the delta progradation in the 1950s and 1960s and accelerated the delta shifting process[161]. Even though there is influx of high sediment, the shoreline remains mostly unchanged, as most of the sediment brought to the rivers bypasses the estuary and is deposited into deeper waters by way of the Swatch of No Ground, a shelf canyon that deeply incises the Bay of Bengal near the Meghna Estuary[162].

❄

3. LIFE

Biodiversity of the region

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Bibhab Kumar Talukdar
M. Monirul H. Khan
Utpal Singha Roy
Karma Chopel Ghongsar
M Niamul Naser
S M Sadik Tanveer
Xiawei Liao
D. B. Gurung
Sayam U. Chowdhury
M Firoz Ahmed
Rekha Chetry
Dilip Chetry
Indra P Acharja
Girish Jathar
S.M.A. Rashid
Partha Sarathi Ghose
Bishal Thakuri

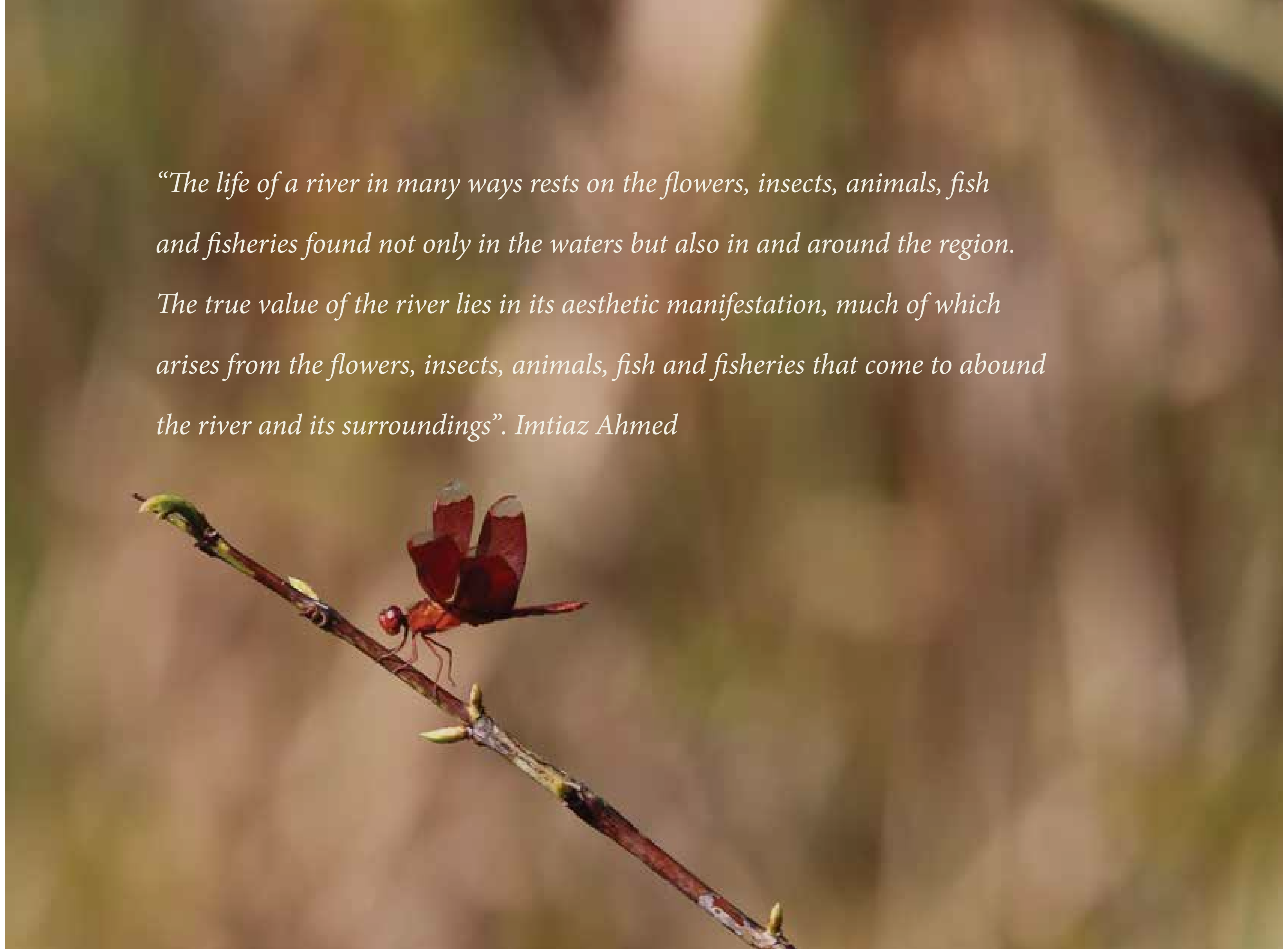
THE CONVENTION on Biological Diversity 1992 defined biological diversity or biodiversity as: 'the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

The Yarlung Tsangpo-Siang-Brahmaputra-Jamuna river system comprises unique and diverse ecosystems and habitats for a large variety of flora and fauna including many endangered species. The biodiversity of living habitats and species brings beauty and vibrancy to the river system making it one of the most fascinating river systems of the world. The aquatic and terrestrial habitats of the river system are dynamic in themselves and also change in character over short and long distances due to the changes in altitude and geographical and climatic conditions in each basin and sub-basin of the river system.

From the high altitude Tibetan plateau with its drought-resistant shrubs and grasses which is home to the yak, to the forests at lower altitudes with unique plant diversity, and the tall reed jungles, grasslands, and wetlands of the floodplains, home to three of Asia's largest herbivores-the greater one-horned rhino, the wild water buffalo and the Asian elephant, and the largest carnivore, the Bengal tiger, this river system showcases diverse environments and ecosystems.

This chapter provides an overview of the biodiversity of the Yarlung Tangpo-Siang-Brahmaputra-Jamuna river system.

Blue pitta *(Hydrornis cyaneus)*



"The life of a river in many ways rests on the flowers, insects, animals, fish and fisheries found not only in the waters but also in and around the region. The true value of the river lies in its aesthetic manifestation, much of which arises from the flowers, insects, animals, fish and fisheries that come to abound the river and its surroundings". Imtiaz Ahmed

YARLUNG TSANGPO BASIN

Biodiversity

Marc Foggin

THE YARLUNG TSANGPO is an international river that flows more than 2,000 kilometers from west to east across the southern part of the Tibetan plateau, just north of the Himalayan range, at an average elevation over 4,600 metres above sea level. In total, its watershed encompasses approximately 242,000 square kilometers and it is divided in three main sub-basins (see Map 1 and Table 1). Based on the physical geography, including average altitude, topography, precipitation, and main land cover types, each of the sub-basins has relatively unique ecological characteristics, both in terms of biodiversity and of their socio-ecological features (traditional livelihoods) based on the areas' long-term environmental constraints and opportunities, including human-nature interactions and pressures.

Map 1: The Yarlung Tsangpo and its sub-basins, including visualisation of altitude as well as spatial distribution of meteorological and hydrological stations in Tibet Autonomous Region, China[1]

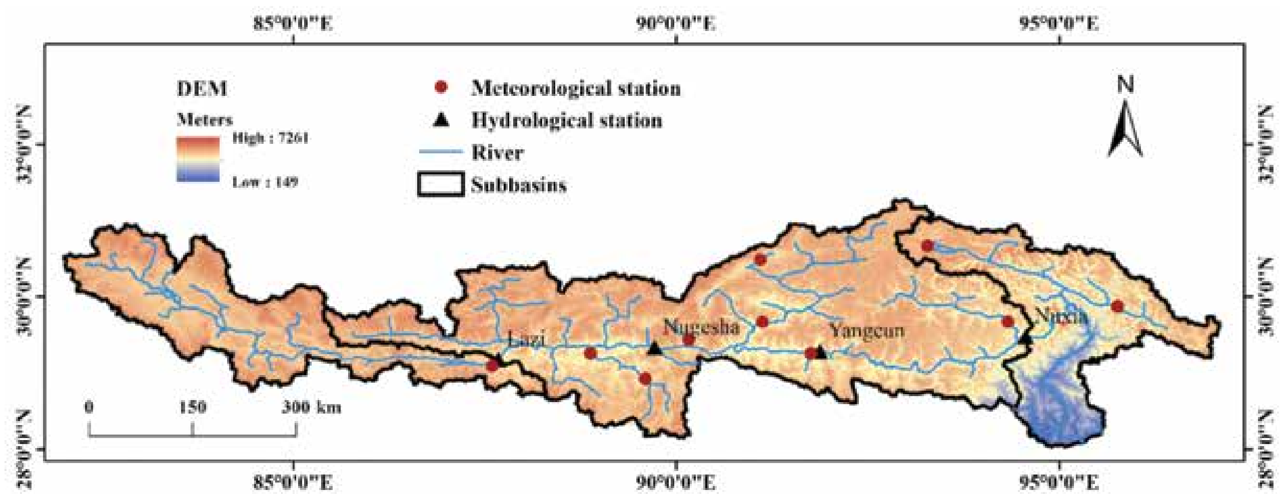


Table 1. Basic information about the Yarlung Tsangpo and its sub-basins[2]

Yarlung Tsangpo	Area (km^2)	Length (km)	Precipitation (mm)	Average annual temp. (°C)	Main types of land cover	Population
Upper sub-basin	26,000	268	< 300 (arid area)	- 0.3	Alpine steppe, alpine meadow, alpine bushes	153,400
Middle sub-basin	166,000	1,293	300 – 600 (semi-arid area)	5.2	Semi-arid herbs, broad leaf shrubs	1,297,000
Lower sub-basin	50,000	500	> 4,000 (humid area)	7.0	Alpine forest, tropical forest	82,000

Within the Yarlung Tsangpo's vast watershed, its westernmost headwaters, the upper basin, are most similar to the Tibetan Plateau as a whole. As high altitude arid and semiarid rangelands, this ecological region is particularly noteworthy for its unique suite of large ungulate (hoofed mammal) species including the migratory Tibetan antelope (or *chiru*; *Pantholops hodgsonii*), Tibetan gazelle (*Procapra picticaudata*), blue sheep (or *bharal*; *Pseudois nayaur*), argali (*Ovis ammon*), and wild yak (*Bos grunniens*); large carnivores such as Tibetan wolf (*Canis lupus chanco*), Eurasian lynx (*Lynx lynx*), snow leopard (*Panthera uncia*) and Pallas' cat (*Otocolobus manul*); and other native wildlife including Tibetan bear (*Ursus arctos*) as well as the black-lipped or plateau pika (*Ochotona curzoniae*). Plateau pika is itself a keystone species[3], that is, a species that enables the survival of many others including many mid-size terrestrial and aerial predators that depend on the plateau pika as prey in winter, a wide range of birds (including a suite of snow finches, e.g. *Montifringilla* species, as well as Hume's ground-tit, *Pseudopodoces humilis*) and lizards (*Phrynocephalus erythrurus*) that co-utilize the pikas' burrows, and a unique and rich plant diversity enabled by the pikas' burrowing activities.

The middle section of the Yarlung Tsangpo watershed is its most populated sub-basin. This region of southern Tibet is agriculturally the most productive, often referred to as the 'bread-basket' of Tibet due to its long history of crop production. Even here, however, cultivation is limited due to the cold and semiarid environment and is dependent on cropping systems characterised by relatively heavy tillage, frequent irrigation, high seeding rates and fertiliser applications[4] and there remain land use conflicts for production of food for human consumption versus forage[5]. Yet, along all the waterways and in lakes and wetlands of south-central Tibet, there is also a rich biodiversity. In the Lhasa urban area, the Lalu wetlands are recognized internationally under the Ramsar Convention for their global significance, providing critical habitat for endemic, rare and/or representative Tibetan avifauna including ruddy shelduck (*Tadorna ferruginea*), bar-headed goose (*Anser indicus*), brown-headed gull (*Larus brunnicephalus*), white stork (*Ciconia ciconia*), common redshank (*Tringa totanus*) and many other local and migratory species. In these wetlands as elsewhere across the middle stretch of the Yarlung Tsangpo, the black-necked crane (*Grus nigricollis*) is particularly noteworthy, being of great cultural significance to Tibetan people.

Around two-thirds of all vascular plants, half of the mammals and four-fifths of the insects that are known in Tibet are found in this unique land, one of China's most exceptional biodiversity hotspots

Moving further eastward and downstream along this world river, finally the most extraordinary of sections in this unique and diverse watershed is encountered: the Yarlung Tsangpo Grand Canyon. Wrapping around Namche Barwa mountain (7,782 meters) in eastern Tibet Autonomous Region, China, the river makes its "great bend", cutting through the Eastern Himalayas, in the process dropping from around 2,900 meters on the Tibetan plateau to around 600 meters when it flows into India, where it is then known as the Brahmaputra River. Flowing around 250 kilometers between Namche Barwa and Gyala Peri mountain (7,294 meters), with an average depth of 5,000 meters, this is indisputably the deepest canyon in the world. At its extreme, a single slope rises from the river all the way to the snow-capped peak with an elevational difference over 6,000 meters – thus presenting a multitude of ecosystems across all altitude zones, with climatic conditions ranging from sub-tropical to Artic in just a few kilometres. Around two-thirds of all vascular plants, half of the mammals and four-fifths of the insects that are known in Tibet are found in this unique land, one of China's most exceptional biodiversity hotspots. Though largely unexplored (with no permanent road access until 2014), recent camera trap surveys in subtropical Metog county have confirmed the presence of 23 medium and large terrestrial mammal species and six pheasant species, including the very rare Bengal tiger (*Panthera tigris tigris*) as well as the dhole (*Cuon alpinus*), golden cat (*Catopuma temminckii*), marbled cat (*Pardofelis marmorata*) and clouded leopard (*Neofelis nebulosa*)[6], highlighting the exceptional conservation value of this spectacular lower sub-basin of the Yarlung Tsangpo river.

Plant diversity

Liu Jiang

Overview of the vegetation and species diversity[7]

The vertical distribution of vegetation in the Yarlung Tsangpo River Basin shows significant zonal characteristics, including coniferous forests, broad-leaved forests, thickets, deserts, grasslands, grasses, and meadows. From the perspective of a diversity index, its value gradually increased as the elevation declined from the upper reaches to the lower reaches of the Yarlung Tsangpo River.

There are more than 3,700 species of vascular plants in the Yarlung Tsangpo River valley belonging to 210 families and 1,106 genera[8], ranging from vines and epiphytes in tropical forests to alpine cushion vegetation in alpine subnival belt. There are 11 cover types and 21 cover types in alpine vegetation[9]. More than 150 species are endemic to Tibet. Some dominant species, such as *Ericaceae* in alpine shrubs, has a total number of 154, accounting for 26 percent of the global population. Also, there are more than 50 genera and 150 species of orchids, and some of them are almost impossible to find elsewhere in China.

The water-vapor passageway along the Yarlung Tsangpo River has resulted in a complete vertical distribution of natural zones in the Yarlung Tsangpo canyon. Due to the special landform and climate conditions, the canyon has become the high and north limitation for tropical plants and also the low and the south limitation for temperate plants distribution. Often in this region tropical and temperate plants meet to form a floristic junction and a strange geographical distribution in a small area at the same time, presenting a significant flora transition from tropical to temperate zones.

According to a survey on middle reaches of the Yarlung Tsangpo River Basin[10], almost 60 percent species belong to the families of *Compositae, Rosaceae, Ranunculaceae, Papilionaceae, Labiatae, Liliaceae, Scrophulariaceae, Polygonaceae, Umbelliferae, Gramineae, Cruciferae and Saxifragaceae*. Families with tropical flora and temperate flora account for 50 percent respectively, indicating the seed flora in the middle reaches of the Yarlung Tsangpo River is the transitional type from tropical to temperate zone.

In the riparian zone of the Yarlung Tsangpo River, the top three families are *Compositae, Gramineae and Leguminosae* [11]. Species of high occurrence include *Heteropappus gouldii*, *Artemisia wellbyi*, *Sophor moorcroftiana*, *Astragalus strictus*, *Oxytropis sericopetala*, *Eragrostis mino, Pennisetum flaccidum*, *Orinus thoroldii*, and *Microula sikkimensis*.

On the basis of the different climatic and geographic conditions, the Yarlung Tsangpo River Basin can be divided into three main regions based on the typical vegetation in upstream, middle and downstream basin areas.

The downstream region of the Yarlung Tsangpo River Basin is the most complete vertical mountain ecosystem in the world

Headwater and upstream region

Headwater region is located at an altitude of 4,000 meters to 6,000 meters. The river in the upper valley is composed of many bays, center bar, swamps and lakes, under the climate of arid and semi-arid zone. The landforms on both sides of the river are dominated by barchan dunes. This region has Alpine grassland, Alpine meadow, Alpine shrub, Alpine cushion vegetation, Alpine scree vegetation.

Middle reach

The middle reaches of the river are like a string of beads, wide or narrow, with broad valley, providing the main farming areas in Tibet. Altitude of this region is from 3,000 meters to 4,000 meters. This reach has Subalpine dark coniferous forest which includes tree moss and lichen in abundance, in addition to Alpine pine forest and sand dune vegetation.

Downstream region

The downstream, flowing in the grand mountain valley, is the area with abundant vegetation types and plant species. It is the most complete vertical mountain ecosystem in the world. The reach has Alpine shrub meadow with a good quality grass layer which is suitable for grazing cattle, sheep and other herds in the summer season. The Alpine shrub meadow, Alpine and Subalpine coniferous forest, is the forest group with widest distribution, largest area, strongest stability and highest productivity. In the vertical zone with an elevation from 2,700 meters to 4,300 meters, mountain semi-evergreen broad-leaved forest, evergreen broad-leaved forest and the valley monsoon rainforest can be found.







Black-necked cranes

Xiawei Liao

THE BLACK-NECKED crane (*Grus nigricollis*) belongs to the *Grus* genus, *Gruidae* family and *Gruiformes* order. It is the latest crane discovered among the 15 kinds of cranes worldwide by the Russian naturalist, Przhewalski, near the Qinghai Lake in 1876. It is also the only kind that inhabits high-altitude plateau areas between 2,500 and 5,000 meters above the sea level. There are estimated 10,000 to 10,200 black-necked cranes in the world and Tibet is home to 7,000 to 8,000, making up about 70 to 80 percent of the global population[12].

The black-necked cranes are featured with red head, black neck and white body. An adult crane is around 110 to 120 centimeters tall and weighs 4 to 6 kilograms. The breeding areas of black-necked cranes in China are located in the rivers and wetlands in the northern and western parts of the Qinghai-Tibet plateau, and scattered in the swamps in the southwest of the Qinghai-Tibet plateau as well as in Gansu and Northern Sichuan. They arrive at the breeding areas in March and build their nets that are about 10 centimeters tall and 90 centimeters in diameter in swamps or wetlands which cannot be easily accessed by humans and other animals. From early May, female and male black-necked cranes start to mate. They are known to usually mate in the mornings. They begin laying eggs in late May. Nestlings start to hatch after 30 to 33 days.

There are estimated 10,000 to 10,200 black-necked cranes in the world and Tibet is home to 7,000 to 8,000, making up about 70 to 80 percent of the global population

Attracted by the warmer climate and abundant food, including barley, wheat and grassroots, black-necked cranes migrate to the middle reach of the Yarlung Tsangpo River and its two tributaries, Lhasa River and Nyang Chu River from middle-October to March to spend the winter[13].

The black-necked crane is endangered because of habitat losses and illegal hunting. Due to the development of lakes and construction of infrastructure, such as fishing ponds and roads, the habitats of black-necked cranes are being gradually threatened. In southern Tibet, black-necked cranes are also affected by the changing farming practices. Due to technology improvement, many farmers started to grow winter wheat. When the black-necked cranes arrive, the winter wheat has not yet started to germinate and therefore cranes cannot find food. Black-necked cranes are now on China's first-class protection list, along with other 90 endangered species including the giant panda and golden monkeys. The National Black-necked Crane Natural Reserve in the middle reach of the Yarlung Tsangpo River (28°39'-30°00'N, 87°34'-91°54'E) was established in 1993 and elevated to a National Natural Reserve in 2003 with a total area of 6,143.5 square kilometers.

Frescoe in a monastry in Tibet (left)

Fish diversity

Xiawei Liao

THERE IS a long history of fishery in Tibet. Fish bones and fishing gears were found in the Qugong ancestor village ruins in Lhasa that date back to four to five thousand years. Fishery in Tibet took off from the early nineteen eighties, with the total catches tripling from 450 to 1,291 tons in ten years from 1985 to 1995.

There are 71 species[14] or subspecies of fish in Tibet, many of which are unique to the Qinghai-Tibet Plateau, including *Schizothoracinae*, *Triplophysa*, and *Sisoridae*. In the downstream, besides the species mentioned above, there are also other typical oriental region fish species, including *Barbodes hexagonlepis, Sinilabeo dero, Garra Kempi, Nemacheilus subfuscus,* and *Aborichthys kempi*. There are 13 alien species found in Tibetan water bodies, including rivers, wetlands and reservoirs. *Cyprinus carpio* and *Carassius auratus* are the most widely seen.

According to the Chinese Fishery Statistics, in 2017, fishery GDP amounted to RMB 32.7 million (approximately USD 4.7 million), making up 0.2 percent of the provincial agricultural GDP. The total fishery output in Tibet in 2017 was 454 tons, including 383 tons of catches from the rivers and 71 tons of aquaculture production. In recent years, the total aquaculture production in Tibet ranges from 60 to 100 tons. The main aquaculture species include *Hypophthalmichthys molitrix, Oreochromis spp,* and *Silurus asotus*.

Lalu wetlands, Lhasa Town

Red Pandas are members of Ailuridae family and are endemic to the Himalayan and Hengduan mountain ranges. Red panda population has probably declined by 50 percent over the last three generations and is likely to continue to decline in future

Fire cat: red panda

Partha Sarathi Ghose, Shalini Thapa, Megha Moktan and Abhishek V. Shukla

RED PANDAS are members of *Ailuridae* family and are endemic to the Himalayan and Hengduan mountain ranges. They occur in the mountainous regions of Nepal, India, Bhutan, Myanmar and China. Red pandas have recently been classified into two distinct species, the Himalayan red panda (*Ailurus fulgens*), distributed across Nepal, India, Bhutan, parts of southern China and northern Myanmar, and the Chinese red panda (*Ailurus styani*), which is endemic to China. The *A. fulgens* is distributed across the Yarlung Tsangpo and the Siang-Brahmaputra basin.

Red pandas essentially indicate the health of temperate forests that ranges from 1,500 to 4,800 meters above sea level. The species shows high preference for mixed temperate and conifer forests in different landscapes across its range. Red pandas prefer dense forest with healthy bamboo understory and proximity to water sources. Potential red panda habitats across the range countries range between 47,100 and 134,975 square kilometers. Red panda is a member of the Order *Carnivora*. However, its principal food is bamboo. The species of bamboo preferred by red pandas vary considerably across its range. Across the Himalayan range countries red pandas prefer *Yushania maling* and *Thamnocalamus aristatus* for food. Red panda population has probably declined by 50 percent over the last three generations and is likely to continue to decline in future. Negative impact of human related causes on red panda population and its habitat are undeniable. International Union for Conservation of Nature has categorised the red panda as an Endangered species and receives protection as a critically threatened species across all the range countries.

SIANG BRAHMAPUTRA BASIN

Biodiversity

Ravindra Kumar Sinha

THE RIVER Brahmaputra is the abode of rich biological diversity with over 300 species of fish and other megafauna, including the endangered Gangetic Dolphin, *Platanista gangetica gangetica*. The International Union for Conservation of Nature (IUCN) has found four species of fish to be critically endangered, 11 endangered and 25 vulnerable in the Ganges-Brahmaputra-Meghna basin. There is not enough data available for 27 percent of the species, some of which might turn out to be in the "threatened" category as well, after obtaining more data.

Among zooplankton 220 rotifer species (21 families and 46 genera), and *Cladocera*, termed as "water fleas" (74 species belonging to 41 genera) have been recorded from

the Brahmaputra floodplains of Assam. It is the richest diversity of rotifer recorded from any part of the Indian sub-region and one of the richest known globally. The Brahmaputra also has the richest diversity of *Cladocera* in India as well as South and Southeast Asia.

Changeable hawk eagle *(Nisaetus cirrhatus)*

Deepor *beel,* a Ramsar designated wetland in the Brahmaputra valley is recognized globally as a rich rotifer ecosystem with its 171 species of rotifer and 58 species of *Cladocera*. Majuli, the largest riverine island which is located in the floodplains has a rich micro-metazoan diversity with 131 species of rotifer and 55 species of *Cladocera*.

The *beels*, streams and rivers provide ideal habitats for turtles and amphibians. Out of 24 species of freshwater turtles in India, 21 are present in the Brahmaputra river. More than 250 species of birds have been recorded in the river basin.

Bar-headed geese *(Anser indicus)*

The floodplains also harbor a total of 76 species of macrophytes or aquatic plants belonging to 36 families and 55 genera. A detailed checklist of Angiosperms and Gymnosperms of Assam state prepared in 2014, lists 3,854 taxa (including infra-specific taxa) under 1,394 genera and 236 families. Out of these, 2,752 taxa are dicotyledons, 1,080 taxa are monocotyledons, and 22 taxa are gymnosperms.

The flora of Assam represents 18 percent of the total species of flora in India. However, the figures are provisional as many areas of the state are still unexplored or underexplored. The flora of Umananda island (having an area of only 4.7 hectares) on the Brahmaputra near Guwahati includes 146 species of plants belonging to Macro-Fungi, *Bryophytes, Pteridophytes, Gymnosperms* and *Angiosperms*. Macro-fungi are represented by 4 species belonging to 4 genera and 3 families; Bryophytes are represented by 4 species belonging to 3 genera and 3 families; Pteridophytes are represented by 11 species belonging to 8 genera and 6 families; Gymnosperms are represented by 2 species belonging to 2 genera and 2 families; Dicots are represented by 100 species belonging to 88 genera and 42 families and, finally, Monocots are represented by 25 species belonging to 22 genera and 11 families.

Linked Ecosystems of the Siang-Brahmaputra River Basin

Sanchita Boruah and S.P. Biswas

THE NORTHEASTERN region of India is blessed with high endemism due to its highly assorted and complex habitat which includes the numerous floodplain lakes scattered throughout the valley covering an estimated area of 0.1 million hectares[15]. The Brahmaputra, aptly considered as the 'lifeline' of Assam, boasts some unique flora and fauna, which makes it a paradise for nature and wildlife lovers. The diverse types of aquatic habitat scattered throughout the river basin are the abode of a variety of edible and ornamental fish species as well.

The five critical components of the flow regime which regulate river ecosystems are: magnitude, frequency, duration, timing and rate of change of hydrologic conditions[16]. In maintaining river health, the water quality and quantity is the master variable, which includes natural flow regimes, physio-chemical properties, sediment transport and drainage basin runoff. These collectively give rise to diverse habitats which comprise "linked ecosystems" within a particular river ecosystem. The Brahmaputra river system comprises such linked ecosystems.

Wetlands (Floodplain lakes)

The Brahmaputra basin is blessed with innumerable wetlands variously named as *beel, anua* and *haor* depending on the size and origin of the wetland in question. The marshes and swamps are locally known by different names such as *jalah, doloni, pitoni, doba*. These water bodies with diverse aquatic macrophytes are home to many aquatic faunas and a major source of capture fisheries which provide livelihood support to the local population. Deepor *beel,* Maguri *beel,* Mer *beel,* Chatla *haor,* Bakri *haor,* Sone *beel* are among the prominent wetlands in Assam. The *beels* and *anuas* are repositories of a wide array of riverine species including Indian Major Carps while *hoars* are abode of food as well as ornamental fish species. Over 100 species of commercially important fish have so far been recorded from the wetlands of Assam. Fishing is conducted in the wetlands almost round the year except in the season when fishing is banned. Fish production from these wetlands is far below their potential production of about 1,000 kilograms per hectare per year. Siltation of wetlands, wanton killing of brood and juveniles and lack of management plans are identified as major contributory factors for the poor fish production in the wetlands. However, proper management can turn these wetlands into fish granaries of the region.

Man-made tanks

The upper Brahmaputra basin has large excavated tanks which are centuries old and

Lesser whistling teal *(Dendrocygna javanica)*

White-winged wood duck (Asarconis scutulata) Highly endangered, only about 800 survive in the wild

are perennial tanks being fed by underground streams. The tanks provide shelter for a variety of flora and fauna and provide drinking water to thousands of people residing in their periphery. During the *Ahom* rule in Assam, many large tanks were constructed which are still in their full splendor. The *Ahoms* adopted a special technique to construct these tanks. One such tank is the Joysagar tank which is one of the largest man-made tanks in south Asia having an area of 4,50,000 square meters. The tank holds about 22, 02, 240 cubic meters of water during winter. Maximum depth of the tank ranges from about 8.85 meters in winter to about 9.67 meters in the monsoon season. Twenty-three species of aquatic macrophytes belonging to 18 families have been recorded from the tank. The faunal composition comprises of insects (19 genera), fish (21 species), and birds (22 species) including many migratory forms. Between December and February, thousands of migratory birds throng into Joysagar and other historical tanks of upper Assam which could be developed as ecotourism destinations.

Paddy fields

In the eastern and southern states of India, paddy fields are often flooded with small wild fishes during monsoon months which are retained within for varying periods of time; but production is low as many of the traditional systems of rearing are inefficient[17]. In Assam, people trap varieties of wild fish, mostly murrel and other air-breathing forms in seasonal water bodies like ditches, road-side canals, and deeper areas of paddy fields by making 'shelter' or traps for the fishes during the rainy season. The fishes are harvested during post-monsoon/winter months. However, the method of trapping fish is still 'primitive' and therefore the yield is very erratic and usually low. In the Siang Basin, composite rice-fish culture has been adopted by the Apatani tribe in their paddy fields, mostly for common carps[18]. In agriculture dominated areas, expansion of paddy cum fish culture may be an alternative livelihood option for the farmers.

Ephemeral streams

In the northeastern Himalayan region, most of the rivers are perennial, as these are fed by both snowmelt and rainwater alternatively during summer and monsoon seasons respectively. However, a special type of lotic system known as ephemeral or seasonal streams emerge during monsoon. Ephemeral streams represent a semi-arid existence which harbour fish diversity uniquely adapted to survive in those adverse micro habitats. These are locally known as *Jiadhal* and create havoc due to flooding particularly in Dhemaji and Lakhimpur districts of upper Assam. The small sized fish like *Danionella*, *Pseudolaguvia*, and other biota living in this type of biome have specific adaptive capability to cope with harsh and fluctuating abiotic parameters of seasonal streams.

Threats/Issues

Aquatic biodiversity especially is in critical crisis due to human exploitation, pollution and developmental activities[19]. The depletion of biodiversity is accelerated by various anthropogenic activities such as (a) release of toxic waste elements from the factories/ industries and agricultural fields into open water sources; (b) felling of trees in catchment areas for setting up of industries and large scale construction works which also have an adverse impact on aquatic life; (c) leakage of crude oil into water sources from the nearby oil reservoir; (d) injudicious fishing, high rate of siltation in river bed and above all, non- implementation of the existing fishing policies which are the root causes of declining aquatic diversity in the basin; (e) climate change is inevitably a major challenge for fishermen and riparian communities.

Local ecological knowledge constitutes a potentially useful source of information for conservation of ephemeral fish, some of which are very rare and endemic

Eco restoration, Sustainable development, Livelihood & Flood mitigation plan

Local ecological knowledge constitutes a potentially useful source of information for conservation of ephemeral fish, some of which are very rare and endemic. Although there are limitations and biases of this type of untested traditional knowledge, the local information from fishing communities is likely to help in monitoring the population status of target species.

The following suggestions have been put forward for maintaining a balance between economic activities and ecological resilience.

» Minimize environmental stresses such as pollution, habitat alteration, and exotic species introduction in the aquatic system
» Retain riparian forests that shade streams and rivers for maintenance of existing habitat quality
» Reduce nutrient loading to rivers and wetlands by maintaining natural flow
» Maintain flow of water and sediments critical to riverine ecosystems
» Restore aquatic and wetland ecosystems to the maximum extent possible to promote ecosystem resilience to climate change and other stressors
» Use groundwater judiciously for irrigation and human consumption in the rain shadow areas of the region
» Conduct a comprehensive study on impacts, mitigation and adaptation in the vulnerable areas, combined with practical actions involving resource users.

Brahmaputra Grasslands

Girish Jathar

THE GRASSLANDS of the Brahmaputra floodplains are a suitable habitat for many threatened species such as the Indian rhinoceros *Rhinoceros unicornis*, Bengal tiger *Panthera tigris tigris,* Asian elephant *Elephus maximus*, wild water buffalo *Bubalus arnee*, hog deer *Axis porcinus* and the swamp deer *Rucervus duvaucelii*. Most of the important grassland bird species of the Indian subcontinent[20] are found in the Brahmaputra floodplains. The Assam Plains Endemic Bird Area which includes the floodplains, has three restricted range species namely Manipur bush-quail *Perdicula manipurensis*, black-breasted parrotbill *Paradoxornis flavirostris* and marsh babbler *Pellorneum palustre*[21]. Other threatened bird species found in the grasslands of the Brahmaputra are listed in Table 2[22].

Table 2: Threatened grassland birds found in the Brahmaputra Floodplains

S.No	Common Name	Scientific Name	IUCN Status
1	Bengal Florican	*Houbaropsis bengalensis*	CR
2	Swamp Grass Babbler	*Laticilla cinerascens*	EN
3	Swamp Francolin	*Francolinus gularis*	VU
4	White-throated Bushchat	*Saxicola insignis*	VU
5	Jerdon's Babbler	*Chrysomma altirostre*	VU
6	Slender-billed Babbler	*Turdoides longirostris*	VU
7	Marsh Babbler	*Pellorneum palustre*	VU
8	Black-breasted Parrotbill	*Paradoxornis flavirostris*	VU
9	Bristled Grassbird	*Chaetornis striata*	VU
10	Yellow-breasted Bunting	*Emberiza aureola*	VU
11	Finn's Weaver	*Ploceus megarhynchus*	VU

Encroachment is one of the major threats to the Brahmaputra floodplains[23]. Grasslands outside protected areas are currently under great threat owing to rise in human population throughout the Brahmaputra floodplains. Protected areas such as Dibru-Saikhowa National Park are heavily disturbed by humans and overgrazing by livestock[24].

In most of the non-protected areas, various anthropogenic activities and natural events have changed the habitats leading to their degradation and transformation. Land use has changed due to expansion of agriculture, human settlements, developmental projects, and breaking up of the grasslands into smaller and patchy fragments. Over the last 45 years, the mosaic of grasslands, wetlands, agriculture patches have been converted to either tea gardens or contiguous agriculture areas in most of the districts of Assam.

These grassland floodplains are of great importance to both wildlife and human beings. The ecosystem services they provide are invaluable in terms of water recycling, arresting soil erosion, controlling floods, providing habitats for threatened wildlife, carbon storage, and most importantly livelihood to local communities. Conservation of these grasslands are of great importance in view of the changing climate and needs to be integrated into the policy and action plans of the government.

The ecosystem services they provide are invaluable in terms of water recycling, arresting soil erosion, controlling floods, providing habitats for threatened wildlife, carbon storage, and most importantly livelihood to local communities

❄

Avifaunal diversity

Utpal Singha Roy

MORE THAN 900 different bird species including birds of global conservation concern and restricted-range bird species have been recorded from North-east India the majority of which are found in the Brahmaputra valley ecoregion[25]. Wide geographic areas under this region have been designated as Important Bird Areas (IBAs). These include National Parks such Dibru-Saikhowa, Kaziranga and Orang; Sanctuaries such as D'Ering, Panidihing and Chakrashila; and Reserved/Protected Areas such as Dibang and Majuli island. On the basis of the large number of endemic birds found in these areas, two Endemic Bird Areas have been designated from this region; the Eastern Himalayas (EBA 130) and the Assam Plains (EBA 131)[26].

Several important studies on avifaunal diversity of Brahmaputra valley have been conducted. However, most of the studies have been limited to areas with easier access. Studies from remote areas covering different seasons throughout the year are likely to result in newer interesting findings.

Among the numerous residential and migratory birds recorded from the Brahmaputra Valley, many belong to the threatened category. Most notable among these threatened birds are the critically endangered Bengal florican (*Houbaropsis bengalensis*), white-bellied heron (*Ardea insignis*), Baer's pochard (*Aythya baeri*), spoon-billed sandpiper (*Eurynorhynchus pygmeus*), Indian vulture (*Gyps indicus*), slender-billed vulture (*Gyps tenuirostris*) and white-rumped vulture (*Gyps bengalensis*). Among the Endangered category most notable are white-winged duck (*Asarcornis scutulata*), oriental white stork (*Ciconia boyciana*), greater adjutant-stork (*Leptoptilos dubius*) and masked



***From left to right:* Long-tailed broadbill** *(Psarisomus dalhousiae);* **Crimson sunbird** *(Aethopyga siparaja);* **Red-billed leiothrix** *(Leiothrix lutea)*

finfoot (*Heliopais personatus*). Vulnerable birds from this region include Dalmatian pelican (*Pelecanus crispus*), lesser adjutant stork (*Leptoptilos javanicus*) and great knot (*Calidris tenuirostris*). Apart from these, black-bellied tern (Sterna acuticauda), black-headed ibis (*Threskiornis melanocephalus*), black-necked stork (*Ephippiorhynchus asiaticus*), Blyth's kingfisher (*Alcedo Hercules*) and ferruginous pochard (*Aythya nyroca*) all belong to the Near Threatened category.

Deforestation in the Brahmaputra watershed has resulted in higher siltation and soil erosion often leading to flash floods in downstream habitats causing huge loss to biota (including birds) thriving therein. Hunting and poisoning of birds are other major threats for both migratory and resident avifauna of this area. Thus, habitat loss, habitat alteration, restricted geographic range, pollution, climate change, hunting and various diseases are affecting the birds of this region negatively[27].

The Wild Life (Protection) Act 1972 of India prohibits hunting of water-birds under Schedule IV. Also, birds like white-bellied heron, oriental white stork, pink-headed duck, white-winged wood duck are protected under Schedule I under the same act that prohibits killing or capturing them. However, these laws need to be enforced without prejudice to save the bird population. Habitat protection is another excellent approach to conserve wildlife and the Brahmaputra valley semi-evergreen forests ecoregion has been included in the 200 global priority ecoregions identified by WWF in the year 2000. To conserve the rich biodiversity of this region a number of protected areas have been designated of which Kaziranga National Park is also a 'World Heritage Site'. Brahmaputra valley with its enormous avian diversity can be easily considered a birds paradise, however, it is obvious that this region needs proper scientific management strategies including conservation education and awareness for long-term sustenance.

Fisheries and aquatic biodiversity

S.P. Biswas

Riverine Biota

Brahmaputra basin is made up of alluvial soil, with high percentages of sand and silt. The riverbank is almost perpendicular in most of the 640 kilometer stretches and highly prone to erosion. Based on the topography of the Brahmaputra river basin, fish habitats and their faunal types are as follows: - (I) *Bedrock reaches* (fast flowing river): Rapid streams having relatively steep gradient and rocky bed that harbour small fish genera like *Amblyceps*, *Barilius, Danio, Garra, Glyptothorax* and *Hara*; (II) *Step-pool* (upstream pools): Sluggish and deeper parts of upland streams. Fishes like *Bangana dero, Labeo pangusia, Neolissocheilus hexagonolepis, Raiamas bola, Tor* spp., are dominant here. (III) *Regime reaches* (river meandering & confluence): The eddy counter-current system at the junction of two rivers is an ideal place for fish assemblages. The confluences are also the passageways for upstream fish migration. Similarly, the channel meanderings offer suitable home for a large variety of fish species; (IV) *Braided reaches* (adjoining floodplain lakes): *Beels* are weed infested shallow water bodies temporarily or permanently connected with the main river. (V) *Plane-bed reaches* (open river): Large sized species such as *Sperata, Bagarius, Chitala, Pangasius*, *Silonia* and other giant aquatic fauna like *Platanista* and *Nilssonia* (*Trionix*) are mainly encountered in the open river; (VI) *Ephemeral streams*: These streams are 'alive' during rainy months. Varieties of small and medium sized fish are encountered; (VII) *Seasonal water bodies*: Low lying paddy fields, derelict ponds, swamps and road-side *nallahs* (depressions) are also 'temporary homes' for a variety of small fish species. The Brahmaputra system shares its fish resources with the Indo-Gangetic plain gene pool and to a lesser extent with the Myanmar and south Chinese fauna.

Biota of Riparian Ecotones

Over 3,500 floodplain lakes or *beels*, including both tectonic (closed type) and ox-bow lakes (open type) scattered throughout the Brahmaputra valley receive regular flood pulses during monsoon. Almost all types of riverine fish including Indian major carps depend on riparian ecotones for spawning. This lateral migration of spawning fish alters the species composition of floodplain lakes during rainy months. Trophic structure is typically present from surface dwelling to typical substrate dwelling species like *Glossogobius giuris* to mud-dwellers like *Monopterus cuchia* or burrower like *Channa barca*. Fish species may be grouped into five habitat guilds, such as surface water guilds, column dwellers, bottom dwellers, marginal dwellers and mud dwellers. Further, wetland fish may also be categorized as: (a) food fish; (b) ornamental; (c) larvicidal and (d) medicinal. Flood water rejuvenates the *beel* by providing fresh water and nutrients, auto stocking of fish as well as flushing out of floating macrophytes mainly water hyacinth. The common fish biota of *beels* and seasonal water bodies are *Amblypharyngodon, Botia, Esomus, Channa, Crossocheilus, Danio, Glossogobius, Leiodon, Macrognathus, Pethia, Puntius, Rasbora, Salmophasia, Trichogaster* and *Xenentodon*. The *beels* constitute a major fishery resource of Assam and have provided livelihood support to thousands of riparian fisher folks for centuries.

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Maguri *beel* is one of the largest floodplain lakes in upper Brahmaputra basin located in the periphery of Dibru-Saikhowa National Park in Tinsukia district, Assam. Maguri, an important source of capture fisheries, covers an area of 167.4 hectares at full storage level. The ecology and faunal assemblage of the wetland is almost entirely regulated by rainfall and combined discharge of rivers Dibru and Lohit. Altogether 110 fish species, mostly dominated by air breathing forms and also a good number of ornamental and endemic species like *Badis assamensis, Channa aurantimaculata, C. barca, C. bleheri, C. stewartii* and *Mystus dibrugarensis* have been recorded from this wetland. It is also a rich habitat for chelonians and avian fauna. Over 500 avian species including a large number of migratory birds in the locality attracts a large number of tourists every year.

Wetlands are also rich in benthic fauna found attached with aquatic macrophytes or sediments as nymphs or larvae. Two insect species (*Cybistertri punctatus* and *Lethocerus indicus*) and several ubiquitous mollusc species like *Lamellidens corrianus*, *L. marginalis*, *Corbicula assamensis*, *C. striatal*, *Brotia costula*, *Bellamya bengalensis*, *Tarebia lineate* are used as non-conventional food as well as for medicinal purposes by indigenous people. Further, rare and endemic mollusc species such as *Solenaia soleniformis*, *Parreysia* spp. and *Pseudodon* spp., have also been recorded from wetlands and slow moving streams of upper Brahmaputra basin.

Conclusion

About 200 fish species reported in the mid-twentieth century from the Brahmaputra valley have now disappeared especially between Saikhowaghat and Dhansirimukh. High fishing pressure and wanton killing of gravid and juveniles by using explosives and chemicals as well as the *jeng* fishing (a local destructive fishing technique) have been identified as major threats to the fish biodiversity. Deforestation in the catchment area, construction of roads and embankments and blockade of feeder channels of floodplain lakes have contributed to the reduction of habitat complexity. Excessive boulder and sand excavation from the riverbed also alter the micro-habitats of many hill-stream fish species. A comprehensive study on the entire Brahmaputra basin must be carried out to assess anthropogenic and environmental stresses on instream and also riparian biota so that effective policies for river management can be formulated to maintain environmental flow for sustenance of existing riverine biota as well as dependent economy and livelihoods of riparian people.

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Gangetic dolphin

S.P. Biswas

OUT OF the four freshwater dolphins found around the globe, the one which is found in the Ganga-Brahmaputra-Meghna system is known by a plethora of names: *Sus*, *Shushuk*, *Xihu* in Hindi, Bengali and Assamese respectively. To the scientific community this rare cetacean mammal is- *Platanista gangetica gangetica.*

The Gangetic dolphin is the national aquatic animal of India. It has a robust fish-like body and may attain 2 meters length and weigh about 100 kilograms or more. Calves and young dolphins are dark colored but as they grow, the body colour changes and the adults are mostly slate grey. Gangetic dolphins are virtually blind but are champion swimmers and movement even in highly turbid water is possible with the help of a sonar system (echolocation) located on the forehead (melon). Gangetic dolphins prefer sandy riverbeds, moderate water currents, and are often encountered in small groups of 3 or 4 in relatively deeper portions of the river (depth of more than 3 meters), usually at a river confluence and also at river meanders during dry months. The long, pointed rostrum bears a series of homodont teeth meant for grasping the prey, mostly fish.

Dolphins perform all their metabolic activities under water, except breathing. The mean time between two surfacing has been recorded as 38 to 45 seconds for adults. They roll over rather quietly exposing the forehead and part of the back for a second or so. The infants are very playful, surface more frequently (15 to 20 seconds between two intervals) and often jump over the water.

Sanjay Das

The Gangetic dolphin is the national aquatic animal of India. The presence of dolphins is a clear indication of the 'good health' of a river

The dolphin is the keystone species in a riverine ecosystem. It maintains the ecosystem equilibrium by controlling the population of secondary consumers. In fact, the presence of dolphins is a clear indication of the 'good health' of a river. Dolphins were once abundant in the Brahmaputra river but the population came down drastically in the eighties primarily due to intentional killing of dolphins for their oil which is believed to be a master drug against various ailments. Dolphin oil was also used for catching cat fishes especially *Clupisoma garua*. People were ignorant about the importance of dolphins in a riverine ecosystem. In one particular instance, more than 50 dolphins were killed, and their body oil extracted by some professional killers at Narain Dahr, upstream of the Barak (Meghna river system) in 1985-86. This led to a virtual extinction of dolphins from the Barak River in southern Assam. At present only 'fragmented populations' of dolphins can be sighted in certain pockets in protected areas like Dibru-Saikhowa National Park, river Subansiri, Kaziranga National Park and River Kulsi in the Brahmaputra valley.

Continuous widening and aggradations of the river due to bank erosion, high rate of siltation and loss of prey base in the habitat are major threats for the survival of dolphins. High rate of siltation has reduced the depth of the river especially 'deep pools' by 30 percent in the last four decades and this is the prime reason for the shrinkage of dolphin habitats in the upper reaches of the Brahmaputra. Fortunately, the number of Gangetic dolphins in the central and lower reaches of the Brahmaputra has shown an increasing trend due to continuous efforts by conservation groups in the last two decades.

Hoolock gibbon

Dilip Chetry

WESTERN HOOLOCK gibbon (*Hoolock hoolock*) and Eastern Hoolock gibbon (*Hoolock leuconedys*) are two charismatic primates that represent the ape group in India. Their distribution in India is restricted to the southern bank of the Dibang–Brahmaputra river system in the northeastern states of India excluding Sikkim. The Eastern Hoolock gibbon occurs only in the Siang basin and in Assam. Extremely elusive, the gibbons inhabit tropical wet evergreen, tropical semi-evergreen and sub-tropical moist deciduous forests. Being exclusively arboreal, Hoolock gibbons depend on the high canopy coverage in their habitats. They are diurnal and exhibit extreme form of brachiating skill. Fruit is the staple food of frugivore Hoolock gibbons. They live in monogamous families and an ideal Hoolock gibbon family has one adult male, one adult female and one to four offspring. The average group size is three. Each gibbon family maintains its own territory through their trademark duet song. Adult males are black in colour with white eyebrows and adult females are copper tanned in colour. Neonates are milky white in colour. Juveniles of both the sexes are black with white eyebrows. Females turn gray to tan colour in sub-adult stage, but males retain the black colour till adulthood. There is no marked size variation between males and females. Some morphological differences are there between the two species. Females attain sexual maturity at the age of 6 to 8 years and the age for sexual maturity in males is 7 years. Estimated gestation period is 183 to 225 days and inter-birth interval is 2 to 3 years. The gibbon is our close living relative and wild gibbons share 95 percent of their genetic material with us. Gibbons play a vital role in the regeneration of forests as active seed dispersers.

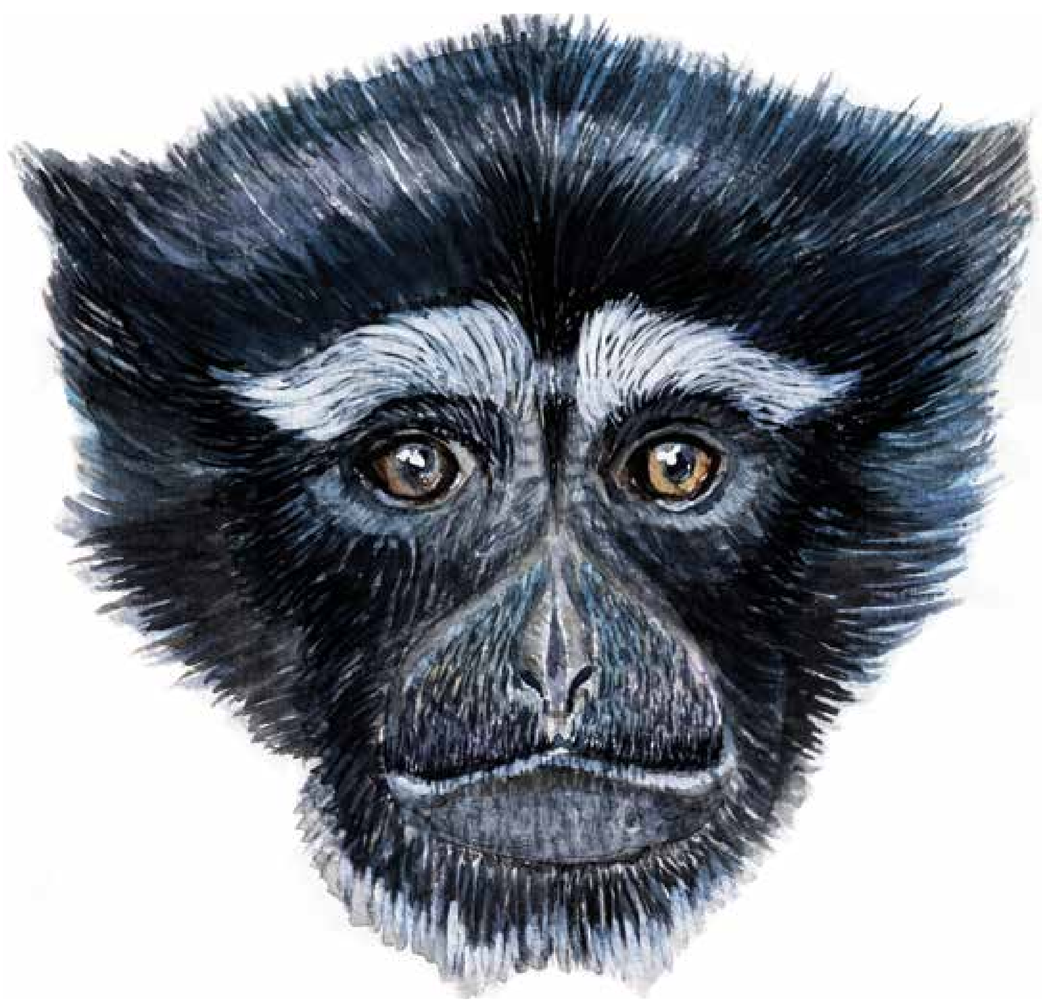

Illustration by Tania Zakir

Gibbons play a vital role in the regeneration of forests as active seed dispersers

The principal threats to gibbons in Assam are massive habitat loss, intensive habitat fragmentation, *jhum* cultivation and hunting. Loss of habitat is a result of wanton destruction of forests, encroachment, agro-expansion, and development projects. Along with habitat loss, fragmentation of habitats is becoming another major threat to gibbons. Reducing cycles of traditional *jhum* cultivation has also threatened gibbons by creating secondary forests. Hunting of gibbons as food, for traditional medicine, sports, and ornaments is also a common custom among many tribes.

Hunting of gibbons as food, for traditional medicine, sports, and ornaments is also a common custom among many tribes

In the Indian Wildlife Protection Act, 1972, both species of Hoolock gibbons are listed as Schedule I species. According to the IUCN red list of 2019, Western Hoolock gibbon is endangered and Eastern Hoolock gibbon is vulnerable. The Gibbon Wildlife Sanctuary in Jorhat district of Assam is the only protected habitat in the country to be named after a primate species. Thirteen protected habitats in Assam support the Western Hoolock gibbon. Only three reserve forests in Sadiya harbour protect the eastern Hoolock gibbon in Assam. Implementation of the slogan “Save Forest, Save Gibbon” in its true sense can only ensure long-term conservation of gibbons and their habitats in Assam.

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Golden langur

Rekha Chetry

THE GOLDEN langur (*Trachypithecus geei*) is a highly attractive arboreal primate discovered in 1953. It is endemic to northwest Assam in India and neighbouring Bhutan. In India, its distribution is limited to an area bounded by the river Manas in the east, Sankosh in the west and the Brahmaputra in the south. In India they are primarily inhabitants of wet evergreen forests and semi-evergreen forests. Sal (*Shorea robusta*) dominated forests and secondary forests also support them. The diurnal golden langurs spend 99 percent of their active time in trees exploring the top and middle strata of forests, though in degraded habitats they descend to the ground.

Highly social golden langurs live in diverse social frameworks such as uni male–multi female troop or society, bi male-multi female troop, multi male-multi female society, all male bands or societies and lone males. Uni male–multi female troops are more common and stable. Average troop size varies in different habitats and generally ranges from 2 to 12 individuals. Inter-individual bonding between the troop members is very strong which is the key to their peaceful societies.

The major activities of golden langurs are locomotion, resting, feeding, and monitoring. Other activities include grooming and playing. Golden langurs are folivorous and leaves contribute 60 percent or more of their daily diet. Fruits, seeds, flowers and flower buds, stem cortex, twigs, bamboo shoots are other food items. Gum feeding, soil feeding, algae feeding, insect feeding, snail feeding have also been observed. More than 200 species of food plants have been identified from different habitats in Assam. Langurs spend their nights on selective tall trees to avoid predators.

From 2016 to 2020, it has been in the IUCN list of top 25 most endangered primate species of the globe

Illustration by Tania Zakir

Golden langurs are seasonal breeders and June to January is the breeding season. The typical golden coat colour of the species can be observed only during the breeding season. The estimated gestation period is 168 to 180 days, and inter-birth interval is two years. January to June is the birthing season. Male golden langurs attain sexual maturity at 5 to7 years, while the age of sexual maturity for the female is four years. The golden langur is a Schedule-I species in the Indian Wildlife (protection) act, 1972, and an endangered species in the IUCN Red list (2020). From 2016 to 2020, it has been in the IUCN list of top 25 most endangered primate species of the globe. Chakrashila Wildlife Sanctuary and Manas National Park are the only protected habitats for golden langur in India. Habitat destruction and fragmentation are the most severe threats to golden langurs in Assam. Fatalities due to electrocution, dog predation and vehicular accidents are emerging threats. We the people of Assam should do our best for the conservation of golden langur which is a part of our rich natural heritage.

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Greater one-horned rhino

Bibhab Kumar Talukdar

EVERY RIVER in this world carries stories of culture and biodiversity of which humans are an integral part. The alluvial floodplain grassland ecosystems of the Brahmaputra provide an excellent habitat for the greater one horned rhino (*Rhinoceros unicornis*). The rhino represents the floodplain ecosystem of the Brahmaputra. For Assamese people, the rhino is the epitome of the conservation movement in Assam, reflecting the success of the conservation efforts which began early in the nineteenth century, when it was assumed that the Kaziranga area in Assam had only about a dozen rhinos left.

The alluvial floodplain grassland ecosystems of the Brahmaputra provide an excellent habitat for the greater one horned rhino

The rhino has been a conservation dependent species since early nineteenth century because of the threats from poaching and destruction of grassland habitats. The conservation of rhinos in early nineteenth century got a boon through the declaration of key rhino habitats in Assam as protected areas. The first sincere efforts to protect the estimated population of a dozen rhinos in Kaziranga was initiated in the year 1905. Kaziranga, Manas and Laokhowa were finally declared as Game Reserves in the year 1908. In the year 1968, the Assam Government realized the need to convert the Kaziranga Wildlife Sanctuary into a national park and began making efforts to enact the Assam National Park Act, which came into effect in 1969. In January 1974, in pursuance of the Assam National Park Act 1968, the Kaziranga was declared as the first National Park covering an area of about 430 square kilometers.

Due to proactive conservation initiatives, Assam currently (in year 2020) has about 2,650 rhinos. This conservation success has been achieved due to the dedicated work of the forest officials, including frontline wildlife staff working hard to conserve and protect

The rhino conservation effort is one of the biggest conservation success stories of India. From just a dozen rhinos left in the wild in early nineteenth century, today there are more 2650 rhinos!

the rhino and their habitats despite diverse challenges. Support and cooperation is being rendered by local communities, complimentary support is being rendered by district administration and Assam police and also by various non-government organisations. The media also proactively assisted in spreading conservation awareness to reach out to diverse audiences with regards to rhino conservation. The rhino conservation success is the pride of Assam.

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Asian elephant
(Elephas maximus indicus)
Red jungle fowl
(Gallus gallus)
Wild water buffalo
(Bubalus arnee)

Amphibian and reptile diversity

M Firoz Ahmed

THE AMPHIBIANS and reptiles are one of the poorly understood groups of vertebrates across the globe. Our understanding about these groups in many areas, bestowed with high biological diversity has just got momentum. The hills of northeast India and the eastern Himalayas represent a complex of ecosystems of extraordinarily rich biodiversity, resulting from the meeting of three biogeographic regions of the world: Indian, Indo-Chinese, and Indo-Malayan. The Brahmaputra river traversing through the hills and plains of the region for millions of years, continues to influence all forms of life. The unique position, climate and physiography have laid the foundation for proliferation of a variety of ecosystems that raised a diverse biota with high level of endemism.

The Himalayas, the topography, the monsoon, the forests, and the river systems, all together, contributed to the evolution of the region as a hotspot for amphibians and reptiles: 146 species of amphibians and 180 species of reptiles are recorded in this region. This number is only going to increase as explorers and scientists have started to take more effort to understand their diversity only recently. Positioned next to the Tropic of Cancer, with an altitudinal range from 20 meters to 5,000 meters above sea level, the region houses a striking range of habitats, from tropical floodplains and forests to alpine meadows and forests, through vast subtropical humid forests as altitude rises from south to north. This unique mix of ecosystems is intricately complex.

Once thought extinct in the wild, the black softshell turtle lives in the lakes and networked channel systems of the Brahmaputra and its major tributaries

Northeast India is characterized by a hot, wet summer, and a cool, usually dry winter. Temperature varies from subzero to maximum 38 degrees centigrade. Annual average rainfall is above 2,000 millimeters which varies from less than 1,000 millimeters in parts of central Assam to more than 12,000 millimeters in parts of the southern Meghalaya plateau such as in Cherrapunjee and Mawsynram.

Understanding reasons for the high diversity of herpetofauna in the northeast region of India can be complex but not impossible. As the Ganges drains into Bangladesh territory and shares the same floodplains as the Brahmaputra, northeast India receives several mainland Indian species such as gharial *Gavialis gangeticus*, Gangetic softshell turtle *Nilssonia gangeticus,* Indian bull frog *Hoplobatrachus tigerinus* and *Polypedates taeniatus*. Even further, the floodplain connects the region to an African genera of tree frog, *Chiromantis sp*. found in the east and northeast of India.

As we move upstream of the Brahmaputra, the diversity of species of herpetofauna also starts going up. There are as many as 25 species of amphibians and 95 species of reptiles found in the floodplains itself. Once thought extinct in the wild, the black softshell turtle *Nilssonia nigricans* lives in the lakes and networked channel systems of the Brahmaputra and its major tributaries.

Indian bullfrog *(Hoplobatrachus tigerinus)*

Just above the floodplains up to the base of the hills, a number of unique and endemic species of amphibians are found in the region, such as Orang sticky frog *Kalophrynus orangensis* and Assamese baloon frog *Kaloula assamensis*. This is the transition zone from floodplains to the hills, where the endemic Assam roof turtle *Pangshura sylhetensis,* inhabits. Further up, in the lower hills, two species of turtles and tortoises, Asian brown tortoise *Manouria emys* and Malayan box turtle *Cuora mouhotii*, indicative of their names, connects the region to the Malaya and the rest of Southeast Asia, bringing in more complexity to its diversity.

The herpetological diversity in the northeast hills increases with increasing altitudes up to the mid elevation before it goes down near the snow line. The hills thus also connect to several species of Malayan origin that occur in Southeast Asia, the reason being the similarity in habitats and ecosystems extending to Southeast Asia over Myanmar and Thailand to peninsular Malaysia.

A unique species of amphibia, Jerdon's tree frog *Nasutixalus jerdonii* occurs in the subtropical broadleaf forests in the hills of northeast India and southeast Asia that lives in the holes of trees that contain small quantities of water. As life is hard in such an uncommon habitat, particularly for a tadpole confined to such a narrow space without mobility and food resources, the mother comes to their rescue. The female visits such breeding tree holes regularly and deposits unfertilized eggs for

Diamond-backed lizard *(Sitana)*

Asian roofed turtle *(Pangshura sylhetensis)*

King cobra
(Ophiophagus hannah)

The largest and longest venomous snake in the world, the King Cobra is the unique snake species where the females lay eggs in nests made with fallen leaves and guard them until the eggs hatch

her tadpoles on which they feed and grow to miniature frogs one day to explore the vibrant world outside.

Similarly, the forest floors of the tropical forests of northeast India, often with thick leaflitters, is home to many species of herpetofauna. The largest and longest venomous snake in the world, the King Cobra *Ophiophagus hannah* occurs widely in the moist evergreen forests. This is the unique snake species where the females lay eggs in nests made with fallen leaves and guard them until the eggs hatch.

Further upstream of the Brahmaputra river, as it becomes narrower and powerful, it is known by the name of Siang, and creates a unique topography in the Himalayas. It is where the Himalayas are cut deep by the Tsangpo and Siang at an altitude of 550 meters at the Xizang-India border with a sharp fall from 2,950 meters near Nyingchi in Xizang. This transition of Tsangpo through the 'Great Bends' creates a pass for several species from Tibet and south China into India using the Himalayan foothills as a conduit. Medo pit viper *Trimerusurus medoensis*, and Cross barred treefrog *Rhacophorus translineatus* are two best examples of Indo-Chinese cross over.

While the Himalayas act as a barrier for most terrestrial species between India and the Tibetan plateau, some amphibians (*Scutiger sp.*) still exist across the Himalayas. The amphibian Scutiger genera are found to occur in the high Himalayas that may seem inhospitable for them, between 3,000 and 4,000 meters above sea level. It might be possible that they were separated by the rising Himalayas millions of years ago or they speciated on both the north and south flank of the Himalayas using the Yarlung-Tsangpo-Siang as a biological corridor after the rise of the Himalayas.

The Brahmaputra basin in northeast India has witnessed human induced local extinctions of at least two species of reptiles in recent times: the mugger *Crocodylus palustris* and the gharial *Gavialis gangeticus*. The mugger was extirpated much earlier, the gharial followed more recently in the nineteen seventies. Human intolerance towards 'dangerous' crocodilians was the primary reason for extirpation of these giant reptiles since human occupation of the river basins began overlapping their habitats in the mid-twentieth century.

Many species of amphibians and reptiles are endemic to this region or with restricted range. Such species face high threat to extinction than those widely distributed. However, limited information on distribution of such species hampers diligent evaluation of their conservation status. Among the known species of the northeast region of India, nine species of amphibians, about 6 percent of known species, and 29 species of reptiles, about 16 percent of known species are threatened as per the IUCN red list.

The amphibians and reptiles are known indicators of environmental changes in an ecosystem given their high sensitivity to their surrounding environment. Humans have always benefited by their presence. For example, reptiles control the rodent population. However, herpetofauna are threatened today due to our own actions leading to diminishing the ecosystem services over generations. This is very prominent, particularly, where habitats have been converted into agriculture and monocropping by removing many species living there. Pollution of air, water, and soil through negative human actions on ecosystems is another major threat to the herpetofauna. More importantly, unplanned, and overoptimistic river valley development projects in the Brahmaputra basin is a serious conservation concern to amphibians and reptiles.

The critically endangered Elongated tortoise *(Indotestudo elongata)*

While superior technology has brought down cost of solar power production globally, hydropower is still being promoted with misinformation as profitable and ecofriendly in the upper Brahmaputra basin areas in northeast India. Ecological disaster is inevitable from such hydropower dams and reservoirs, with far reaching consequences. A dam on a river not only kills the living river, but it also inundates a large area which includes habitats for endemic, rare, and threatened species of herpetofauna or displacement of individuals living there, causing stress in the ecosystem.

Policies and planning must be aggressively changed to make the world more livable and sustainable for our future generations. This is more so in the light of climate change events. Value of ecosystem and nature needs to be part of our economic and development agenda to ensure that we grow sustainably.

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MANAS BASIN

Wetlands of Bhutan

Karma Chopel Ghongsar

BHUTAN HAS a number of wetlands in the form of glacial lakes, marshes, swamps, and ponds which also have particular biological, spiritual and socio-cultural functions. Wetlands in Bhutan are under increasing pressure from unplanned development, disturbances and lack of awareness among the general public leading to the loss of integrity of the wetland ecosystem. Even though there is no aggregated data to make an unambiguous demonstration, there is a strong perception, backed by informal reporting, that Bhutan is experiencing a drying up of streams and creeks with the disappearance of their associated marshes and swamps.

Wetlands support high biological diversity including migratory birds and other flora and fauna. They are also important for water storage and release which sustains the perpetual flow in our rivers that is crucial for our hydropower generation. Culturally these wetlands and lakes are revered as sacred sites and are associated strongly with the traditional belief systems and lifestyles. It is reported that 104 bird species inhabit these freshwater ecosystems in Bhutan and many other aquatic plant and animal species such as *Rununculus trichophyllus, Hydrilla verticillate, Potamogeton crispus, R. Tricuspis, Acorus calamus, Acorus grmineus, Shoenoplectus juncoides, Typhus spp., Phragmites spp., Equisetum spp., Aconogonum alpinum, Carex spp., Juncus spp.* and *Salix sp.* Similarly, large predators such as *Panthera tigris tigris, Panthera pardus, Panthera uncia,* and smaller predators such as *Neofelis nebulosa, Cuon alpinus,* and *Felis bengalensis* come to drink water and stalk prey species at water sources. Other mammals associated with wetland ecosystems include *Platanista gangetica Lutra lutra*, *Lutrogale perspicillata*, *Bubalus arnee, Felis viverrinus, Herpestes urva, Nectogale elegans, Chimarrogale himalayica*.

Culturally these wetlands and lakes are revered as sacred sites and are associated strongly with the traditional belief systems and lifestyles

The Coleoptera species *Hydraena karmai* was discovered from a puddle in a place called Zomyuethang behind Punakha Dzong. This species was never known to science before. Several new species of Ephemeroptera (may flies), Plecoptera (stone flies) and Trichoptera (caddis flies) EPT taxa were also discovered from the water bodies in Bhutan in a few weeks of sampling and assessment from Paro, Thimphu, Tsirang and Sarpang Dzongkhags (EU funded Assessment System to Evaluate the Ecological Status of Rivers in the Hindu Kush-Himalayan Region (ASSESS HKH) project led by the author). The impacts of climate change compounded by the ad hoc developmental activities will wipe these newly discovered species and others even before they are discovered, signaling the importance and the need to address the impacts of climate change and ad hoc developmental activities with great urgency.

The relict species of dragon fly larvae, *Epiophlebia laidlawi* was found in the headwater of *Drey Chhu* stream above Dechencholing, Thimphu and in *Lamchela Chhu* stream in Chendebji, Trongsa. This species is categorized as rare and highly threatened and the only other places where it is ever found to this day is in eastern Japan and Nepal. This species is an indicator of the pristine water quality.

Karma Chopel Ghongsar

Hydraena Karmai (left picture) found only in Bhutan; *Epiophlebia laidlawi* (right) indicator of pristine water quality.

Bhutan acceded to the Ramsar Convention on Wetlands on 7 May 2012.

Currently Bhutan has three Ramsar sites:

1. **Bumdeling Wildlife Sanctuary**, Tashiyangtse; 142 ha; 27°40'23"N 091°26'29"E. This glacial valley in the northeast Bhutan was a rice producing area. At least 74 bird species including the endangered black necked cranes (*Grus nigricollis*) inhabit this site. Other endangered species recorded at the site include the snow leopard (*Panthera unica*), tiger (*Panthera tigris tigris*), Asiatic wild dog (*Cuon alpines primaevus*) and Himalayan musk deer (*Moschus leucogaster*).
2. **Khotokha** in Wangdue District with an area 114 ha; 27°25'55"N 89°59'33"E, is located west of the Black Mountain range. Khotokha wetland is one of the sources for the tributaries of the Punatsang Chhu, and also provides drinking water and irrigation water for potato farms. The subalpine shrub marsh, consisting of peat bogs and fens, is one of the last remaining places in Bhutan where summer-winter migrations of farmers are practiced. The black necked crane along with other endangered species such as the Himalayan musk deer (*Moschus leucogaster*) and the Asiatic wild dog (*Cuon alpines primaevus*) inhabit this site.
3. The **Gangtey-Phobji** is the third and largest wetland in Bhutan of international importance. This site lies in a wide glacial valley with scenic beauty and clear streams in the valley such as Nakey Chhu, and Khewang Chhu. This site comprises of rich ecosystems and provides prime winter habitat for up to 300 black necked cranes (*Grus nigricollis*), and other globally threatened species such as the endangered red panda (*Ailurus fulgens*) and tiger (*Panthera tigris tigris*), and the vulnerable sambar (*Cervus unicolor*).

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White-bellied heron

Indra P Acharja

THE WHITE-BELLIED heron (*Ardea insignis*) is a large wader species of family *Ardeidae*, order *Pelecaniformes*, found in freshwater ecosystems of the Himalayas. Historically known to be found across South Asia, it is now one of the rarest birds in the world, having disappeared from most of its historical range including Nepal and Bangladesh. The global estimated population is between 49 and 250 adults according to IUCN data, however fewer than 60 individuals are known to live in the wilds of Bhutan, Northeast India, China, and Myanmar. There are five actively breeding pairs in Bhutan and are the only currently known breeding population in the world. The heron is categorized as critically endangered under the IUCN Red List of threatened species since 2007 and the species is also protected under respective laws in all the range countries.

The White-bellied heron is now one of the rarest birds in the world

The white-bellied heron is the second largest heron standing up to 130 centimeters tall with a wingspan of nearly 2 meters and weighs up to 5 kilograms. The heron has a dark greyish body with contrasting white belly and vent, white-streaked scapulars, fore neck, and upper breast with prominent crest and long sharply pointed black bill with slight serration on the tip of the lower mandible. Juveniles are darker than adults, with browner-tinged vent, the neck is more streaked, the plumes are smaller, and the bill is shorter and greyish in colour. White-bellied herons are sexually monomorphic and differentiating sexes visually is almost impossible. During breeding seasons, the plumage turns light grey with a whitish neck and crest.

The white-bellied heron is a rare, elusive, and highly sensitive piscivore species, inhabiting freshwater rivers, streams, lakes, and wetlands up to 2000 meters altitude. The herons forage in silent open waters by walking along the shallow banks of up to 60 centimeters depth with low to medium riffle. They are non-migratory but move up to 200 kilometers from one feeding locale to another looking for food during seasons when food is scarce. Generally, they are solitary, but groups of up to 4 are seen during breeding seasons and up to 6 are seen before juveniles attain independence. They are very silent and only make loud croaking calls; *auk auk auk urrrrrr,* during courtship or when alerted.

There are only five actively breeding pairs in Bhutan and are the only currently known breeding population in the world

Unlike many other heron species which breed in colonies, the white-bellied heron breeds in solitude. Generally, the breeding season begins from January and juveniles fledge by end of June, but sometimes it prolongs through July or August. They build simple platform nests of dried twigs and small branches without foliage on tall trees with open canopy at a height of 10 to 30 meters, both on conifer and broadleaved species, within 10 to 100 meters from the nearest waterbodies, preferably on slopes with ample open space and good exposure to sun, at an altitude of 200 to 1,500 meters. The average clutch size is three, the incubation period is 30 to 33 days, the average brood size is of two and nestlings fledge 70 to 75 days after hatching. Juveniles reach independence and leave their parents after 2 to 3 months of fledging.

The distribution range of the white-bellied heron has shrunk by 90 percent over the century. The extremely low and shrinking population across the region is attributed to human exploitation of river systems and disturbance in core foraging and breeding habitats. The small gene pool with a few breeding pairs restricted to small geographical range is of immediate concern. The conversion of sections of rivers or tributaries or entire rivers to hydroelectric dam regimes is the single biggest threat to the white-bellied heron and its habitat across the range. Most of the habitats are very susceptible to disturbances both man-made and natural, making the species highly vulnerable to extinction. The call to save this species from extinction is urgent and the only way is to save our rivers.

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Fish diversity

D B Gurung

Ichthyology in Bhutan

Bhutan is rich in freshwater biodiversity. Bhutan has four major river systems viz. Amochhu (Toorsa), Wangchhu (Raidak), Punatsangchhu (Sankosh), and Drangmechhu-Mangdechhu (Manas)[28]. There are 2,674 glacial lakes in Bhutan and the largest glacier has an area of 36 square kilometers and is located in the Punatsangchhu basin[29]. Besides rivers, lakes and glaciers, Bhutan also has 3,027 high altitude wetlands including supra-snow lakes[30].

The National Research Centre for Riverine and Lake Fisheries of the Department of Livestock of the Ministry of Agriculture and Forests has prepared a checklist of 104 species from the Amochhu, Wangchhu and Punatsangchhu river basins of western Bhutan[31]. However, since ichthyology is a new science in Bhutan, many of these species are identified up to the genus taxa only.

Bhutan is rich in freshwater biodiversity. About 51.44 percent of the country's geographical area has been declared as Protected Areas

Threats to Water Resources and Fish Conservation

About 51.44 percent of the country's geographical area has been declared as Protected Areas which include National Parks, Wildlife Sanctuaries, Strict Nature Reserve, and Biological Corridors[32]. It is perhaps assumed that the protected area system takes care of the aquatic biodiversity and aquatic ecosystems per se, but this is not the case. Climate change, hydropower dams, farm road construction, mining, and introduced and invasive species are some of the major conservation threats for native fish species.

Hydropower projects

The construction of hydropower projects results in blocking fish migration, habitat fragmentation, river-bed siltation and other environmental degradation around the dam construction site. Construction of fish ladder and lifts may not be the best options when the minimum flow of the river is not maintained below the dams for most part of the year once the power plants start operating.

Introduced and invasive species

In 1940, the Scottish origin Brown trout ova were transported to Darjeeling from Kashmir, from which some developing fry were transported to Bhutan, reared in Haa hatchery and the fingerlings released in Haachhu river in 1941[33]. In Bhutan, so far there is no assessment on the impact of introduced species on the native species. However, field observations indicate that the fingerlings of native species are rarely found in areas where Brown trout has established successfully.

Besides Brown trout, many species of fish are introduced through aquaculture, fish market, aquarium trade and socio-religious practice called *Tsethar* – live release[34,35]. *Clarias gariepinus* Burchell is one such species which has established in Amochhu

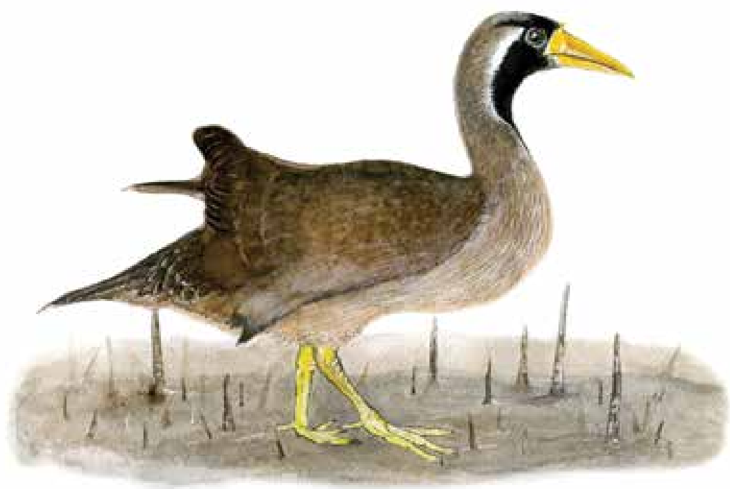
Endangered fauna of the River basin

Illustrations by Tania Zakir

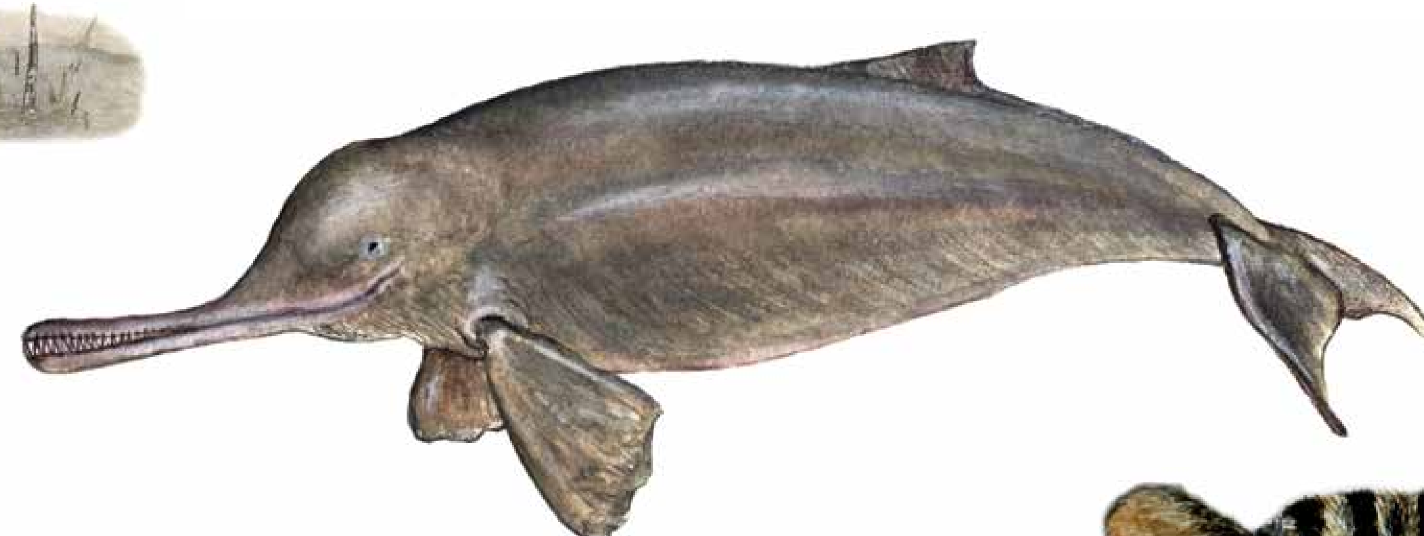
Western Hoolock Gibbon *(Hoolock hoolock)*

Golden Langur *(Trachypithecus geei)*

Greater Adjutant *(Leptoptilos dubius)*



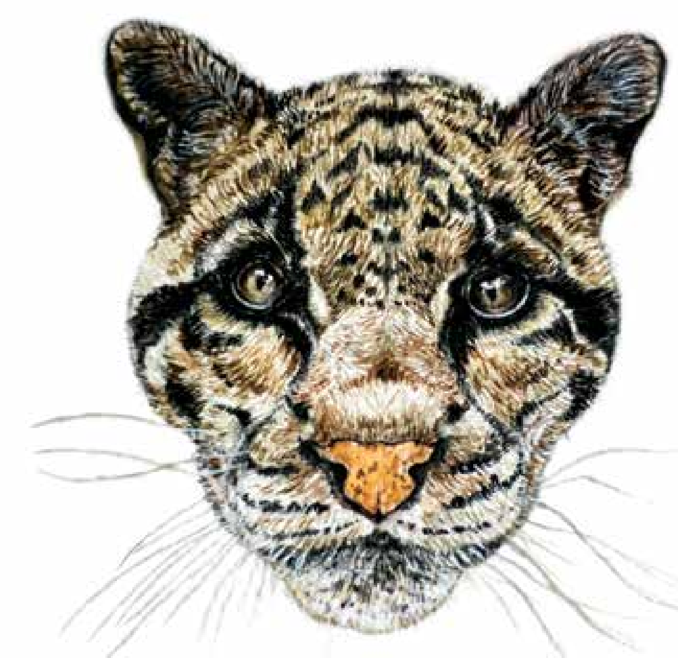
Masked Finfoot *(Heliopais personatus)*



Gangetic River Dolphin *(Platanista gangetica)*

Golden Mahseer *(Tor putitora)*

Fishing Cat *(Prionailurus viverrinus)*



Clouded Leopard *(Neofelis nebulosa)*

River, bordering the Indian state of West Bengal[36]. This fish primarily feeds on the fingerlings of native species. *Oreochromis niloticus* (Linnaeus), *Cyprinus carpio* Linneaus, *Hypophthalmichthys molitrix* (Valenciennes), *Hypophthalmichthys nobilis* (Richardson), *Ctenopharyngodon idella* (Valenciennes), *Cirrhinus mrigala* (Hamilton), *Catla catla* (Hamilton), *Labeo rohita* (Hamilton), and *Oncorhynchus mykiss* (Walbaum) are other species introduced in aquaculture in Bhutan. Among these species, the Rainbow trout (*O. mykiss*) has the potential to become an invasive species. Additionally, there are also some aquarium species appearing in the country for which there is no account.

Road construction and mining

Sub-standard farm road construction has resulted in downstream sedimentation, soil erosion, changes in hydrological characteristics, increased surface runoff, deforestation, and loss of biodiversity[37]. Careless disposal of excavated road materials often results in muddy river water causing considerable damage to aquatic biodiversity.

Careless disposal of excavated road materials often results in muddy river water causing considerable damage to aquatic biodiversity

The environmental costs of mining include mud slides, sedimentation downstream, soil erosion, and water pollution besides noise and air pollution[38]. In southern Bhutan, during monsoon, few overburden slips from the mines have been noted in blocking of river and stream courses temporarily. Therefore, priority should be given to maintaining certain environmental standards in the construction of farm roads and mining operations.

Low priority species

While Bhutan is recognised for its conservation efforts, its priorities are on protection of charismatic megafauna such as the Royal Bengal tiger, snow leopard, and golden mahseer. In the process, some Near Threatened, Threatened or Endemic species such as the *Anguilla bengalensis* (Gray), *Bagarius bagarius* (Hamilton), *Clarias magur* (Hamilton) and *Parachiloglanis drukyulensis*[39] are overlooked. Species such as *P. drukyulensis* have a very narrow distributional range, occurring in few streams of southern Bhutan which are under anthropogenic pressure. Therefore, such species may need to be given conservation priority as well and assessed for IUCN Red List.

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TEESTA BASIN

Taxonomic diversity of birds

Bishal Thakuri and Bhoj Kumar Acharya

THE INDIAN state of Sikkim located in the Teesta basin in eastern Himalaya, forms a part of the Himalayan Biodiversity Hotspot, and is one of the 36 globally significant biodiversity regions[40]. The variation in elevations in the Teesta basin ranging from 300 meters to 8,586 meters, resulting in distinct gradation of vegetation, climate and other topographical features, combined with high humidity have created diverse habitats and novel niches conducive for various species of flora and fauna[41].

A total of 579 bird species belonging to 57 families and 17 orders have been recorded in Sikkim, which is about 44 percent of all the birds found in India[42]. Although there are records of collection of birds dating back to the middle of the eighteenth century during British expeditions, the first systematic study on birds of Sikkim was undertaken by Salim Ali which led to the publication in 1962 of the book "Birds of Sikkim"[43]. Sikkim has a number of wetlands and, hence, bird species dependent on water bodies (either aquatic or depending on water for some activities) are well represented. A majority of the aquatic birds are migratory species, and some species use Sikkim as stop-over during migration.

There are 22 species of birds restricted to Eastern Himalaya Endemic Bird Area out of which 12 species are found in Sikkim. The endemic species are *Tragopan blythii*, *Arborophila mandellii*, *Harpactes wardii*, *Sphenocichla humei*, *Spelaeornis caudatus*, *Babax waddellii*, *Certhia discolor*, *Brachypteryx hyperythra*, *Actinodura nipalensis*, *Tickellia hodgsoni*, *Phylloscopus cantator* and *Yuhina bakeri*. Similarly, 38 bird species are listed in the IUCN red list of threatened species of which fourteen are Vulnerable, two are Endangered (*Falco cherrug* and *Aquila nipalensis*), six are Critically Endangered (*Aythya baeri*, *Gyps indicus*, *Sarcogyps calvus*, *Gyps bengalensis*, *Emberiza aureola* and *Ketupa zeylonensis*) and sixteen are Near Threatened[44]. Seven species of birds found are listed in Appendix I and five species are listed in Appendix II of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES). Similarly, four species of birds (*Lophura leucomelanos*, *Gyps bengalensis*, *Gyps indicus* and *Gracula religiosa*) are included in the Schedule-I category of Wildlife Protection Act of India, 1972.

Recent studies have highlighted the importance of indigenous farming systems for conservation of birds in the region

The Government of Sikkim has designated 11 Important Bird Areas (IBAs) in Sikkim and notified one bird sanctuary (Kitam Bird Sanctuary) for the conservation of birds. Additionally, there are one biosphere reserve and national park and seven wildlife sanctuaries (including Kitam) in Sikkim which protect the habitats of birds as well as other flora and fauna. Our recent studies have highlighted the importance of indigenous farming systems for conservation of birds in the region, but policy intervention is necessary in order to protect these biodiversity rich ecosystems.

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JAMUNA BASIN

Wetlands

S M Sadik Tanveer

THE FORMATION of *beels* and other wetlands on the left and right banks of Jamuna River depend both on geomorphological processes as well as environmental changes.

Environmental changes are not necessarily natural, rather such a change may take place as a result of human interference at various levels. Broadly, the formation processes of all category wetlands are divided into two (i) autogenic and (ii) allogenic[45]. The autogenic process is related to the river regime, such as channel migration, cutoff, loop formation, and allogenic processes include various types of human intercessions. On the right bank of the Jamuna, wetlands were formed as a result of the shifting of the course of Teesta river in 1787 and reduction in the flows of tributaries such as Atrai, Karatoya and Punarbhaba rivers. On the left bank of the Jamuna, wetlands were formed by the shifting of the old course of the river[46].

The allogenic changes that take place mainly as a result of human activities are responsible for formation of many *beels* and ox-bow lakes in the left bank of Jamuna river. Major changes are observed in the river regime after the commissioning of regulatory works on rivers. Construction of structures such as embankments and bunds for flood control and irrigation has caused drastic changes in the river course and altered the wetland environment. In addition, human encroachment across the river and impeding the natural flow of the river significantly changed the flow regime and the denudation pattern of rivers, accelerating the siltation rate of the river as well as of *beels* and large ponds.

The beels *and other water bodies on riverbanks provide ideal habitats for feeding, resting and breeding of a large number of fishes, birds and various aquatic animals*

Beels are of different shapes, sizes and depth. Some of them are partly or fully infested with floating mats of aquatic plants. Reeds, grasses and bushes comprise the common natural vegetation in the shore areas of *beels*. The swampy and marshy areas, such as *jalah*, *pitoni*, and *doloni*, are shallower than the *beels*. They are normally developed close to riverbanks and on ageing shallow *beels*. In general, the *beels* and other water bodies on riverbanks provide ideal habitats for feeding, resting and breeding of a large number of fishes, birds and various aquatic animals.

Chalan *Beel*

Chalan *beel,* a seasonal water body, is the largest *beel* and constitutes one of the largest, most important watersheds in north central Bangladesh. It consists of a series of depressions, interconnected by numerous channels that form more or less one continuous sheet of water during inundation (following the monsoon), covering an area of about 375 square kilometers[47]. The water area then shrinks to a 52 to 78 square kilometers residual cluster of smaller *beels* of varying sizes during the dry season[48]. Chalan *beel* is rapidly silting up and shrinking down.

Chalan *Beel* has a unique natural beauty and provides habitat for diverse wildlife including a variety of fish, aquatic invertebrates, birds and others aquatic animals upon which the local economy and livelihoods of people of surrounding area depends[49]. At least twenty-seven species of mammals, and thirty-four species of reptiles, with amphibians including seven species of frogs and toads can be found on the banks of the *beel*. A total of 81 fish species including 72 indigenous and 9 exotic species under 12 fish orders, 27 families and 59 genera have been recorded

from different studies and surveys[50]. Flora found along the banks of the *beel* includes a perennial grass known as *kans* or *kash* (wild sugarcane). Date palms, *dhol kolmi* (pink morning glory) and *simul* (cotton tree) are also found in and around Chalan *beel*. The fruit from the date palm is used to make jelly, while the sap is boiled to make a sugary product called "*jaggery*"[51].

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Riverine birds

Sayam U. Chowdhury

RIVERINE HABITATS are possibly one of the most neglected ecosystems in terms of conservation efforts in Bangladesh[52]. However, the sandbars, waters, pools and floodplain grasslands of Padma and Jamuna river systems support a wide range of globally important wildlife. The alluvial channels and adjacent floodplains of these two rivers are highly productive, as they are sustained by dynamic hydrologic and

sediment transport regimes, as well as nutrient mobilization and transport through annual flood cycle and water supply[53]. These extremely productive floodplains support early successional tall grasses dominated by wild sugarcane (*Kash*) *Saccharum spontaneum*[54] and several other grass species. These grasslands support 22 avian species of global concern including the Critically Endangered yellow-breasted bunting *Emberiza aureola*[55] and Vulnerable bristled grassbird *Chaetornis striata*, both of which are grassland specialists that inhabit tall grasslands particularly in riverine or swampy areas.

Waterbirds such as the black-bellied tern *Sterna acuticauda* and river tern *Sterna aurantia* were once common along the large river systems of Bangladesh. However due to large-scale destruction of riverine habitats, these species have become extremely rare in Bangladesh and elsewhere. The black-bellied tern has been uplisted in 2012 from Near Threatened to Endangered due to a rapid and continuous decline over the last 27 years, leading to almost becoming extinct in a large part of its range[56].

The population of resident birds that nest on sandbanks such as little tern *Sterna albifrons*, small pratincole *Glareola lacteal*, river lapwing *Vanellus duvaucelii*, great thick-knee *Esacus recurvirostris* and Indian thick-knee *Burhinus indicus* appeared to have declined in Bangladesh.

However, recent surveys along the major rivers of Bangladesh indicate that the Padma and Jamuna river systems still provide breeding and wintering habitats to substantial populations of resident and migratory birds[57]. These include the Critically Endangered Baer's pochard *Aythya baeri* (known to stopover in large rivers during migration), Endangered steppe eagle *Aquila nipalensis*, Vulnerable common pochard *Aythya ferina*, Asian woollyneck *Ciconia episcopus*, Indian skimmer *Rynchops albicollis*, Indian spotted eagle *Clanga hastata*, greater spotted eagle *Clanga clanga*, eastern imperial eagle *Aquila heliaca* and 11 other Near Threatened birds[58].

Large rivers of Bangladesh also support of the Critically Endangered gharial *Gavialis gangeticus* (possibly only migratory population), the Endangered Ganges river dolphin *Platanista gangetica*, crowned river turtle *Hardella thurjii* and Indian narrow-headed softshell turtle *Chitra indica*[59].

Human impact on riverine biodiversity is more apparent in Asia than any other part of

From left to right: Black-headed ibis *(Threskiornis melanocephalus);* ***Little egret*** *(Egretta garzetta);* ***Black-winged stilt*** *(Himantopus himantopus)*

the world. Flow regulation, construction of large dams, flood control, over-harvesting of fish, pollution and conversion of riverine wetlands to agriculture are common threats to many Asian rivers[60]. Sand and gravel extraction for development is common in Padma and Jamuna rivers, especially around large towns[61]. As a result of this ongoing degradation of riverine ecosystems, some taxa have been gravely affected, especially riverine birds[62].

These stresses on the overall riverine ecosystems reduces potential roosting and nesting habitats of riverine bird species and other resident wildlife. However, even where the habitat remains suitable, hunting in winter by local or visiting sport-hunters, collection of eggs and chicks of sand-nesting birds in late-winter are frequent along the Padma and Jamuna rivers. These practices pose a common threat to riverine birds and reduce their overall population. Due to the reduced level of fisheries resources, competition between riverine birds and local fishermen may also be expected, although no evidence of this has been observed so far[63].

Flow regulation, construction of large dams, flood control, over-harvesting of fish, pollution and conversion of riverine wetlands to agriculture are common threats to many Asian rivers

For the protection of these dwindling riverine species, several steps could be undertaken including establishing riverine protected areas. The sandbanks, grasslands and islands (which remain in state ownership) are not leased out and hence any change in management will not be resisted by leaseholders unlike other wetland sites in Bangladesh. Hence, designating riverine sanctuaries/protected areas would be relatively straightforward,[64] and further surveys are recommended to identify breeding sites of all waterbirds that nest on riverbanks.

Once identified, these sites can be declared as sanctuaries in addition to the sites that are already proposed to Bangladesh Forest Department under Ministry of Environment and Forests. There also needs to be a comprehensive conservation strategy for the Padma and Jamuna rivers, including sustainable management plans for both fisheries and wildlife. In order to understand the overall health of the riverine ecosystem, an indicator bird monitoring approach could be established targeting species that are still widespread such as the little pratincole, Indian spot-billed duck and plain martin.

The Bangladesh Wildlife Preservation Act protects all water-bird species that occur in these rivers. Therefore, enforcement by the government and support by local NGOs are needed to tackle bird hunting and prevent illegal habitat encroachment. In addition, awareness-raising activities in villages along these rivers should be carried out to educate local people, especially fishermen and other natural resource harvesters, of the importance of birds and other wildlife to maintain a healthy riverine ecosystem.

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Wildlife of Jamuna basin

Sheikh Muhammad Abdur Rashid

THE GHARIAL is a flagship species of the Jamuna Basin and critically endangered in Bangladesh. Gharial nesting records in the river Jamuna at Pechakhola, Bera Upazilla, Pabna date back to the nineteen seventies. In the nineteen eighties and in the early nineteen nineties, gharial nests were recorded from Char Khidirpur, Padma River (in Rajshahi District) and Baladuba Char (Kurigram District) in the Jamuna River. During later surveys by Centre for Advanced Research in Natural Resources and Management (CARINAM) in the Padma and Jamuna rivers during 2009 to 2011 only juveniles (between 1 to 2 meters) were found, and no nests could be detected, even though several suitable nesting sites were observed.

The Asian freshwater dolphin (*Platanista gangeticus*) is another flagship species of the Jamuna river. Based on the results of a study conducted by CARINAM, three dolphin sanctuaries were designated by the government; one in the Jamuna River and the second in one of the tributaries (Selunda-Hurasagar) of the Jamuna River, while the third is in the Padma River.

The Jamuna basin overlaps the Central Asian and East-Asian-Australasian migratory bird flyways and many migratory birds particularly ducks and waders use this route during migration

The Jamuna basin overlaps the Central Asian and East-Asian-Australasian migratory bird flyways and many migratory birds particularly ducks and waders use this route during migration. Among the raptors, kites, shikra, peregrine falcon, buzzards, and winter visitors like ospreys, harriers, and others can be regularly seen. Unfortunately, the vultures are not seen anymore, however, Eurasian griffon and cinereous vulture occasionally visit the Jamuna basin area.

The sandy riverbanks in the Jamuna basin provide nesting and basking habitat for freshwater turtles, gharials, smooth-coated otters, several species of kingfishers, bee-eaters, sand larks, and bank mynas. The grass cover of the sand bars, mainly *Saccharum spontaneum*, *Typha domingensis*, and *Phragmites karka* support and provide nesting habitats for a variety of small grassland bird species mainly prinias, larks, lapwings, lesser whistling teals, spotbill ducks, baya weaver, streaked weaver, black-breasted weaver, buntings, munias and many more. Rare bird species like the black stork, common merganser also visit the sand bars.

The shallow inundated *chars*, cultivated land and the adjacent human settlements along the river bank support several species of amphibians which include the common toad (*Duttaphrynus melanostictus*), marbled toad (*D. stomaticus*), bull frog (*Hoplobatrachus tigerinus*), skipper frog (*Euphlyctis* sp.), green frog (*E. hexadactylus*), several species of cricket frogs (*Fejervarya* sp.), *Polypedetes* sp., *Hylarana tytleri*, *Kulaula* sp., the recently recorded *Microhyla nilphamariensis*, and the unusual *Humerana humeralis*.

The gharial or the fish-eating crocodile is amongst the longest of all the crocodilians. Once found in freshwater river systems from Pakistan to Myanmar, the critically endangered gharial is on the brink of extinction and is found today only in a few locations in India and Nepal.

Freshwater turtles are threatened by the conversion of wetlands, demand for trade and consumption by some as food. The commercial trade from early nineteen seventies till late nineteen nineties has almost exterminated many of the populations and once common species have become rare and some are critically endangered. The species encountered within the basin include *Batagur kachuga*, *Pangshura tecta*, *P. tentoria*, *P. smithii*, *Hardella thurjii*, *Morenia petersi*, *Lissemys punctata*, *Nilssonia gangetica*, *N. hurum*, and recently *Nilssonia nigricans* has also been found within the basin.

Reptiles include Burmese pythons (*Python bivittatus*), python, venomous snakes such as *Naja kaouthia*, *N. naja*, *Bungarus caeruleus*, *B. walii*, *B. niger* are found, and in recent years *Daboia russelli* is often reported from the villages in the vicinity of the riverbank and also from the *chars*. Other nonvenomous snakes include *Enhydris enhydris*, *Eryx conicus*, *Ahaetulla nasuta*, *Coelognathus radiatus*, *Dendrelaphis pictus*, *Lycodon aulicus*, *Oligodon arnensis*, *Ptyas mucosa*, *Sibynophis sagittarius*, *Amphiesma stolatum*, *Xenochrophis cerasogaster*, *X. piscator*, *Ferania sieboldi*, *Indotyphlops braminus*, and many more.

Although small reptiles are hard to find and are often left unrecorded, some common lizards have been observed and recorded by CARINAM. These include *Calotes versicolor*, *Gekko gecko*, *Hemidactylus brookii*, *H. flaviviridis*, *H. frenatus*, *Eutropis carinata*, *E. dissimilis*, *Lygosoma bowringii*, *L. punctata*, *Varanus bengalensis*, and *V. flavescens*.

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Hilsa fisheries

M Niamul Naser and Anisur Rahman

The river shad, hilsa is the national fish of Bangladesh. This fish received the Geographical Indicator registration in 2017

THE JAMUNA river system is important for migratory fishes and as nursing grounds for natural spawned carp fishes. The river shad, hilsa (*Tenualosa ilisha*) is the national fish of Bangladesh and the most important single species for fishery in the country. The hilsa (*Tenualosa ilisha*) holds a special place in the hearts and in the diets of people living in this region. Locally known as the "Macher Raja Ilish", or the "king of the fishes", this fish received the Geographical Indicator registration in 2017.

The hilsa accounts for nearly half of the total marine catch, and about 12 percent of total fish production of the country contributing about 1 percent to GDP. About 450,000 fishers are directly employed in hilsa fishing with an indirect employment of about 2.6 million people in the wider hilsa sector (trading, processing etc.). In 2017-18, a total 541 metric tons of hilsa was caught from this river system, out of which 320 metric tons were caught from the Jamuna river.

The Ilish represents a shared history, a common ecosystem, and close economic ties between Bangladesh and India. The fish contributes to one percent of the total GDP of Bangladesh

The distribution of hilsa mainly depends on water flow and flooding of the rivers. In years of heavy flooding, they are caught in the small channels and floodplains. Considerable quantities of hilsa are also caught in the lower Arial Khan, Madhumati, and Padma rivers, with lower quantities in the Jamuna and Brahmaputra rivers. The hilsa in breeding season migrates from the Jamuna towards upper Brahmaputra river basin of Assam, India. The hilsa lives and breeds in the Jamuna river due to its unique water quality and habitats; particularly the plankton (both phytoplankton and zooplankton) available in this area are suitable as food for hilsa.

During last few decades over-fishing and indiscriminate catching of *jatka* (juvenile hilsa) had reduced the hilsa population in the river. To sustain as well as to increase hilsa production, several management measures have been undertaken by Department of Fisheries under the Ministry of Fisheries and Livestock. Conservation of *jatka* through declaring six fish sanctuaries in the major nursery and spawning grounds of riverine and estuarine system and prevention of hilsa fishing for 22 days during the peak breeding season are the most important initiatives. Due to conservation of *jatka*, the abundance of grown up/sub-adult hilsa has increased considerably. Overall, there has been a gradual revival of hilsa population, but the threats still remain, as these fish are often caught before they reach maturity of the first spawning stage.

Madhupur National Park[56]

M. Monirul H. Khan

THE 80 KILOMETERS avulsion of the river Brahmaputra by the year 1843 created two rivers in central Bangladesh: Jamuna (main Brahmaputra) and Old Brahmaputra. Between these two rivers lie a fertile highland called the Madhupur Tract. Even a hundred years ago a major part of the Madhupur Tract was covered by moist deciduous forest dominated by sal (*Shorea robusta*) trees. The sal forest used to be teeming with wildlife including some charismatic megafauna like the Indian rhinoceros (*Rhinoceros unicornis*), tiger (*Panthera tigris tigris*), leopard (*Panthera pardus*), Asian elephant (*Elephas maximus*) and Asiatic black bear (*Ursus thibetanus*), but none of them currently survive in the Madhupur Tract. Both the forest and the wildlife were destroyed mercilessly by humans.

The Madhupur National Park holds one of the last remaining natural sal forest patches in Bangladesh

During the Mughal and the British colonial era, the local landlords or *zaminders* preserved some wilderness areas of the Madhupur Tract in order to facilitate game hunting for the elites. Two pockets of these areas in Madhupur and Bhawal eventually got legal protection and became the first legally designated protected areas in Bangladesh. Having an area of 84.36 square kilometers, the Madhupur National Park was formally

Top left:
***Grey heron** (Ardea cinerea)*

Top right:
***Lesser coucal** (Centropus bengalensis)*

Bottom:
Oriental magpie robin** (Copsychus saularis), **the national bird of Bangladesh

established in 1982. It is situated about 125 kilometers north of Dhaka City, in Tangail District, beside the Tangail-Mymensingh Highway. The Park is historical not only because it is the first of its kind, but also because it was the training and sheltering ground of the freedom fighters during the Liberation War in 1971. The Dokhola Rest House in the park is also historical because the drafting of the Bangladesh Wildlife Order, 1973, was done here under which the park was formally established in 1982.

The topography of the Madhupur National Park and its surrounding areas mainly consist of flat- topped highlands or *chalas* intersected by many lowlands or *baids*. The highest altitude of topped ridges is 15 meters above the mean sea level. The climate is moderate, with the temperature rising up to 37°C in May and dropping down to minimum 10°C in January. The depressions or *chalas* are flooded every year during the tropical monsoon from June to September. The soil is loamy, clay and sandy loam, and mostly looks reddish due to rich iron content.

The Park is historical not only because it is the first of its kind, but also because it was the training and sheltering ground of the freedom fighters during the Liberation War in 1971

The Madhupur National Park holds one of the last remaining natural sal forest patches in Bangladesh where about 40 percent of the area is covered with sal trees. It represents an important and treasured part of Bangladesh due to its rich biological and cultural diversity that still prevails despite considerable deforestation in the last few decades. In Tangail District alone the sal forest has shrunk to 10 square kilometers in 1990 from 200 square kilometers in 1970. The ethnic Garo community, together with the local Bengali community, live in scattered villages in and around the park. According to an estimate in 1989, about 100,000 Garo people live in Bangladesh, of which about 14,000 live in the Madhupur forest area. They have been living there for the last few centuries. They cultivate paddy in the lowlands, and pineapple and cassava in the highlands. The Government of Bangladesh has permitted about 4,500 Garo people to reside in the park area since 1968.

There are at least 176 vascular plant species in the park, including 73 tree, 22 shrub, 27 climber, 45 medicinal plants, 8 grass and 1 palm species. The sal trees grow in association with *Dillenia pentagyna*, *Lagerstroemia parviflora*, *Adina cordifolia*, *Miliusa velutina*, *Lannea grandis*, *Albizia* spp., *Bauhinia variegata*, *Spondias mangifera*, *Butea frondosa* and *Barringtonia acutangula*. The undergrowth is shrubby and includes *Eupatoriun odoratum*, *Pennisetum setosum*, *Asparagus racemosus* and *Rauwolfia serpentina*. Plantations of *Acacia* spp., Tectona *grandis*, *Cassia siamea*, *Morus* spp.,*Teminalia arjuna* and *Syzygium cumini* are seen in buffer areas around the park.

About 21 species of mammal, 140 bird, 32 reptile and 21 amphibian species occur in the Madhupur National Park. It is a major stronghold of the globally threatened capped langur (*Trachypithecus pileatus*), which occurs in groups headed by an alpha male. Another globally threatened mammal, the fishing cat (*Prionailurus viverrinus*), rarely occurs in the park. Among other notable wildlife there are rhesus macaque (*Macaca mulatta*), golden jackal (*Canis aureus*), barking deer (*Muntiacus muntjak*), Irrawaddy squirrel (*Callosciurus pygerythrus*), crested serpent eagle (*Spilornis cheela*), red junglefowl (*Gallus gallus*), Indian pitta (*Pitta brachyura*), yellow-footed green-

Brown fish owl *(Ketupa zeylonensis)*

pigeon (*Treron phoenicopterus*), red-breasted parakeet (*Psittacula alexandri*), small minivet (*Pericrocotus cinnamomeus*), spotted flapshell turtle (*Lissemys punctata*), Tokay gecko (*Gekko gecko*), Bengal monitor (*Varanus bengalensis*), painted bronzeback tree snake (*Dendrelaphis pictus*), banded krait (*Bungarus fasciatus*), Indian balloon frog (*Uperodon globulosus*), Indian bull frog (*Hoplobatrachus tigerinus*) and stripe sticky frog (*Kalophrynus interlineatus*). The Madhupur National Park is the only known area in Bangladesh where the rare stripe sticky frog is found.

The Madhupur National Park remains open for visitors throughout the year and is easily accessible by road. It is a popular tourist attraction due to its diversity, scenic beauty and proximity to Dhaka. The Park can be visited even in a day trip from Dhaka City.

4. GROW

Living off the land

Vasudha Pangare

Kshirode Roy

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Xiawei Liao

Raju Mandal

Md Ayub Hossain

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Mohammed Mainuddin

Pooja Kotoky

Md Hossain

Ganesh Pangare

Glossary

Agroecological/agroclimatic zones
Agroclimatic and agroecological zones are regions with similar climate, rainfall, soil types, topography, vegetation, and water resources. An overview of the zones provides a holistic view of ecological characteristics and their relation to agricultural practices.

Transhumant pastoral
Transhumance[2] is the regular movement of herds among fixed points in order to exploit the seasonal availability of pastures. Transhumant pastoralists often have a permanent homestead and base where crops are grown for home consumption. Older members of the community remain here throughout the year. A characteristic feature of transhumance is herd splitting; the herders take most of the animals to search for grazing but leave the resident community with a nucleus of lactating females.

Agropastoral
Agropastoralists[3] can be described as settled pastoralists who cultivate sufficient areas to feed their families from their own crop production. While livestock is still valued property, their herds are smaller, possibly because they no longer rely solely on livestock and depend on a finite grazing area which can be reached from their villages within a day. Agropastoralists invest more in housing and other local infrastructure and, if their herds become large, they often send them away with more nomadic pastoralists.

Agroforestry pastoral mixed production systems
This system typically incorporates different resources through cropping, livestock raising and forestry and gets established over a long period of time.

Crop-based livestock production[4]
Farmers keep only enough livestock that can be fed on crop residues and by-products, especially in spring and winter.

Shifting cultivation[5]
Shifting or *jhum* cultivation is a form of agriculture, in which an area of ground is cleared of vegetation and cultivated for a few years and then fallowed for regeneration until its fertility has been naturally restored. Shifting cultivation is an age-old practice that occupies a distinct place in tribal agriculture and its economy, constituting a vital part of the socio-economic framework of tribal life.

Terraced agriculture
Terraced agriculture can be rain-fed or irrigated and is usually found on slopes which are more than 30 percent. Terraced fields decrease erosion and surface runoff and are effective for growing crops requiring much water, such as rice. Terraces are made by levelling land on the hill slopes and in many places occur as a result of many years of cultivation.

Wet rice cultivation[6]
In wet rice cultivation, the land is thoroughly ploughed and flooded with water upto 5cm in depth. In case of clayey or loamy soil the depth of the water is upto 10 cm. Post puddling the land is levelled so as to ensure uniform water distribution. Seedlings are sown or transplanted after leveling.

Rainfed agriculture[7]
In rainfed agriculture cultivation predominantly depends on rains, allowing single or double crops as per the rainfall pattern of the region.

Irrigated agriculture[8]
In irrigated agriculture water is provided artificially to crops. Irrigation systems draw water from surface and groundwater sources and are also designed to harvest and channel rainwater. Irrigation systems generally consist of diversion channels, surface drainage tanks and wells. Diverting or storing and lifting water from rivers and streams with the help of dams and a network of canals as well as field channels is the most popular system for using water for irrigation. Groundwater is lifted from wells, borewells and tubewells with the help of non-mechanised and mechanised devises. In mountain regions hill streams and glaciers are the assured sources of water and these are tapped by a variety of diversion channels using gravity flow, taken directly to the fields or stored for future use.

Subsistence agriculture
Subsistence agriculture occurs when farmers grow food crops to meet the needs of themselves and their families. In subsistence agriculture, farm output is targeted to survival and is mostly for local requirements with little or no surplus.

AGRICULTURAL SYSTEMS in the Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna river system are dynamic and have been shaped over centuries by farming households living within specific ecological and social ecosystems in each basin and sub-basin of the river system. Most agricultural systems integrate crops and livestock, the level of integration differing according to the natural environment, climate, nutrition and economic needs of the households, and social and community influences. Farming households have adapted farming practices to changing circumstances, natural, ecological, social, political, and the prevailing policy environment. Climate variations, droughts and floods are important drivers for changes in cultivation practices and crop diversification in the river system.

Agropastoral households in the Yarlung Tsangpo basin with its high altitude, low temperatures, short growing season, and variable climate follow a unique plateau agriculture and livestock management system. Indigenous communities in the Siang basin with its hilly terrain and plant agrobiodiversity practice shifting cultivation, an agricultural system strongly linked to their culture. Terraced agriculture is practiced in the hilly regions of the Manas and Teesta sub basins. Wet rice cultivation is practiced in the lower reaches of the river system in the Brahmaputra and Jamuna basin. Tea has a special place in the culture of Yarlung Tsangpo and an intriguing history in the Brahmaputra Valley. Rice is a common crop throughout the river system except in the high altitudes where barley and wheat are grown.

Wet rice cultivation in the Brahmaputra and Jamuna Basin

Water availability either by means of rainfall or irrigation is an important determinant of the farming practice and cropping pattern adopted by farming households. The dry season rice cultivated in the Jamuna basin and Brahmaputra basin is largely dependent on irrigation. A recent study[1] estimates that the quantity of water used for irrigation from the river system in the Jamuna Basin in Bangladesh is highest during winter months when the dry season rice is in its early stages of cultivation, and before the spring rains arrive. In the Brahmaputra Basin in India the quantity of water used for irrigation is highest in March, in the early stages of the first growing season of the year.

High altitude Barley in the Yarlung-Tsangpo Basin

This chapter provides an overview of agricultural systems, major crops and livestock, in four main basins and two sub-basins located within the Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna river system and highlights the unique characteristics of the agricultural systems in each basin and sub-basin.









AGRICULTURAL SYSTEMS in the Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna river system

– compiled by Vasudha Pangare

YARLUNG TSANGPO BASIN [9,10,]

Agroecological/agroclimatic zone & elevation	Agricultural systems	Major crops and livestock
Temperate semi-arid and arid zone. Mean 4920 – 4949 m	Agropastoral	Cattle, yak, sheep, goat Barley
Sub-frigid, semi-arid zone. Mean 4870 m	Agropastoral	Cattle, yak, sheep Barley
Sub-frigid, semi-humid zone. Mean 4499 m	Agropastoral	Cattle, yak, sheep, goat, chicken Barley, spring wheat, pea, rapeseed, apples, peaches, potatoes, vegetables in greenhouses
Temperate humid or semi-humid zone. Mean 4145 m	Crop based livestock production Rainfed agriculture Irrigated agriculture	Yak and zo Cereals, rapeseed
Sub-tropical humid. Mean 1642 – 2552 m	Agroforestry pastoral mixed production systems Shifting cultivation	Yak, cattle, swine, goat Winter wheat, winter barley, maize, rice

SIANG BASIN [11]

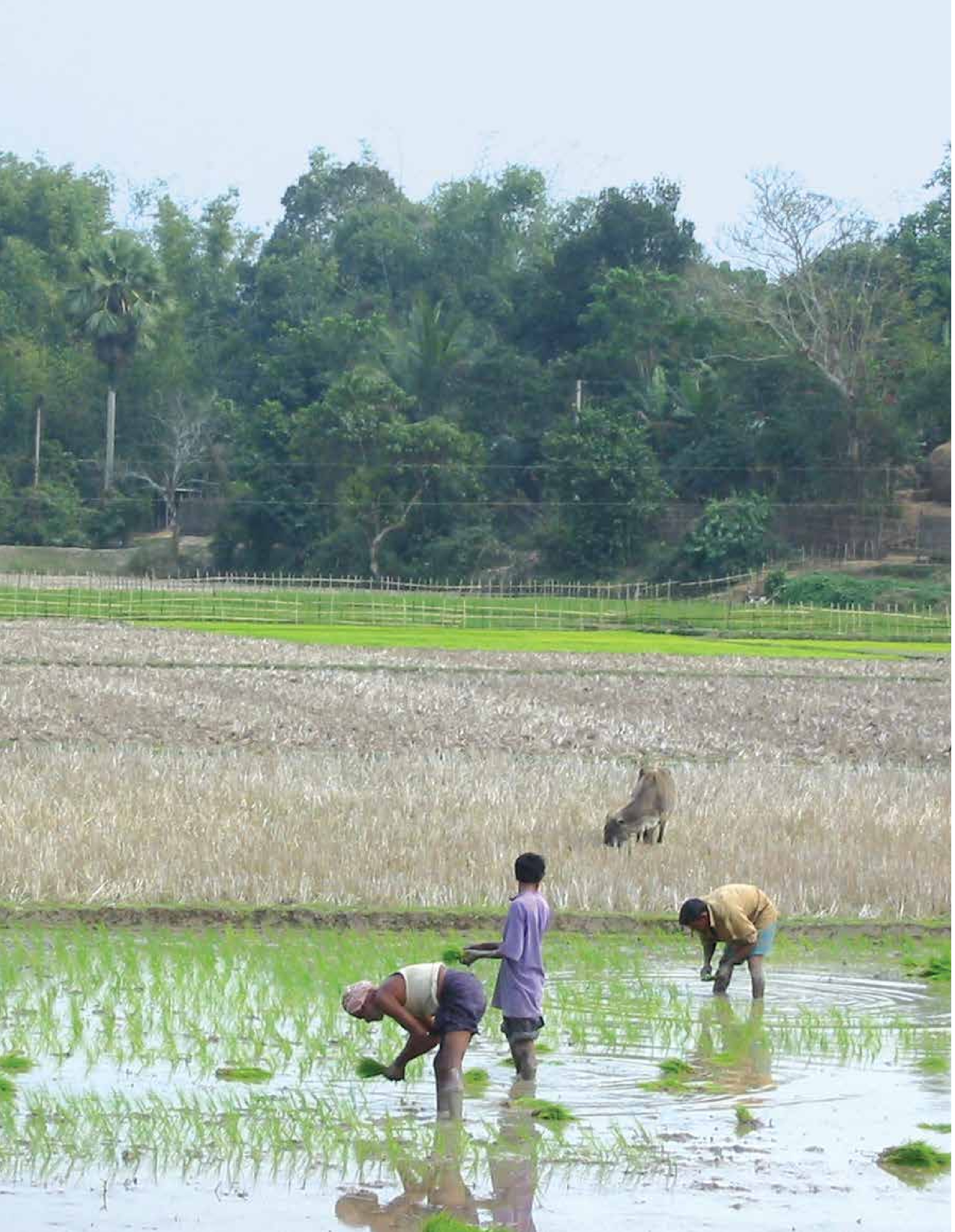
Agroecological/agroclimatic zone	Agricultural system	Major crops and livestock
Alpine zone 3500 + m	Transhumant pastoral	Yak, Dzo-Dzomo, sheep
Temperate sub-Alpine zone 1500 – 3500 m	Shifting cultivation	Barley, wheat, rice, millet, maize, potato, buckwheat, pulses, mustard, Aram Apple, plum, peaches, pears, walnut, vegetables Yak, Dzo-Dzomo, sheep, pig, goats
Sub-tropical hill zone 1000-1500 m	Shifting cultivation Terraced agriculture: rainfed and irrigated	Upland rice, maize, finger millet, beans, tapioca, yam banana, sweet potato, ginger, cotton, tobacco, chilli, sesame, vegetables Citrus, pineapple, pome and stone fruits Pig, cattle, Mithun, goats
Mild tropical plain zone <200 m	Wet rice cultivation	Rice, oilseed, sugarcane, jute, potato, sweet potato Buffalo, cattle, pig

BRAHMAPUTRA BASIN [12,13]

Agroecological/agroclimatic zone	Agricultural system	Major crops and livestock
Central Brahmaputra Valley zone	Wet rice cultivation Tea cultivation	Rice, maize, potato, vegetables and oilseeds Tea Jute Cattle, poultry, goat, pig, buffalo
Hill Temperate zone	Shifting cultivation	Rice, maize, sesame, cotton, tapioca, ginger, turmeric, arum, cucurbits, beans Poultry, cattle, goat, pig, sheep
Lower Brahmaputra Valley zone	Wet rice cultivation Tea cultivation	Rice, maize, potato, vegetables and oilseeds Tea Poultry, cattle, pig
North Bank Plain zone	Wet rice cultivation Tea cultivation	Rice, maize, potato, vegetables and oilseeds Tea Poultry, cattle, pig, Buffalo
Upper Brahmaputra Valley zone	Wet rice cultivation Tea cultivation	Rice, maize, potato, vegetables and oilseeds Tea Poultry, cattle, pig, Buffalo

MANAS BASIN [14]

Agroecological/agroclimatic zone	Agricultural system	Major crops and livestock
Alpine zone 3,600-7,500 m	Transhumant pastoral	Yak, sheep, goat
Cool temperate zone 2,600-3,600 m	Transhumant pastoral Livestock rearing Rainfed agriculture	Yak, sheep, goat Wheat, potato, buckwheat, mustard, barley
Warm temperate zone 1,800-2,600 m	Terraced agriculture; irrigated	Rice, wheat, potato, seasonal fodder, vegetables
Dry sub-tropical zone 1200-1800 m	Rainfed and irrigated agriculture	Rice, maize, mustard, barley, legumes and vegetables
Humid sub-tropical zone 600-1200 m	Terraced agriculture; irrigated	Wheat, mustard, Cardamom at higher elevations Mandarin orange at lower elevations
	Rainfed agriculture	Maize, millet, mustard, legumes, ginger, vegetables
Wet Subtropical zone 100-600 m	Subsistence agriculture; irrigated	Rice, wheat, maize
	Rainfed agriculture	Maize, millet, legumes, mustard, Niger, tubers, vegetables



TEESTA BASIN[15]		
Agroecological/agroclimatic zone	**Agricultural system**	**Major crops and livestock**
Temperate zone 1524 – 2743 m	Subsistence agriculture	Wheat, barley, high altitude maize, potato, cabbage, beans, peas, apple, peach and pear Cattle, poultry, goat
Sub-tropical hill zone 610 – 1524 m	Terraced agriculture Agroforestry	Maize, rice, cardamom Cattle, goat, buffalo
Alpine zone 3962 +	Transhumant pastoral Agropastoral	Yak, dzo, sheep, goats, ponies
Sub- temperate zone 2743 – 3962 m	Shifting cultivation Terraced agriculture	Barley, wheat, potato, cabbage, apple, maize, peas, peach, medicinal plants, tubers Cattle, poultry, goat, ponies

JAMUNA BASIN[16]		
Agroecological/agroclimatic zone	**Agricultural system**	**Major crops and livestock**
Old Himalayan Piedmont Plain	Wet rice cultivation Irrigated agriculture	Rice, potato, wheat, maize, sugarcane
Active Teesta Floodplain	Wet rice cultivation Irrigated agriculture	Rice, potato, mustard, maize, wheat, tobacco Poultry, cattle
Teesta Meander Floodplain	Wet rice cultivation Irrigated	Rice, wheat, maize, potato Poultry, cattle
Karatoya-Bangali Floodplain	Wet rice cultivation, irrigated	Rice, field pea, mustard, onion, lentil Poultry, cattle
Lower Atrai Basin	Wet rice cultivation, rainfed and irrigated	Rice, wheat, mungbean
Active Brahmaputra-Jamuna Floodplain	Wet rice cultivation	Rice, potato, mustard, wheat, maize, sugarcane Poultry, cattle
Young Brahmaputra and Jamuna Floodplain	Wet rice cultivation	Rice, potato, mustard Poultry, cattle
Old Brahmaputra Flood Plain and Jamuna Floodplain	Wet rice cultivation	Rice, mungbean, potato, maize Poultry, cattle

YARLUNG TSANGPO BASIN

The Yarlung Tsangpo Basin is located in southern Tibet, and includes major parts of Shigatse, Lhasa and Shannon prefectures and part of Nyingchi prefecture. This region is the main agricultural area of Tibet Autonomous Region. Most of the population is concentrated here, along the Yarlung-Tsangpo, Lhasa and Niachu rivers.

Agroclimatic zones and agricultural husbandry

Jin Tao

TIBET AUTONOMOUS Region is the main body of the Qinghai Tibet Plateau, with an average altitude of more than 4,000 meters. In terms of its typography, the continuous mountains and rivers divide Tibet into three different natural areas: the northern Tibet Plateau, the southern Tibet Valley and the eastern Tibet mountain canyon. With the change of temperature and precipitation, the huge height difference has formed a variety of agricultural climate zones and unique climate characteristics: strong solar radiation, rich sunshine, low temperature, less accumulated temperature, temperature decreases with the rise of altitude and latitude, large daily temperature difference, clear dry and wet periods with more rain at night; long dry and cold winter with more gale; cool and rainy summer with more hail.

Figure 1. The trend and distribution of the Qinghai Tibet Plateau mountains

North Tibet Plateau - grassland animal husbandry ecological area

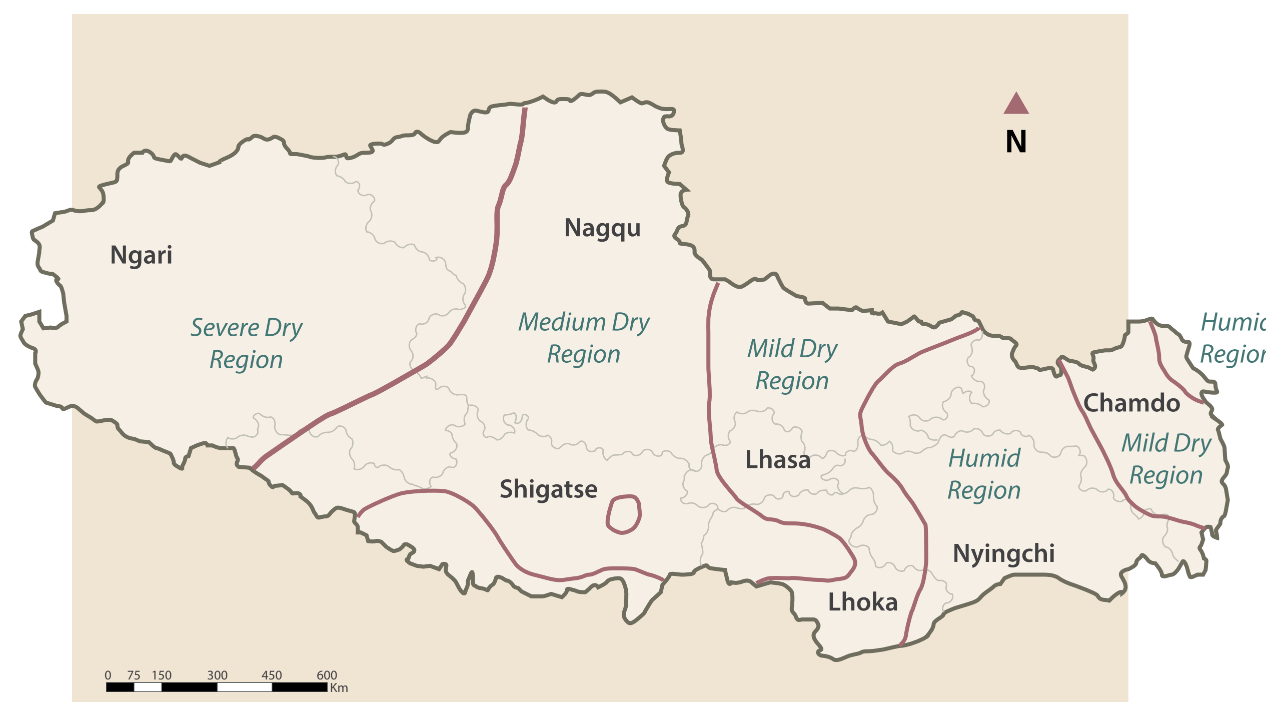
Located in the alpine zone between Kunlun Mountains, Tanggula mountains and Mountain Kailash - Nyainqêntanglha mountains, with an average altitude of more than 4,500 meters, this area accounts for about two-thirds of the land area of Tibet Autonomous Region. The average temperature in July, the warmest month, is less than 6 °C. There is freezing all year round. In the northern Tibet plateau north of Shiquanhe, Ando and Naqu, the average temperature at the surface of 80 centimeters in winter is between - 4 ~ 7 °C. Permafrost is widely developed, with almost no crop growth. There is a vast natural grassland, mainly composed of a small number of native grass types. It is the main grassland animal husbandry area of Tibet Autonomous Region, and the number of livestock accounts for about 30 percent of the total number of over 17 million livestock in the region. Yaks, sheep and goats are the main livestock types in this area. There are a small number of horses and pigs in the area below 4,000 meters above sea level.

The huge height difference has formed a variety of agricultural climate zones and unique climate characteristics

South Tibet Yarlung Tsangpo valley – agricultural and husbandry ecological area

This area is located between the Gangdise mountains and Himalayas, i.e. the Yarlung Tsangpo River and its tributaries. The average altitude is 3,500 meters. There are many flat valleys and lake basins with different width such as Lhasa River, Nyanchu River, Nyang River and other valleys, which are usually 5-8 kilometers wide and 70-100 kilometers long. The climate is relatively mild, the annual average temperature is 5-8 °C, the average annual precipitation is 300-450 millimeters, the frost free period is 120-150

Figure 2. Dry farming map of Tibet



Yak dung cakes stored for fuel in Tibet

days, the average temperature in the warmest month is about 15 °C, the accumulated temperature ≥ 10 °C is about 2,000 °C, and 85 percent of the annual precipitation is concentrated from June to September. The crops can be ripened once a year. The main crops are winter wheat, highland barley, rape, pea, potato, green feed, etc. The economic forest fruits in the temperate zone such as apples and walnuts can also be planted, as the area is suitable for the growth and planting of a variety of cool crops. The vast majority of highland barley is spring highland barley, and winter highland barley is only distributed in the valley agricultural area below 3,700 meters above sea level; winter wheat is the main wheat, accounting for more than 70 percent, the rest is spring wheat; beans are mainly peas, and some potatoes. This area has a concentrated population, a vast grassland, relatively flat terrain, concentrated arable land, and good soil conditions suitable for crop growth. The per unit yield of crops is the highest in Tibet, and it is the most important agricultural region with the combination of agriculture and animal husbandry in Tibet Autonomous Region.

Eastern Tibet - agriculture, forestry and animal husbandry ecological area

Located to the east of Naqu City, this region has a series of high mountains and deep valleys that gradually turn from east-west to north-south. The main part is Jinsha River, Lancang River and Nujiang River (referred to as Sanjiang River Basin) drainage area of Hengduan Mountains. It is high in the north and low in the south, with an altitude of 5,200 meters in the north, more than 3,000 meters in the south, and a height difference of more than 2,000 meters between the top and the bottom of the valley. The vertical difference in climate is obvious. The mountain top is often covered with snow all the year round, the hillside is densely covered with forests, and the Piedmont farmland is interlaced. It is a typical combination area of agriculture, forestry and animal husbandry. This area is the place with the best temperature conditions in Tibet. The annual average temperature is above 15 °C, frost free period is more than 270 days, the average temperature in the warmest month (July) can be more than 20 °C, the average temperature in the coldest month (January) is also above 8 °C, the annual accumulated temperature of ≥ 10 °C can be as high as 4700 ~ 5100 msl, the rainfall is abundant, and the annual average precipitation is more than 600 millimeters. It is the main natural forest area in Tibet, and the income from forest products is the main source of income for farmers in this region. The cultivated land area is small and scattered, most of which is distributed in the valley area or hillside terrace. Every year, the crops can be planted for two to three seasons, suitable for planting corn, rice and other warm food crops, as well as sugarcane, tea, citrus, oil tea, banana and other subtropical economic crops and forest fruits.

The three basic factors of heat, water and soil in the region determine agricultural production and crop distribution

The rest of Tibet is basically a sub cold climate, with an annual average temperature of - 0.6 ~ 4 °C and an average temperature of about 10 °C in the warmest month (July). There are many natural disasters and frost almost all year round. Most areas are pastoral areas. Only in some places with good microclimate environment can spring barley and roots of *genkwa*[17] (Daphne) be planted.

General overview of agriculture and animal husbandry in Tibet

High altitude terrain, low temperature, cold and changeable climate, short effective growth period of plants, slow growth and development of animals, has formed a unique plateau agriculture and animal husbandry, which also makes the output of agricultural and livestock products in Tibet low. The three basic factors of heat, water and soil in the region determine agricultural production and crop distribution, among which heat condition is the key. Altitude has a significant effect on temperature in Tibet, and the difference of temperature limits agricultural production and crop distribution. The total area of Tibet Autonomous Region is 1.2,284 million square kilometers. The cultivated land is distributed in strips or sheets along rivers. The cultivated land area is about 350,000 hectares, accounting for 0.3 percent of the total area. The valley cultivated land accounts for 70 percent of the total area of Tibet cultivated land. The grassland area is about 82.07 million hectares, accounting for 71 percent of the total area. The forest land area is 17.9,819 million hectares, accounting for 14.6 percent of the total area. The main areas of agricultural and animal husbandry production in Tibet Autonomous Region

Sheep account for 60% of the total livestock in Tibet

are the grassland animal husbandry ecological area located in the North Tibet Plateau and the agricultural and animal husbandry ecological area located in the South Tibet River Valley.

The main crops planted in Tibet include winter and spring barley (naked barley), winter and spring wheat, rape, pea, potato, and buckwheat. Rice, corn, soybean, millet, chicken claw grain and other crops are also planted in the area below 2,300 meters above sea level. Among the crops, highland barley has the largest planting area, about 180,000 hectares, wheat 41,000 hectares, rape 28,000 hectares, green fodder 48,000 hectares and vegetables 30,000 hectares. The average yield of spring highland barley is about 4,200 kilograms per hectare, wheat 4,700 kilograms per hectare, beans 3,800 kilograms per hectare, rapeseed 2,000 kilograms per hectare, vegetables 29,900 kilograms per hectare and forage 8,500 kilograms per hectare.

Tibet's livestock and poultry are mainly yak, sheep, goats, pigs, horses, donkeys, mules, and chicken. The main livestock are cattle and sheep, of which sheep account for 60 percent of the total livestock, cattle account for 36 percent, and other livestock account for a relatively small proportion. The average body weight of local adult yaks is 200 kilograms, the heaviest of which can reach 400 kilograms, and they will be released in 7-9 years of breeding; the weight of sheep may be between 40 to 50 kilograms, the heaviest being 60 to 70 kilograms; and the weight of adult goats may be between 25 to 30 kilograms; pigs are mainly local Tibetan pigs, with the weight of 30 kilograms, mainly distributed in forest and agricultural ecological areas.

Agriculture

Xiawei Liao

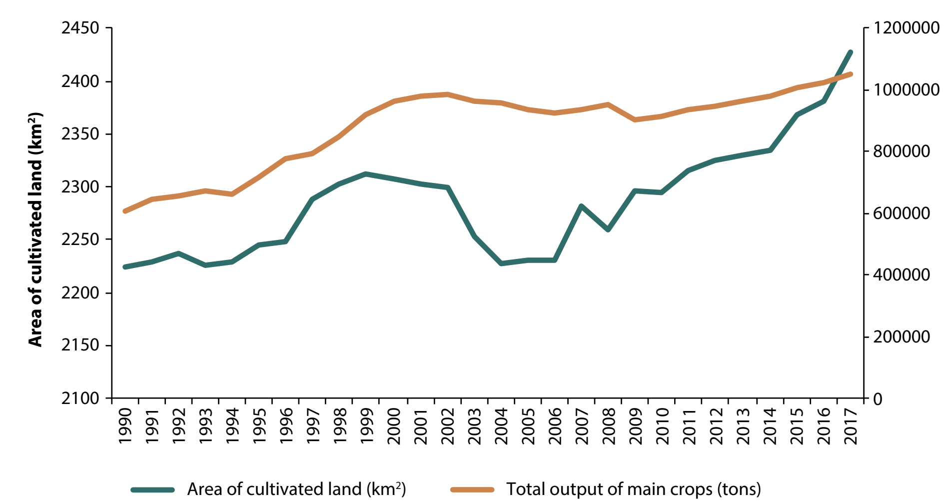
Agricultural GDP[18]

The gross output value of agricultural products in Tibet, including farming, forestry, animal husbandry and fishery, has more than tripled from RMB 5.1 billion (approximately US$ 0.73 billion) in 2000 to RMB 17.8 billion (US$2.54 billion) in 2017, and is approximately 13.5 percent of the provincial GDP. Animal husbandry contributed the largest share, 51.7 percent, to the provincial agricultural GDP, followed by farming products, 44.0 percent. Forestry products and fishery make up very small proportions, 1.7 percent and 0.2 percent respectively in 2017.

Crops

Out of Tibet's total land area of about 1.2 million square kilometers, most of which is made up of highland deserts and glacier areas, only less than 2,500 square kilometers land was cultivated for agricultural use in 2017, and the total crops output was 2,427.5 tons. Figure 3 shows the area of cultivated land and total crop output in Tibet from 1990 to 2017.

Figure 3. Area of cultivated land and total crop output in Tibet



The gross output value of agricultural products in Tibet, including farming, forestry, animal husbandry and fishery, has more than tripled in the last 15 years

About 55 percent of the cultivated land is used to grow highland barley (Figure 4). Among the 74 counties in Tibet, there are in total 65 counties growing highland barley, at altitudes ranging from 800 to 4,750 meters. Wheat occupied the second largest area of land, but with a decreasing trend from about 20 percent of the total cultivated land in 1990 to only 13 percent in 2017. A decreasing proportion of land is being used to grow beans as well, from 10.56 percent in 1990 to 1.56 percent in 2017. On the other hand, growing proportions of land are being used to grow vegetables and green feed, which together occupied 20.92 percent of the cultivated land in 2017.

Figure 4. Composition of crop productions in Tibet

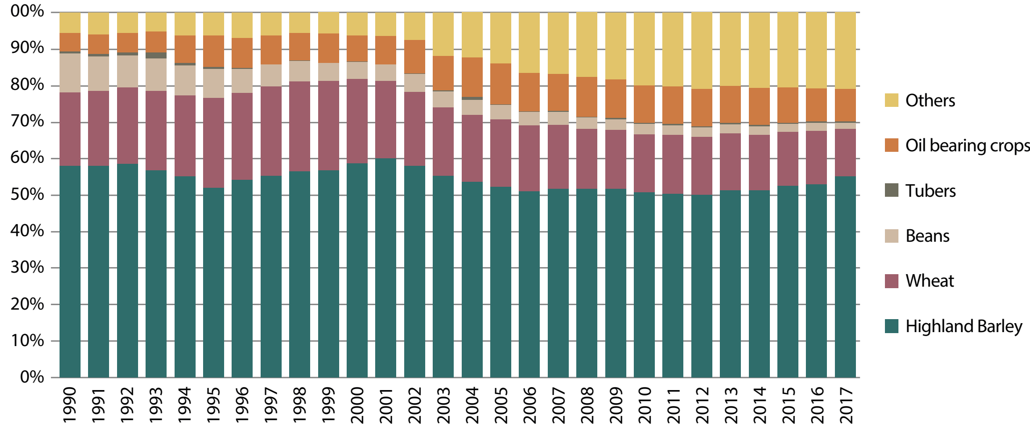
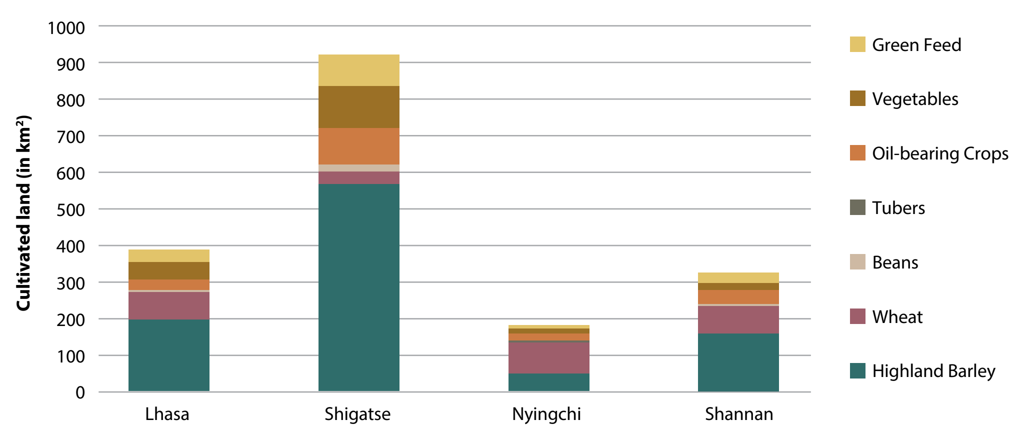


Figure 5 shows the land cultivated under various crops in the Tibetan prefectures in the Yarlung Tsangpo Basin in 2017.

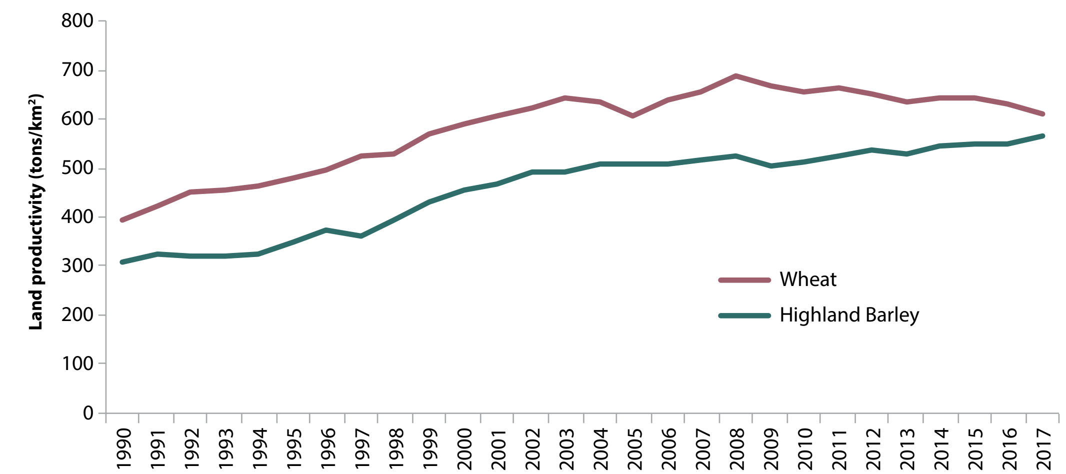
Figure 5. Cultivated land in main Tibetan prefectures in the Yarlung Tsangpo Basin in 2017



Highland barley has the largest production in Tibet, more than doubled from 0.37 million tons in 1990 to 0.79 million tons in 2017, which is followed by wheat productions. However, after peaking at 0.31 million tons in 2000, wheat production has kept decreasing to only 0.2 million tons in 2017, almost the same production level as in 1992.

Tibet has implemented various measures to increase the land productivity, such as scientific fertilization, mechanical seeding, pest and disease control. From Figure 6, it can be seen that land productivity for both highland barley and wheat has increased substantially over the last 30 years, from 307 (highland barley) and 393 (wheat) tons per square kilometers in 1990 to 566 (highland barley) and 609 (wheat) tons per square kilometers in 2017.

Figure 6. Land productivity for highland barley and wheat in Tibet



Tea, apple and pear plantations are occupying increasing land in Tibet, growing substantially from 1.49, 5.08 and 0.41 square kilometers respectively in 1990 to 7.90, 28.76 and 4.32 square kilometers in 2017. Accordingly, annual tea output has grown from 66 tons to 91 tons during the same period, while apple and pear productions have grown from 3,696 and 319 tons, respectively to 11,044 and 1,309 tons.

Initial evidence indicates that increase in cropping intensity on the Tibetan plateau could be attributed to climate warming

The effective irrigated area in Tibet has increased from 1,543.7 square kilometers in 2001 to 1,810.8 square kilometers in 2017, occupying an increasing share in the total cultivated land from 67.10 percent to 76.92 percent. Among which, the areas that are irrigated electromechanically have increased from 58.1 square kilometers to 69.8 square kilometers during the same period.

Initial evidence indicates that increase in cropping intensity[19] on the Tibetan plateau could be attributed to climate warming. The area suitable for single cropping increased from 19,110 square kilometers in 1970s to 19,980 square kilometers in 2000s, expanding from the downstream valleys of Lhasa River and Nyang Qu River to upstream valleys. The area suitable for double cropping gradually increased from 9 square kilometers in 1970s to 2,015 square kilometers in 2000s, expanding from the lower reaches of Yarlung Tsangpo in Lhoka Prefecture to the upper ones, as well as the Lhasa River tributaries. The upper limit elevation suitable for single cropping rose vertically from 5,001 meters above sea level to 5,032 meters above sea level from 1970s to 2000s, and that of double cropping rose from 3,608 meters above sea level to 3,813 meters above sea level.

Organic farming

From 2015 to 2017, total chemical fertilizer use per hectare has steadily decreased from 255 kilograms to 213 kilograms. Nitrogen fertilizer is occupying a decreasing share, from 52.15 percent to 32.64 percent while compound fertilizer is occupying a growing share, from 27.85 percent to 42.53 percent.

In recent years, accompanying the decreasing consumption of chemical fertilizers, organic farming has seen an expansion in Tibet. In 2019, a new project proposes to implement organic barley farming in more than 2.9 square kilometers in Linzhou County in Lhasa, which is expected to benefit 3,089 people in 510 households bring on average RMB 6,900 (approximately USD 975) income increase per household and RMB 1,168 (approximately USD 165) income increase per capita[20].

In Gangba County in Shigatse City, through organic farming and certification, the price per one sheep has increased from 800 RMB (approximately USD 113) to 1700 RMB (approximately USD 240.26) in 2016 and the total economic output of sheep farming in Gangba has reached RMB 1.53 billion in 2016, increasing by RMB 0.9 billion from 2013. It has led to income per capita increase of RMB 1,500 for sheep farmers [21].

Main agricultural pests

Almost 50 percent of the total cultivated land in Tibet is affected by crops diseases, pests and the problem of weeds. Every year, 10 to 30 percent of agricultural production is affected.

The main insect pests include locusts, aphids, underground pests, spiders, and caterpillars[22]. The main diseases are barley bacterial stripe disease, stripe disease, wheat rust, and smut. Locust is a unique species in the Qinghai Tibet Plateau, which has three characteristics of migration, outbreak and destruction. Affected by the continuous climate change, it seriously endangers the production of agriculture and animal husbandry, food security, income increase of farmers and herdsmen, and even the ecological environment. Aphids are mainly wheat aphids, rape aphids and other insect pests. They are very fast in reproduction speed, covering the whole Tibetan area. Red spider (*Tetranychidae*) is widely distributed and can cause harm to many plant species. They have very strong reproductive capacity, especially in high temperature and drought climate.

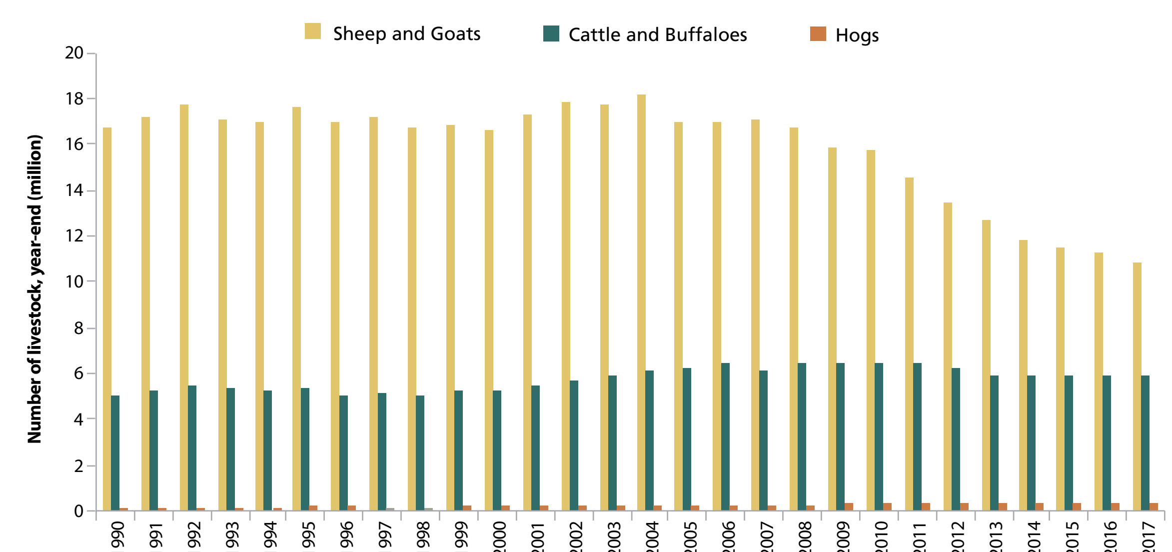
Traditionally, knapsack hand sprayer is used to spray pesticides for pest and disease control, which is labor intensive. After 2015, coordinated prevention and control has been promoted in Tibet, adopting large-scale pesticides application and spraying machines.

In recent years, accompanying the decreasing consumption of chemical fertilizers, organic farming has seen an expansion

Livestock

There are in total 0.88 million square kilometers of grassland in Tibet[23]. Animal husbandry makes up 44.9 percent of the provincial agricultural GDP and 19.4 percent of the provincial GDP. In total, there were 17.56 million livestock in Tibet in 2017. While the number of cattle and buffaloes has kept almost constant at around 6 million, the number of sheep and goats has decreased substantially from peaking at 25 million in 2004. The number of hogs has increased slightly from 0.16 million in 1990 to 0.42 in 2017. (Figure 7)

Figure 7. Number of livestock in Tibet



In terms of livestock products, more beef than mutton is produced in Tibet (Figure 8). In 2017, there were 225.4 thousand tons of beef and 63.5 thousand tons of mutton produced in Tibet, with only 11.4 thousand tons of pork. Diary production has increased by almost three times from 157.5 thousand tons in 1990 to 421.9 thousand tons in 2017. Milk production was 370.6 thousand tons in 2017. Figure 9 shows the livestock production in the main Tibetan prefectures in the Yarlung Tsangpo basin in 2017.

Figure 8. Livestock products in Tibet

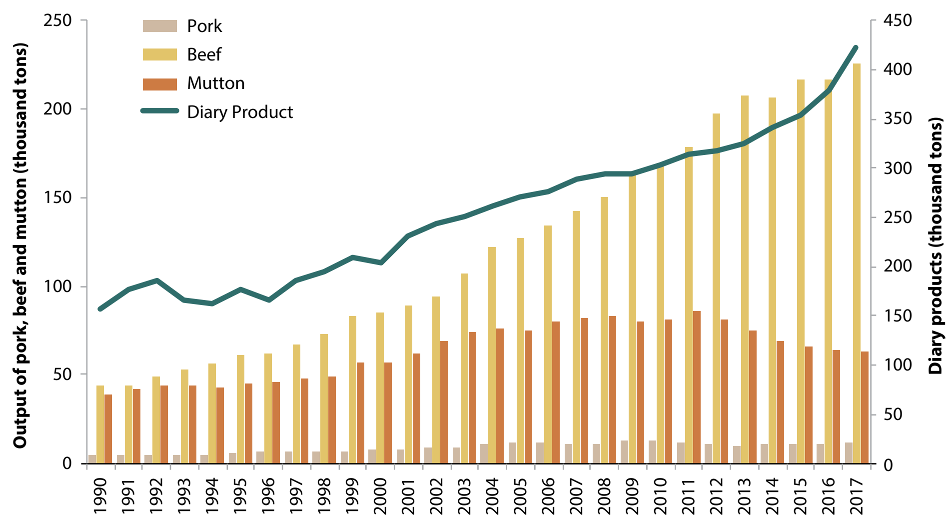
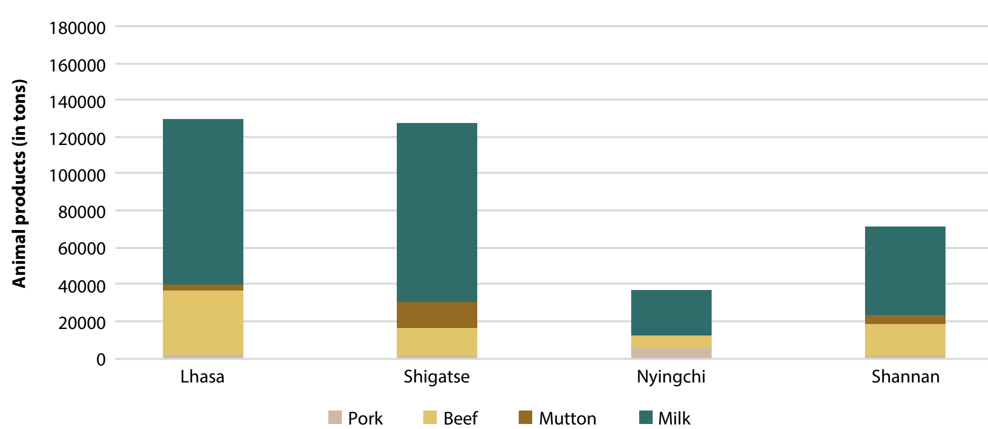


Figure 9. Animal products in main Tibetan prefectures in the Yarlung Tsangpo Basin in 2017



Greenhouses

TIBET IS rich in sunlight resources; the Direct Normal Irradiance is the highest among Chinese provinces. The utilization of greenhouses is a major component of agriculture modernization in Tibet. Greenhouses in Tibet are often built for vegetable growing in the warm season and for keeping livestock in the cold season. Plastic film for agricultural use has increased from 249 tons in 2001 to 1,843 tons in 2017[24].

Before greenhouse technology was adopted in Tibet, vegetable production had been low due to cold night temperatures. The promotion and utilization of greenhouses has basically solved the climate constraint for vegetable production. In 2011, the area under vegetable cultivation grew to 230 million square kilometers. The extent of greenhouses reached over 30 million square kilometers. In 2011, there were 214 green houses in Ngari prefecture, producing 2,074 tons of vegetables and supplying 50 percent to 80 percent of the vegetables in summer[25].

In 2017, over 60 million RMB (approximately 9 million USD) was invested in the Mozhu County in Lhasa to build a modern agricultural demonstration park. There are over 80 greenhouses in the park, with distribution centers and cold storage centers. Peppers, tomatoes, melons and eggplants are the main crops. The park has provided employment for over 80 people and paid an annual dividend of over 2,000 RMB (approximately 309 USD) to over 90 poor households[26].

Highland barley

Xiawei Liao

TIBETAN HIGHLAND barley, also known as naked barley and hulless barley,[27] is the main cereal crop cultivated on the Tibetan Plateau for at least 3,500 years[28]. It is one of the oldest crops of the world and even likely to be the first crop cultivated by humans[29]. It is called '*Qingke*' in Chinese and '*nas*' in Tibetan. Barley can be categorized by the number of its rows, ie. two-rowed, four-rowed and six-rowed hulless barley. While four-rowed hulless barley is the most common type in Qinghai province of China, six-rowed hulless (or naked) barley has been a major staple food of Tibetans for generations. It is used for food, feed, brewing and medicinal purposes. The sown area of highland barley occupies more than 50 percent of the cultivated land in Tibet[30].

Highland barley is a very important cereal crop in the Tibetan plateau due to its high level of cold tolerance, short growth period, high yield, early maturity and strong adaptability. Generally, spring barley is sown from March to May and harvested from July to September and the production period is about 100-130 days. The seedling can withstand the temperature of minus 10 degrees centigrade[31]. Winter barleys are normally sown in October.

Highland barley has higher nutritional components than rice, wheat and corn

Highland barley has higher nutritional components than rice, wheat and corn. Among food crops, highland barley is characterized by its high protein, high fiber, high vitamin, low fat and low sugar contents. Hou and Shen[32] examined the nutritional contents of 29 highland barley varieties in China and found that their protein content ranges from 8.74 percent to 13.15 percent and fat content ranges from 2.44 percent to 4.48 percent, differing substantially by varieties. Highland barley also contains oleic acid, linoleic acid, and linolenic acid and is rich in Vitamins B and C. The soluble fiber and total fiber are higher than other cereal crops. It has a higher content of microelements such

as calcium, phosphorus, iron, copper, zinc, manganese and selenium than corn. It also contains 18 kinds of amino acids, especially the ones that are essential for the human body[33].

Tibet has been improving the productivity of highland barley. From 1990 to 2017, the yield of highland barley per square kilometer in Tibet has increased substantially from lower than 400 tons to more than 600 tons per year[34]. Since 2013, Tibet has been promoting the cultivation of the barley variety '*Zangqing 2000*'; by 2016, over 50 percent of the total barley cultivation comprised of this variety.

TSAMPA made from Highland Barley is the staple food of Tibetan people. *Tsampa* is a dough made with roasted barley flour and yak butter. The roasted barley flour is mixed with boiled water or tea, ghee (yak butter) and kneaded into balls. The *tsampa* served with buttered tea is salty, while the *tsampa* made into porridge is often sweet. Tibetan people eat *tsampa* at every meal, and bring it along as a ready-made meal when traveling. The *tsampa* not only provides nutrition but also fortifies the people to withstand the cold climate.

SIANG BASIN

Vasudha Pangare

WHEN THE Yarlung-Tsangpo leaves China and enters India, the section of the river before it becomes known as the Brahmaputra, is called Siang. The Siang basin is divided into four agroclimatic zones ranging from an altitude of above 3,500 meters above sea level to below 900 meters above sea level. Shifting cultivation or *jhum* and settled agriculture on terraces and flat land are the two main agricultural systems in the mountain regions below 3,500 meters. Settled agriculture is both rainfed and irrigated.

Crops

Siang basin has a plant agrobiodiversity which supports the cultivation of about 70 crop species. Crop biodiversity is the main characteristic of the food supply system, contributing to its sustainability. About 134 plant species[35] are consumed by the people in this region. The agroclimatic zones and hilly terrain of the basin is conducive to the cultivation of spices, aromatic and medicinal plants, flowers, and mushroom. More than 80 percent of the crop production is organic is nature, cultivated without the use of chemical fertilizers and agrochemicals. Data available for the year 2017-2018[36] indicates that 81 percent of the cropped area is under organic practice.

There are two cropping seasons in the Siang Basin, monsoon or *kharif* (southwesterly monsoon season from July to October) and winter or *rabi* (post-monsoon season or winter season from October to March). Upland rice is the main crop and is grown in association with maize, finger millet, beans, tapioca, potato, ginger, mustard, and large cardamom. Sweet potato, cotton, tobacco, chilli, sesame and off-season vegetables are also grown. In general, the productivity is highest for rice in both the seasons. The production of pulses is 20 percent more in the *rabi* season[37].

Indigenous pig breed in Siang Basin

Mithun in Siang basin

Thirty-five percent of the net cropped area was under double cropping during the cropping seasons in 2016-2017[38]. Out of the total rainfed cropped area, 54 percent was under settled agriculture and 46 percent was under shifting cultivation. Approximately 17 percent of the gross cropped area was irrigated. Out of the total irrigated area, 46 percent was flat land and 54 percent was terraced. The nature of the terrain makes it difficult to install large irrigation systems in the region. Many traditional, community-based irrigation systems are still in use. These systems channel water from mountain streams and rivulets to the fields for irrigation purposes.

Livestock

Among the different species of livestock, yak, dzo-dzomo and sheep are reared mainly in high altitude alpine and temperate pastures and grazing lands. Mithun are reared almost all across the basin. The livestock census of 2012 shows a high increase in mithun population[39]. Cattle, goats and pigs are also reared in all parts of the basin except buffaloes which are found in warmer climates in the lower reaches of the basin. Pig rearing is a popular and traditional occupation since time immemorial. Most of the pigs reared are indigenous breeds. Pork constitutes 60 percent of the total food of animal origin consumed by the local population.

Apatani fish-rice cultivation[40]

Ganesh Pangare

THE APATANI tribe lives on the Ziro plateau located at an elevation of 1,572 meters above sea level in the Lower Subansiri part of the Siang Basin. This plateau lies between the Kamala, Khru and Panior ranges in the Eastern Himalayas. Traditional varieties of rice, *Amo* and *Mipa*, under wet rice cultivation, rainfed millet, maize, swine, poultry and fish are the important components of this unique agricultural system.

The knowledge of the traditional wet rice cultivation system has been passed down from generation to generation. Using natural gradients and contours to prepare and cultivate the fields and irrigate them, this farming system covers about 30 square kilometers of area in the villages of Hing, Siro and Ziro. The fields are separated by 0.6 meters high earthen dams supported by bamboo frames. These dams serve to hold water and soil in the fields. Millet is grown on these dams in order to strengthen them. Bamboo and pine are planted around the fields. Since the fields are located in valleys, the soil remains fertile due to the nutrient wash-out from the hill slopes. Fertility is maintained due to the manure which is available from the waste occurring from the pisiculture which is practiced in the rice fields and from the manure of domestic animals. Refuge from homesteads is also used; channels leading to the field carry refuse along with the rainwater from the habitation to the fields.

The rice fields are irrigated by an intricate system of channels and ducts which carry water from the Kele river and the streams that flow into it. The life of these springs and streams is closely dependent upon the health of the catchment from where they originate. The catchment has a good forest cover which is being preserved by the community. Water is distributed through a management system that ensures irrigation equitably to fields located in the upstream and downstream areas. After the upper fields receive their share of the water, the outlet channel is opened so that the next series of fields receive water. This method is followed until the last field is reached. However, in this process it takes some time for the water to reach the tail end. During this time the lower fields have to remain without water. To overcome this problem, a separate channel at the head is made from the mainstream through which water is diverted to fields located at the tail end. The place where the channel separates is called a *boring*. The community takes collective responsibility to maintain the systems and women contribute most of the labour required for maintaining the channels.

In the 1950s the Apatanis initiated an innovative method of fish-rice farming, in which fish is cultivated within the rice fields. Small pits are dug in the rice fields, filled with water and fingerlings are put in these pits. During the monsoon the fields are kept submerged with 5 to 10 cms of water. The fish move around in the entire submerged area. If water is scarce, the fish return to the pits and grow there.

The Apatani system of rice cultivation is not found anywhere else in the world. Research has proved that the system is highly efficient and helps to preserve the ecosystem in which it is practiced. The farming system is still largely organic in nature. The preservation of biodiversity in the area is closely linked with the practice of the Apatani rice farming system.

The Apatani system of rice cultivation is not found anywhere else in the world. The preservation of biodiversity in the area is closely linked with the practice of the Apatani rice farming system

SHIFTING CULTIVATION

Jhum: a misunderstood practice

Dhrupad Choudhury

SHIFTING CULTIVATION is the predominant agricultural practice in most of the catchment areas of the Siang and Brahmaputra basins. Locally known as *jhum*, the practice traditionally consisted of a short cultivation phase of one or two years – though exceptions exist and a cultivation phase of 4-5 years is also known - followed by a long fallow phase of over 25 years, sufficient to allow for rejuvenation of the soil and regeneration of the fallow into mature secondary forests. Common perceptions of the practice view it as subsistence, economically unviable and environmentally destructive. This perception views shifting cultivation solely as an agricultural practice and strives to replace it with settled agriculture. This view overlooks the fact that shifting cultivation is a sequential agricultural and forest management system that is practiced on the same plot of land but separated in time.

Shifting cultivation is a sequential agricultural and forest management system that is practiced on the same plot of land but separated in time

Shifting cultivators, or *jhumiyas* know that fallow forests are the backbone of *jhum* and hence diligently observe strict fallow management practices even as they clear a plot for cultivation. Plot preparation begins towards end November or early December when vegetation is carefully cleared from a pre-designated regenerating fallow. Branches of tall trees are lopped, while others are felled at breast height and the trunk left standing for coppicing after the first rains. Tree stubs and roots of selected plants are left undisturbed and together, these plant parts regenerate into new shoots at the onset of rains and as cultivation proceeds, setting the process of forest regeneration into motion. The slashed biomass is left to dry for about two months after which useful parts are retrieved from the plot for firewood, building houses, fencing and timber and the remaining debris set afire towards end February or early March. Fire is used to convert the biomass into ash and nutrients, hastening the process of decomposition, while also helping to control weeds and pests by killing off seeds and propagules of weeds, and eggs and larvae of pests through the intense heat generated during burning. Post burning, seeds of legumes, cucurbits, vegetables, spices and some cereals are dibbled into the soil while others, particularly upland paddy, millets and oilseeds are broadcast onto the slopes, thus following a 'zero tillage' practice. After cultivation for a year or two, the *jhumiya* moves to clear a fresh fallow, leaving the cultivated fields to rejuvenate and regenerate into fallow forests. *Jhumiyas* move to a new plot every second or third year in order to conserve soil nutrients and not 'bleed Mother Earth dry' - a move misinterpreted by scientists to indicate the depletion of soil nutrients.

A shifting cultivation landscape, in the cultivation phase is a rich repository of agro-biodiversity with an average of over 40 crops being grown, including diverse landraces of each crop. On a landscape level, shifting cultivation systems comprise of rich agro-biodiversity living gene banks, interspersed with a mosaic of different aged regenerating fallow forests. Viewed from this perspective, shifting cultivation, therefore, is not just an agricultural practice, but one that includes a sequential forest management practice at the landscape level. Ignorance of this view attempting to replace the practice has encouraged the promotion of wet terraces and permanent plantations at the cost of regenerating fallows, effectively shortening fallow cycles and permanently changing the landcover. The approach has resulted in erosion of forest cover and depletion of the rich agro-diversity in the process, severely restricting opportunities for harnessing the diverse agro-germplasm as building blocks for tomorrow's stress tolerant crops, or for safeguarding forests and the ecosystem services rendered by them, both essential for adapting to the growing challenges resulting from climate change.

JHUM CYCLE

December-January
selection of new plots based on presence/absence of some selective vegetation, type of soil, and the crop to be grown, followed by cutting and slashing
January-February
burning of slash and distribution of ash in the field; sowing of early rice and other location-based crops.
February-March
terracing of steep slopes and higher areas, preparing contours with half burnt old logs, weeds, stems, etc. and sowing of maize
March-April
sowing of some vegetables mainly in the boundaries, and tuber varieties along the peripheries that act as live fence for protection against animals
April-May
weeding and sowing of paddy by women with minimum soil disturbance
October-November
harvesting, grain kept aside for seed

Jhum: A cultural tradition

Vasudha Pangare

SHIFTING CULTIVATION or *jhum* is an age-old practice constituting a vital part of the socio-economic framework of tribal life. *Jhum* cultivation is not just a source of livelihood but is traditionally allied to the culture, customs and ethnicity of the people. Each stage and activity in the *jhum* cycle is associated with festivals and rituals, as indicated in location-specific traditional calendars of events.

A shifting cultivation landscape, in the cultivation phase is a rich repository of agro-biodiversity and is important for ensuring food security

Shifting cultivation is important for ensuring food security, as in addition to staple foods like rice and tubers, maize and millet, a broad range of vegetables and herbs as well as a large number of medicinal plants are grown in fields and fallows. Many varieties of rice are grown in the *jhum* fields. Various crops are grown on the contour bunds constructed with bamboo for soil conservation. Some farmers cultivate cash crops like turmeric, ginger and large cardamom for commercial purpose. Rice is also used for making local beer.

Indigenous women perform 70 percent of the work related to shifting cultivation[41]. They are responsible for the selection of seeds, for weeding the fields, gathering, processing, and selling the surplus products. Men do the identification of land suitable for shifting cultivation and the land preparation, women help in clearing the land. Sowing is done by women using the dibbling technique in which a small hole is made with the help of a sharp stick and two-three seeds are dropped into the hole. This technique involves minimum soil disturbance and requires expertise and practice. The dibbling and sowing of seeds are done exclusively by women, usually for crops such as maize, pulses, cotton, sesame and vegetables. Men broadcast seeds of crops like millets and small millets.

Both men and women make the firebreaks, harvest the crops, and conduct the rituals during the shifting cultivation cycle. Indigenous women possess a rich knowledge of seeds, crop varieties and medicinal plants, and transfer this knowledge to the younger generation. Indigenous women preserve seeds and play a key role in preserving agrobiodiversity.

BRAHMAPUTRA BASIN

Vasudha Pangare

FROM THE Siang Basin, the river enters the state of Assam. The section of the river that flows through Assam is known as the Brahmaputra. The Brahmaputra basin is situated between the hill ranges of the eastern and north-eastern Himalayan ranges in Eastern India. There are five agroclimatic zones in the Brahmaputra basin. Shifting cultivation is practiced in the hill temperate zone. Wet rice cultivation and tea cultivation are the main systems in the valley zones; rice is the main staple crop and tea is the main cash crop. Tea is grown in four agroclimatic valley zones. Assam is known for its tea gardens, and the world-renowned Assam tea gets its distinctive flavour from the soil and climate of the Brahmaputra valley.

Livestock contributes to food and crop production for smallholder farming households and are important as savings, as a source of daily cash income, and as insurance against adversity, particularly in the face of climate uncertainties

Crops

Five crop combination systems of rice, maize, potato, vegetables and oilseed are found in the fertile alluvial plains of the Brahmaputra Basin. This region is also the second largest producer of Jute in India. Jute is cultivated in an area of 75,140 hectares with an average yield of 1,923 kilograms per hectare.

Rice is a three-season crop; autumn, winter and summer[42]. Autumn rice is called *Ahu* and is usually sown in February–March and harvested in July–August. Winter rice or *Sali* is sown in July–August and harvested in November–December. Summer rice or *Boro* is sown in November–December and harvested in March–April. *Boro* is considered a low-risk rice with 30 to 40 percent higher yield[43]. Data for 2016-2017[44] shows that the average yield of *Ahu* (autumn) rice cultivation was 1,380 kilograms per hectare, the average yield of *Sali* (winter) was 2,023 kilograms per hectare, and the average yield of *Boro* (summer) rice was 2,773 kilograms per hectare.

Agriculture in the valley is challenged by floods and high rainfall, particularly in the *kharif* (monsoon) season. The State Agriculture Department[45] promotes *rabi* (winter) crops by developing irrigation facilities through the installation of Pump Sets (Shallow Tube Well & Low Lift Pump). Assured irrigation has been effective in raising cropping intensity to 146 percent[46].

Livestock

Almost 90 per cent of the rural households keep indigenous livestock of one species or the other; cattle, buffalo, sheep, goat, pig, poultry[47]. Livestock contributes to food and crop production for smallholder farming households and are important as savings, as a source of daily cash income, and as insurance against adversity, particularly in the face of climate uncertainties. Animal traction is still used. Cattle and buffalo are important for agricultural operations whereas milk production is secondary.

There are pockets of nomadic systems of cattle rearing, mostly in the fringes of the forests. In recent years, farmers have begun to keep improved livestock and commercial poultry. Livestock is largely fed on crop residues, and food waste. High-producing animals are given concentrated grain-based feed as supplements.

Coping with floods

Raju Mandal

ASSAM IS home to a large network of rivers. The rivers Brahmaputra and Barak, and their tributaries play an important role in the lives and livelihoods of people in the plains of the state. Because of its unique geological location in the foothills of the Himalayas the abundance of monsoon precipitations and fertile alluvial soil deposition by the rivers during rainy season have enabled majority of the population to depend on cultivation as the principal source of livelihood for generations. However, being located in a heavy rainfall zone, excessive precipitations in the state and upper catchment areas during monsoon cause widespread water logging and flood—sometimes four to five times in a year—in the plain areas of the state. The plains of Assam, covering 81 percent of total geographical area and accommodating 97 percent of total population of the state, are highly prone to floods[48]. The flood-proneness of Assam is around four times the national figure as 39.58 percent of total area of the state is flood-prone compared to the corresponding national figure of 10.2 percent[49].

Although flood is a known and regular annual phenomenon in Assam, its varying timing, intensity and frequency pose a great risk and uncertainty particularly for the crop growing sector. Floods in the early phase of the monsoon mainly damage the *Ahu* seasonal type of paddy. But floods occurring late in the season are most devastating as they damage the standing *Sali* paddy, which happens to be the main *kharif* (monsoon) crop of the state. Apart from causing instability in production, occurrence of frequent floods is one of the factors responsible for low rate of adoption of modern techniques of agricultural production.

Although flood is a known and regular annual phenomenon in Assam, its varying timing, intensity and frequency pose a great risk and uncertainty particularly for the crop growing sector

Notwithstanding the fact that the agriculture sector of Assam is highly exposed to flood risk every year, more than half of its workforce still depends on it for their livelihoods. Naturally the question arises as to how the farmers in the state are surviving in the face of flood induced production risks while they do not have any institutional safeguards like crop insurance. In this regard Goyari[50] and Mandal[51] using district level aggregated data have found that the attempt to minimize production risk arising out of recurring floods has led many farmers to adjust the cropping pattern and/or season as a result of which there has been a decline in the acreage shares of *kharif* (monsoons) food grains that are largely affected by flood, and a corresponding increase in the acreage shares of *rabi* (winter) food grains and vegetables. Such adaptations by the farmers have been possible particularly after the introduction of privately-owned shallow tube well based irrigation system in the state in the mid-1990s[52].

Analysis of farm level data and interactions with farm households by Mandal[53] reveals that the farmers who are exposed to greater risk arising from floods tend to adopt a cropping pattern that is more diversified across crops and seasons to hedge against flood induced risks and limitations in agriculture. Farmers with better irrigation facilities and access to institutional credit are found to be more successful in this strategy. This apart, the farms with a diversified cropping pattern have been able to extract more returns by compensating for losses in output of one or two crops by others that do not suffer such losses. These coping mechanisms by the farmers in the flood plains of Assam have important policy relevance for attaining and maintaining a higher growth rate of the agriculture sector and making farming a remunerative profession in the state.

MANAS BASIN

Kinlay Tshering and Vasudha Pangare

THE MANAS river, flowing through Bhutan is an international tributary of the Brahmaputra river.[54].

Bhutan is broadly divided into six major agroecological zones[55] corresponding with altitude range and climatic conditions, for the purpose of agricultural planning. At higher altitudes, livestock rearing is the most common source of livelihood, with some dryland farming. In the lower altitudes, agriculture is widely practiced in terraced irrigated wetlands and drylands. The main crop cultivated in the terraced irrigated wetland agricultural areas is rice followed by wheat and mustard. Citrus (mandarin orange) plantation in the lower altitude and cardamom in the higher elevations are the main cash crops. In the sloped dryland agricultural areas, maize, millet, mustard, several types of legumes, ginger and vegetables are the predominant crops.

Agricultural production

Agriculture[56] is one of the Five Jewels of the Economic Development Policy[57] of Bhutan. In 2017, the crop sector contributed about 10.64 percent of the total Renewable Natural Resources sector contribution to the country's Gross Domestic Product. Agriculture provides employment to 57.2 percent of the total population[58]. Although only 2.75 percent of the total land is under cultivation[59], agriculture production in Bhutan has made significant contribution to enhance food and nutrition security and reduce

Terraced rice fields in Bhutan

The main crop cultivated in the terraced irrigated wetland agricultural areas is rice followed by wheat and mustard rural poverty. Rice is the major crop associated with food security and has cultural significance for the people of Bhutan. It symbolizes a way of life and epitomizes environmental and landscape beauty.

With an average farm size of 0.89 hectares[60], often spread over different agro-ecological zones and altitudes, most farmers practice subsistence to semi-subsistence integrated farming systems. In many parts of the country, farmers continue to depend on the monsoon rains, which have become ever more erratic and unreliable. Though the country is blessed with many river systems, their use in agriculture had been limited due to unavailability of appropriate technology to tap irrigation potential. In 2017, assured irrigation covered about 27,500 hectares of cultivated land. In an effort to reduce irrigation water scarcity, 212 water harvesting reservoirs were constructed on cost sharing basis at various locations.

Rice is the major crop associated with food security and has cultural significance for the people of Bhutan. It symbolizes a way of life and epitomizes environmental and landscape beauty

Approximately 90 percent of rural farmers raise some form of livestock[61] for dairy products, draught power, meat, and dung. For most small holder farmers, livestock provide a ready source of income to help purchase the necessary inputs for crop production such as seeds and fertilizers. Most agro pastoralists graze their livestock in nearby forests and keep them in sheds during the night. Dung is used for crop production, greatly reducing or eliminating the use of chemical fertilizers. Cattle is most preferred because of its multiple uses. Poultry is raised for eggs and pigs for meat. Horses are used for traction and transport.

Over the last decade, farming in Bhutan has seen a dynamic shift from subsistent to commercialized farming. Farm mechanization has been promoted with power tillers and mini tillers, and rural accessibility has been improved. The major interventions that have triggered this transition process are investments in irrigation and farm roads; electric fencing to protect crops from wildlife damages (3,492 kilometers of electric fencing was installed across the country); development and promotion of high yielding crop varieties and protected cultivation; focused commodity approach, agricultural land development including sustainable land management practices and provision of essential support services including market infrastructures[62]. A total of 841 different post-production structures were established to reduce post-harvest losses and add value to agricultural produce.

Organic agriculture[63]

The Ministry of Agriculture and Forests launched the National Framework for Organic Farming in 2006. The inherently organic nature of Bhutanese farming systems guided the evolution of the country's development of organic agriculture. The approach and strategies promoted conservative, sustainable, self-sustaining, resilient production systems that prevented exploitation of ecosystems and sustainable use of natural resources. Under the National Organic Programme, about 10,387 hectares of land is currently under organic management, out of which 7,837.5 hectares comprises forest land certified for collection of various Non-Wood Forest Products.

About 2,650 households have been supported by the National Organic Programme to practice organic agriculture on 2,250 hectares of agricultural land. Training, inputs, infrastructure, equipment, product development and marketing support have been provided to the households. Twenty-four farmer groups/cooperatives have been formed. Three retailers, and one exporter support the production and marketing of organic produce. Three organic manure production plants have been established to supply bio-inputs for organic production.

The Local Organic Assurance System (LOAS) certification was established in 2017 for locally produced organic products. In collaboration with National Certification Body (BAFRA) and International Certification Body (IMO) for organic certification, 10 products have been certified including potato, garlic and carrot from Gasa, turmeric from Zhemgang, seabuckthorn, chamomile, mint from Bumthang, Green Tea from Trongsa, and rhododendron and lemongrass essential oils from Mongar.

A flagship program on organic agriculture was approved for implementation in the Twelfth Five Year Plan (2018-2023), to commercialize organic production for export and domestic market, and to make organic inputs available in the country on a larger scale.

TEESTA BASIN

Vasudha Pangare

THE TEESTA River originates in the Himalayas and flows through the Indian States of Sikkim and West Bengal before joining the Jamuna in Bangladesh. Flowing through the length of Sikkim, the Teesta River is considered to be the lifeline of the state. The basin has four agroclimatic zones. Shifting cultivation, terraced agriculture and subsistence agriculture are the main agricultural systems.

The hilly terrain and difficulty in access to markets has made villages self sufficient; most households are engaged in subsistence agriculture, and produce food grains for home consumption, with shortfalls being met by supplies under the public distribution system[64]. Milk is traded across the rural areas, in outside markets as well as in the milk cooperative society areas. Milk constitutes a major source of household income. Meat markets are local, confined to village clusters both in the case of beef and chevon. Eggs are traded among village clusters but the poultry meat is kept for home consumption[65].

Shifting cultivation, terraced agriculture and subsistence agriculture are the main agricultural systems. Most of the agriculture is organic and has traditionally been in practice since ages

Crops

Sikkim is rich in biodiversity with abundant plant species because of which the soil is rich in organic matter content and makes the nutrient conversion easier. Sustainable farming practices that conserve and maintain the fragile ecosystem are important for soil and ecosystem protection. A variety of crops can be produced because of the varied agroclimatic conditions in the basin. Most of the agriculture is organic and has traditionally been in practice since ages[66].

Agricultural holdings are spread between an elevation of 300 to 3,000 meters. Farming is done in about 10.20 percent[67] of the total geographical area of the state. Most of the cultivable lands are terraced. Marginal holdings and small holdings together comprise about 50 percent of all operational holdings and occupy 41 percent of the total area. Agriculture is largely rainfed with traditional system of cultivation and low inputs. Due to topographical features, medium/major irrigation projects are not feasible and therefore only minor irrigation channels are installed. About 11 percent[68] of the cultivated area is irrigated.

Traditional communities in the upper reaches of the basin, in the cool temperate and lower alpine zones between 2,500 to 4,000 meters, grow wheat, barley, and seasonal vegetables such as beans, potato, cabbage, cauliflower, and radish in the summer when the snow melts. Large cardamom-based and farm-based traditional agroforestry can be found in the subtropical to warm temperate zones at an elevation between 600 and 2,500 meters. Wet rice cultivation is practiced in terraces and along river valleys in the tropical zone at an elevation greater than 500 meters.

Other crops include maize, buckwheat, *urad* (black lentil) rice bean, soybean and mustard. Orange and pears are the main horticultural crops; ginger, cardamom, turmeric and cherry pepper are the main spice crops; peas, bean, tomato, potato are the main vegetable crops. Off-season vegetables are being cultivated extensively. In recent years, a large number of farmers have adopted floriculture as a commercial venture and the cultivation of flowers like cymbidium, rose, gerbera, anthurium is generating a good income.

Livestock

Livestock production had always been an integral part of the rural livelihoods in Sikkim and is predominantly the endeavour of small producers[69]. Marginal and small farmers own nearly 85 percent of all species of livestock and poultry, even though they own or operate less than 55 percent of the farmland in Sikkim. Even the tiny organised poultry industry in Sikkim is made up of small broiler farms. Over 80 percent of all rural households own livestock (often a mix of several species) as part of the traditional mixed crop-livestock farming system, earning substantial incomes and enriching family diets with nutrient rich animal products. Income from livestock is thus a substantial contribution to the subsistence farming systems in Sikkim.

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JAMUNA BASIN

Jamuna basin is one of the three major river systems of Bangladesh. The basin is often characterized as a granary or the breadbasket of the country

The Brahmaputra River flows through the Indian state of Assam and enters Bangladesh after the Assamese town of Dhubri. In Bangladesh the river is known as the Jamuna and is the last stretch of the river system before it meets the Ganges river.

Agriculture

Md. Ayub Hossain

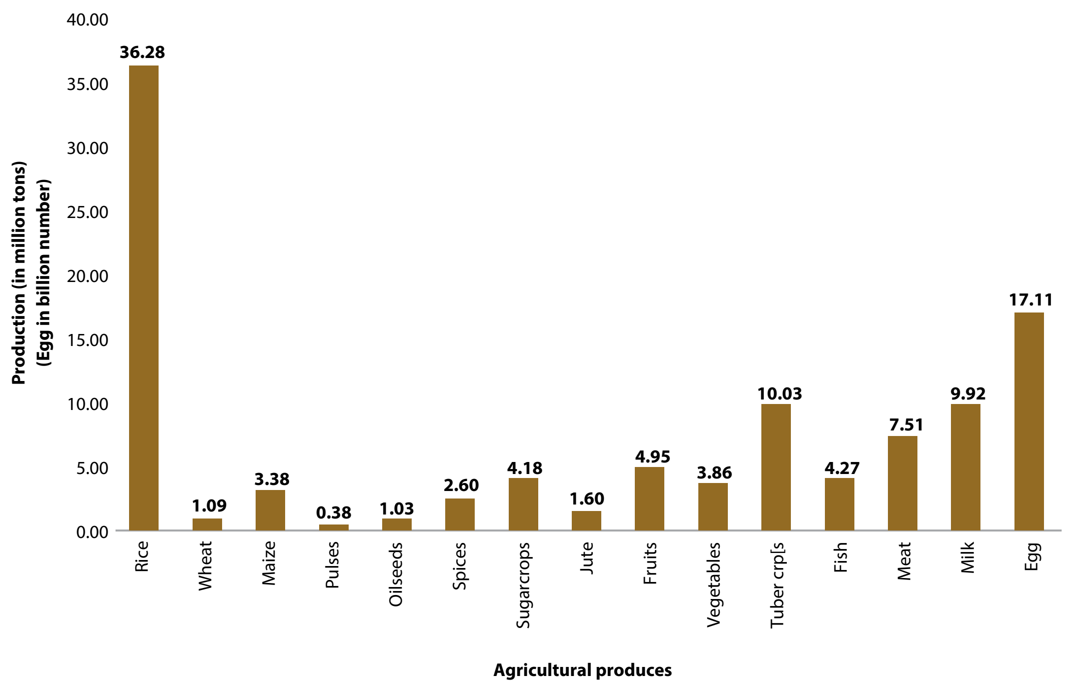
Agriculture systems in the basin

Jamuna basin is one of the three major river systems of Bangladesh. Brahmaputra-Jamuna and old Brahmaputra with their main tributary Teesta and a good number of small tributaries and distributaries constitute the largest floodplain of Bangladesh. The Brahmaputra-Jamuna drains the northern and eastern slopes of the Himalayas and has a catchment area of 5,83,000 square kilometers[70]. The administrative districts of Panchagarh, Thakurgaon, Dinajpur, Kurigram, Rangpur, Nilphamari, Lalmonirhat, Gaibandha, Joypurhat, Naogaon, Rajshahi, Bogura, Shirajganj, Pabna, Jamalpur, Mymensingh, Narayanganj, Munshiganj, Manikganj and Dhaka are included in the Jamuna basin[71]. The land of Jamuna basin is alluvial soil and it is fertile. Jamuna basin consists of eight agro ecological zones. The total area of the Jamuna basin is 3,962,077 hectares which is 27.67 percent of the total land area of Bangladesh[72].

Jamuna basin is often characterized as a granary or the breadbasket of Bangladesh. Agriculture or farming remains the mainstay of the people of this region. The crop profile includes multiple crops such as rice, cereals and cash crops such as sugarcane, oilseeds, pulses, and tobacco. Besides these, many fruits, vegetables and spices are also grown.

Agroforestry is a popular and widely practiced intervention in Jamuna basin. Agroforestry is commonly practiced in establishment of fruit orchards especially in early stages of plantation (1-3 years). Some shade crops like turmeric, ginger, and grasses, are cultivated in this area. Social forestry[73] is generally practiced by 39.4 percent of farmers for fuelwood, fruits, and timber. About 24.6 percent of households also practice roadside plantation, about 11.8 percent are involved in embankment cropping[74–75].

Figure 10. Agricultural production in Bangladesh in 2018-19



The soil of Jamuna basin is comparatively more fertile than other regions of the country. Most area of the basin is suitable for agricultural crop production

Crop production in the basin

The soil of Jamuna basin is comparatively more fertile than other regions of the country. Most area of Jamuna basin is suitable for agricultural crop production. There are three main seasonal types of rice grown in Jamuna basin; *aus, aman* and *boro* rice. *Aus* is a pre-monsoon rainfed crop, *aman* is a rainy season rice, whereas *boro* is irrigated rice grown during the dry winter season (January through May). Transplanted *aman* and *boro* rice are grown all over the Jamuna Basin. *Aus* rice is cultivated in some locations. Due to its higher yield potential (3.4 tons ha^{-1}) compared to *aus* (1.6 tons tons ha^{-1}) and *aman* (2.0 tons ha^{-1}), *boro* rice production has expanded in the last three decades[76]. *Boro* rice is widely cultivated, contributing about 55 percent of the overall rice production[77].

The main field crops in Jamuna basin are cereals (rice, wheat, maize, millets, etc.), pulses (lentil, grasspea, chickpea, mungbean and blackgram, etc.) oilseeds (mustard, groundnut, sesame, sunflower, etc.), vegetables (Potato, radish, tomato, brinjal, sweet gourd, pumpkin, bittergourd, pointed gourd, snake gourd, leafy vegetables, etc.) and spices (onion, chilli, garlic, ginger, turmeric, etc.). Different types of local and exotic fruits are grown in different seasons.

About 200 cropping patterns are followed in this region. The cropping intensity (211 percent) is higher than the national average (195 percent) of the country[78]. As a whole the crop diversity index of Jamuna basin is 0.90 which indicates a high crop diversity[79]. The region includes 7.58 percent single cropped area, 48.09 percent double cropped

area and 41.15 percent triple cropped area. The area and production of maize in Jamuna basin is increasing day by day. Farmers are cultivating mainly hybrid maize[80]. About 60 percent of total maize production in the country is in Jamuna basin[81].

Irrigation systems

The farmers of Jamuna basin practice multiple cropping system, hence the fields get irrigated more than once a year. The sum of these multiple gross irrigated areas is about 4.24 million hectares[82]. About 80 percent of Jamuna basin area is irrigated. Government organizations such as Bangladesh Agricultural Development Corporation, Barind Multipurpose Development Authority and Bangladesh Water Development Board

The positive benefit of increasing use of groundwater irrigation is that almost the whole region has achieved food self-sufficiency and has contributed significantly to rural wealth creation

are involved in executing some big irrigation projects. The country enjoys tropical monsoon climate with two prominent seasons; dry season (November-May) and wet season (June-October). Up to 85 percent of the annual rainfall occurs between June and September. Mean annual rainfall ranges from about 1,200 millimeters in the west to almost 6,000 millimeters in the northeast[83]. In Jamuna basin about 88 percent land is irrigated by groundwater and rest is irrigated by surface water. The positive benefit of increasing use of groundwater irrigation is that almost the whole region has achieved food self-sufficiency and has contributed significantly to rural wealth creation[84].

Irrigation is applied first in *Boro* rice and vegetable cultivation and then for wheat, maize, oilseeds and spices. *Aman* rice is mainly cultivated under rainfed condition, but sometimes supplementary irrigation is required if monsoon rain is not sufficient. Shallow tubewells and deep tubewells are the major groundwater lifting devices in Jamuna Basin area. There are also low lift pumps for surface water irrigation, but their numbers are insignificant and concentrated near the river and irrigation canal. About

Almost all rural households rear livestock

58 percent of the lifted water is used for *boro* rice cultivation and the rest is used for irrigating other crops. About 68 percent of the groundwater is lifted from shallow tubewells and rest from deep tubewells[85]. These pumps are operated by diesel engine, electric power and a few by solar energy. Solar irrigation pump is a new and emerging irrigation technology and is becoming popular in Jamuna basin. There are about 1,600 solar irrigation pumps operating in Bangladesh, among them about 60 percent are in Jamuna basin[86]. Most of the irrigation pumps are used on custom hire basis.

Fisheries and aquaculture

The fisheries sector, in Bangladesh, plays a crucial role among the poor as a main or additional source of employment, livelihood and income. The sector is the second largest part-time and fulltime employer in rural areas. Bangladesh produced 4.27 million tons of fish during 2017-18 from inland and marine waterbodies and aquaculture contributed more than 50 percent of the total production[87]. Fisheries accounts for 3.69 percent of Bangladesh GDP, 22.60 percent of agriculture sector and 2.5 percent of total export earnings. It also contributes 60 percent of the animal protein intake in Bangladesh. Bangladeshi people largely depend on fish to meet their protein needs[88]. Until the 70s, there was an abundance of fish in the natural waters-the floodplain, rivers, rivulets, *beels*, lakes, ditches and canals of the country to satisfy the demand of fish. Presently, capture fish production has declined to about 50 percent, with a negative trend of 1.24 percent per year[89].

In the past the major source of fish production in Bangladesh was the inland open water capture fisheries. Now aquaculture has become an emerging sector of fisheries in Bangladesh. Inland pond culture represents the mainstay of aquaculture in Bangladesh, accounting more than 80 percent total recorded aquaculture production and presently dominated by carps (indigenous and exotic), pangas and tilapia. The aquaculture production both in fresh water and brackish water has significantly increased during the last two and a half decades with development of technology.

Inland fishery in Jamuna basin is composed of rivers, *beel* and ponds. The *beel* is a Bengali term used for a relatively large surface, static waterbody that accumulates surface run-off water through an internal drainage channel[90]. The most famous *beel* in the country known as the Chalan *beel* is located in Jamuna basin. In the Jamuna basin, 86 percent of total production of inland fish[91] is from aquaculture. Major inland fishes in Jamuna basin are major carp (*Rui, Catla, Mrigal*), minor carp (*Kalibaus, Bata, Ghania*, etc.) exotic Carp (Silver Carp, Grass Carp, Common Carp, Mirror Carp, Big Head Carp, Black Carp, etc.), cat fish (*Boal, Air, Silon, Rita*, etc.), snake head (*Shoil, Gazar, Taki*), live fish (*Koi, Singhi, Magur*, etc.) and small fish (*Mola, Dhela, Punti, Khoilsha*, etc.) The major stakeholders of aquaculture include fish farmer, hatchery owner, farm/hatchery technicians/workers, input (feed ingredient, fertilizer, hormone, chemical, instrument etc.) importers/suppliers, feed mill owners, homestead feed producer, fisher, fish processor, fish transporter, wholesaler, exporter, retailer, consumer, technology provider (government and non-government) and many more[92].

The aquaculture production both in fresh water and brackish water has significantly increased during the last two and a half decades with development of technology

Livestock production

Livestock is an integral component of the complex farming system in Bangladesh as it not only serves as a source of meat protein but is also a major source of farm power services as well as employment[93]. The livestock sub-sector provides full time employment for 20 percent of the total population and part-time employment for another 50 percent of the total population[94]. The poultry meat alone contributes a substantial 37 percent of the total meat production in Bangladesh. The GDP contribution of this sub-sector has been a modest 1.47 percent and the share of livestock in agricultural GDP is 13.62 percent[95]. Livestock species available in Bangladesh are the most versatile in relation to existing integrated agricultural farming system. About 24.5 million heads of cattle are distributed in Jamuna basin. About 85 percent of cattle are indigenous in origin and rest of them are *Red Chattogram*, *Pabna, North Bengal Grey* and *Munshiganj*[96].

About 98 percent households in Jamuna basin keep cows and population of cows is 3.3 per household. Buffalo and sheep in this area are very small in number. About 16 percent households keep goats with an average size of 2.9 per sheep keeper household[97]. About 33 percent of households are involved in semi-scavenger housing for goat, duck, and hen rearing as climate-resilient practice for livestock rearing in Jamuna basin.

About 2.90 million tons of meat and 4.23 million tons of milk are produced in Jamuna basin. The eggs produced from both local and commercial brides of poultry and ducks in this area are 46.56 million[98]. The dairy and poultry farms have grown rapidly in this area. Almost all rural households rear local poultry and ducks for their own consumption. Sometimes the housewife of a household sells excess poultry, duck and eggs for cash which is used for children's food and education expenses and to buy cosmetics and cheap ornaments.

Agriculture in northwest Bangladesh

Shahriar Wahid, Fazlul Karim and Mohammed Mainuddin

Water and agricultural livelihoods

In 1974, Bangladesh suffered its worst famine. Acute food shortages resulted in the mass starvation of millions. Successive governments targeted food self-sufficiency as their key strategic development goal. The outcomes have been most encouraging. Today, the country is mostly food self-sufficient[99] and one of the largest rice producers in the world. The noted positive achievement of the last few decades has been possible due to water and land management reforms such as widespread adoption of the minor irrigation system, liberalization of the water market, strengthening of extension services, and participation of private and government organizations.

However, climate and other environmental changes pose a major challenge to food self-sufficiency. Northwest Bangladesh is a case in point (Figure 11). The region is bordered by two major transboundary rivers - Ganges (called Padma River in Bangladesh) in the south and Brahmaputra in the east (called Jamuna River in Bangladesh) and part of the Ganges-Brahmaputra Basin. It produces thirty-five per cent of the nation's dry season rice and sixty per cent of wheat and maize[100].

Today Bangladesh is mostly food self-sufficient and one of the largest rice producers in the world

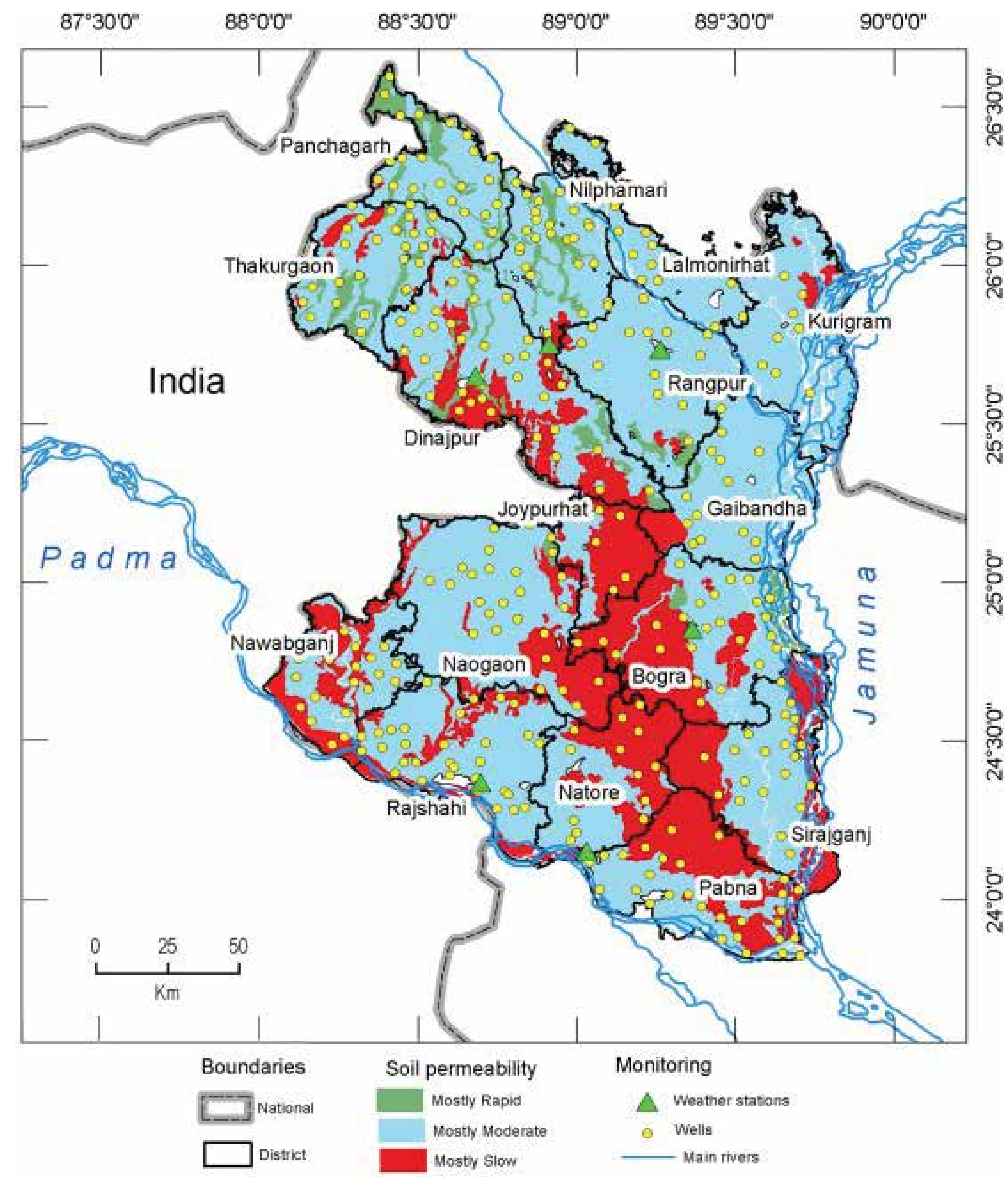
Challenges of declining surface water flow in rivers and groundwater table in recent times is a serious threat to the livelihoods of millions of farmers[101–102]. In severely dry years, many poor agricultural labourers seek to out-migrate from rural areas to bigger cities in search of better livelihoods options. Past mass internal out-migration of agricultural labourers from greater Rangpur region who did not get a job to survive during the *Monga* seasons[103] is well documented. Repeated episodes of such events can catalyse political unrest and social instability and their impact on rural livelihoods is a source of concern for Bangladesh. Here, we present a first-hand account of the irrigation trend and how it can sustain agricultural growth in the northwest region of Bangladesh.

Changing irrigation dynamics

Irrigation plays a crucial role in crop production in northwest Bangladesh. It scales down crop loss, allows multiple and high yielding variety cropping and reduces excessive dependence on rainfall. Both surface and groundwater were used for irrigation in the region. However, surface water availability in the major rivers of northwest Bangladesh started to decline three decades ago. Dey et al[104] reported that the yearly mean river water flow has reduced by about fifty per cent on an average in major regional rivers since 1980. The worst-hit districts are Dinajpur, Rangpur, Bogra and Rajshahi.

Shortage of surface water from rivers, ponds, and canals during the dry season forced the farmers to rely on groundwater to irrigate farmland, found within 4-8 meters below the ground surface, to cope with the intermittent surface water supply. The government

Figure 11. Geographic characteristics of northwest Bangladesh (Source: Peña-Arancibia et al. 2020)



of Bangladesh supported the farmers to adopt groundwater irrigation by lifting the restriction on irrigation pump standardization, allowing import and operation by the private sector and subsidizing farmers' energy consumption to lift groundwater. Strong institutional support was provided by several agencies including Bangladesh Agriculture Development Corporation and Barind Multipurpose Development Agency and large national projects like National Minor Irrigation Development Project under the Ministry of Agriculture. This has resulted in a drastic increase in the ratio of surface water and groundwater use for total irrigated agriculture in the last two decades. Today, about ninety-five percent of the irrigation water in northwest Bangladesh comes from groundwater[105]. Access to cheap groundwater has changed the cropping pattern markedly during the last decades in the region. Farmers grow more than two crops a year, with up to four crops in some areas. Peña-Arancibia et al[106] estimated a large increase in the area planted with Boro (dry season) rice (from 116,007 hectares to 1,598,105 hectares) and a large decrease in the area of the early wet season (Aus) rice (from 954,226 hectares to 225,190 hectares). Cultivation of Boro rice requires a higher amount of water and a longer period to irrigate compared to Aus crops and transition to Boro rice cultivation comes at the cost of substantially more irrigation. Additionally, farmers increasingly plant potatoes, wheat, maize, oilseeds and pulses during the dry season.

Unabated promotion and popularity of groundwater irrigation come at a price. The increasing extraction of groundwater for irrigation without any increase in rainfall has significantly lowered groundwater table of northwest Bangladesh especially in the districts of Rajshahi, Dinajpur, Bogra, Pabna and Rangpur. Rahman et al[107] observed that dry spells have become more frequent than ever before. The total annual rainfall over the region has been continuously reducing in the last three decades directly impacting aquifer recharge[108]. Farmers are not able to adequately irrigate their farmland due to increasing cost of lifting water from a deeper aquifer, and in some years even lack adequate drinking water during the dry season. Every year the groundwater table remains below the suction lift limit (6 meters) of the suction-mode pumps (e.g. shallow tube well) in sixty percent of the monitoring wells for about 3 to 6 dry season months[109]. Peña-Arancibia et al[110] analysed a large number of (over 1,200) groundwater monitoring well data collected by the Bangladesh Water Development Board and reported that during January 1980 to December 2015, groundwater table declined by 0.08 meters every year over the region. In three southern districts of Naogaon, Rajshahi and Nawabganj, the groundwater table fell by 0.2 meters every year. These findings are consistent with other researchers[111]. Another major reason for the lowering of the groundwater table is declining river flow in the major rivers. Though the surface water-ground water interaction is a complex process, water flows from the Jamuna River to the aquifer (rechange) are about five times higher than the water flows from aquifer to the river (discharge)[112]. The flow of the transboundary Teesta River is one of the major contributors to groundwater recharge in Dinajpur and Rangpur districts where predominantly silty clay soil has higher hydraulic conductivity[113]. River flow reduction in the major transboundary rivers of the Brahmaputra basin (Jamuna and Teesta Rivers) in Bangladesh will create more head difference for water to flow from the aquifer to the river thereby adding to the challenges to groundwater irrigation.

Sustainable irrigation management will require managing the two ostensibly distinct water sources as one

The falling groundwater table indicates large declines in groundwater storage over time and the northwest region lost about 3.74 km^3 of groundwater during 2003-2016[114]. Many planners and researchers fear that if groundwater extraction continues to increase in the future, it will push the groundwater levels down to such levels that it may not get replenished adequately and call to increase the use of surface water irrigation. Kirby et al[115] point out that excessive water withdrawal may cause a lower equilibrium level of groundwater aquifer and suggests local level studies to improve the sustainability of irrigation in the region.

Sustaining agricultural growth

Food self-sufficiency in northwest Bangladesh heavily relies on irrigation. Changing climatic condition such as reducing rainfall, increasing over-reliance on groundwater irrigation and reduction in transboundary river water flow pose serious challenges to planners and farmers alike. No single policy intervention and practice change will be adequate to face the challenge. Past water dynamics clearly highlight the importance of treating surface and groundwater as a hydrologically connected singular source of water and recognising that changes in either affect the other. Sustainable irrigation management will require managing the two ostensibly distinct water sources as one. The government will need to think about reducing irrigation demand through rationalizing less water demanding crops.

The Bangladesh Agriculture Policy[116], which called for the use of surface and groundwater to accelerate crop intensification and increase yield, is a move in the right direction. Efforts need to continue to accelerate and coordinate the activities of various agencies involved in surface and groundwater irrigation programmes and ensure river flows in the major rivers many of which are transboundary in nature. Markets need to be created for non-rice crops and agricultural extension services need to facilitate farmers' transition to less water demanding crops. Management approaches such as variable and/or crop-specific irrigation rates and efficient irrigation scheduling can play an important role in reducing demand. In an era of climatic extremes, planners and farmers will need to augment natural water supply through innovative technology as managed aquifer recharges. Transboundary water cooperation will play a crucial role to ensure waters in the rivers since many come across international boundaries from upstream.

Today, about ninety-five percent of the irrigation water in northwest Bangladesh comes from groundwater

TEA

Tibetan Tea

Xiawei Liao

TIBETANS DRINK butter tea every day. Butter tea is made by mixing butter that is made from yak or sheep milk with brick tea and salt. A typical Tibetan breakfast includes butter tea with *tsampa*, a Tibetan pancake made from highland barley flour. For Tibetans living a nomadic lifestyle with high-fat and low vegetable and low fruit diets, butter tea not only warms up the body against the coldness but also supplements the dietary fibers, helping to break down and digest the oil.

Butter tea not only warms up the body against the coldness but also supplements the dietary fibers. Yigong tea plantation is the highest tea plantation in the world

According to anecdotal evidence Tibetan monks started to grow tea trees between AD 220 to 280 but did not succeed due to the harsh climate. Modern tea plantations started in 1956 when the army based on Rima County planted 200 tea trees that survived and thrived. In 1971, Tibetan provincial agriculture and husbandry department imported 0.1 million kilograms of tea tree seeds from Sichuan, Yunnan and Hunan and sowed them in over 20 counties at altitude ranging from 1,570 to 3,700 meters above the sea level. Although most seeds did not survive the cold and harsh climate, tea plantations started to develop in several counties such as Chayu, Milin, Linzhi, Motuo and Bomi[117].

Currently, tea plantations[118] in Tibet are mainly located in the Yigong village of the Bomi county and Motuo county in the Nyingchi prefecture in the Southeastern part of the province. Yigong tea plantation is the highest tea plantation in the world. The plantation covers an area of 1.47 sqaure kilometers. In 2013, it produced 3,200 kilograms of Tibetan black tea, 3,600 kilograms of Nyingchi green tea, 900 kilograms of dark tea, 34,000 kilograms of brick tea and 3,000 kilograms of autumn tea. Since 2010, Motuo county has developed 13 highland organic tea plantations with a total area of 2.86 square kilometers. The main tea types are Fuding white tea, Ti kuan yin and pekoe.

From 1990 to 2017, the area of tea plantations in Tibet has increased from 149 to 790 hectares[119]. However, tea production in Tibet is not enough to support the population's tea consumption, therefore Tibet imports large amount of tea from other provinces in China, such as its neighboring Sichuan.

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Assam Tea

Pooja Kotoky

ASSAM IS the largest contiguous tea-growing area in the world[120]. Only those teas grown and manufactured in tea estates located in the Brahmaputra valley qualify to be called

Assam teas. Both Orthodox and CTC (Crush/Tear/Curl) varieties of tea are manufactured here. Assam Orthodox Tea is a registered Geographical Indication (GI). The distinctive second flush orthodox Assam teas are valued for their rich taste, bright liquors and are considered to be one of the choicest teas in the world. The Brahmaputra valley with its high rainfall, high humidity, and rich loamy soil provides the perfect environment for growing the tea that is most famous for its strong, smooth and malty taste. Half of India's tea production comes from Assam. The estimated annual average production of tea in Assam is about 630-700 million kilograms[121]. The Assam CTC tea auction centre is the world's largest, and the world's second largest in terms of total tea auctioned. The Tocklai Experimental Station, established in 1911, the world's oldest and largest research station of its kind, carries out clonal propagation and constant research in order to retain the flavours of Assam teas.

Assam is the largest contiguous tea-growing area in the world. The Assam CTC tea auction centre is the world's largest, and the world's second largest in terms of total tea auctioned

History of tea in Assam

The tea industry in Assam is about 172 years old. In 1823 Major Robert Bruce discovered wild tea plants growing in Assam with the help of a local noble man, Maniram Dutta Borua 'Dewan' in an adventure and trade trip to Upper Assam by boat. Maniram Dewan introduced Bruce to Singpho Chief Beesa who presented Bruce his first bowl of wild tea found in the Singpho village near Margherita in Upper Assam. Bruce made an agreement with the Chief to supply some plants and seeds. In the following year Singpho Chief kept his commitment by handing the plants and seeds to Major Robert Bruce's brother C.A. Bruce who visited Sadiya town. Later these were sent to Dr. N. Wallich, botanist to the East India Company and Superintendent of the Botanical Garden in Calcutta.

In 1834, Lord William Bentinck the Governor-General at that time, set up a tea committee to explore and discover new land for tea cultivation in India. The Tea Committee received communication and reports from Col. Jenkins, the then Commissioner of Assam that the tea plants found in Assam were of indigenous variety. The following year a scientific committee proceeded to Sadiya for research. They ascertained that the tea plants found in the North Bank of Brahmaputra were of indigenous kind and there was great similarity in the topography and the climatic conditions to that of the Chinese province of Yunnan, which was known for tea production.

C.A. Bruce travelled through the length of the Brahmaputra valley and along Buri Dihing river, and discovered wild tea grown in places such as Phakial, Tingri near Indo-Burma boarder. With his knowledge of languages and mannerism of the natives he became instrumental in establishing friendly relations with the hill tribes and their chiefs and transferred forests and waste lands from the tribals to the British Government. Bruce started plantations at Jaipur and Chabua with the local tribes and set up nurseries at Chota Tingrai and Hukanpuki to have large plantation drives by 1840.

In order to streamline business operations in Assam and import tea to London, in February of 1839 Bengal Tea Association was formed in Calcutta and a joint stock company – Assam Company was formed in London. Both the companies were amalgamated as the Assam Company within the year and became the first private owned tea company to operate in Assam. Initially the company made losses because of the high cost of production but started recovering and profiting from 1848. In March of 1841 the first auction sale of Assam tea manufactured by Singpho Chief Ningrula and the Government plantation took place in Calcutta. Sensing opportunities a number of private enterprises approached the Government in London and Calcutta to obtain tea plantations.

Currently, the tea plantation is the largest employer among the organized sector in Assam, employing about more than 6.86 lakh persons daily

The tea industry started to change after 1850s when George Williamson Senior and his cousins formed Williamson, Magor & Co in 1853 and started private plantations. They produced 21,000 kgs tea in 200 acres land in 1857. By 1859 there were 160 gardens, 57 were privately owned and rest by Assam Company, the Jorehaut Tea Company, The East India Company, the Lower Assam Tea Company and the Central Assam Tea Company.

Although the tea industry has gone through many ups and downs over the years in terms of financial stability, price fluctuations, changes in demand and supply, great improvements have also been made in the yield per acre, in the grouping of gardens under a limited number of companies, in the progressive mechanisation and rationalisation of production and in increasing their efficiency in regard to the productivity of labour[122]. Modernisation of factories and production techniques also took place. The Indian Tea Control Act,1933, was enacted and an International Tea Committee and Indian Tea Licensing Committee were instituted.

Present scenario

Currently, the tea plantation is the largest employer among the organized sector of the state, employing about more than 6.86 lakh persons daily[123]. Although an almost equal number of female and male employees work in these plantations, female labour is largely employed to pluck tea leaves, while male employees work in maintenance of estates (including pruning), factory work, pesticide application and weed removal. Women are often paid lower wages than men.

A sizable number of small farmers especially in upper Assam have taken up tea cultivation during the last 15 years. As per 2016[124] data, out of the total number of tea gardens, there were 84,577 small growers with a total area of 78,203 hectares under tea cultivation, and 767 big growers with a total area of 226,197 hectares under tea cultivation. Total tea produced in 2016 was 642,180 (000) kgs. As of 2017-18, 676,000 tons of tea leaves were produced in 312,000 hectares of land which accounted for 51.7 percent of the total national production of India.

The relative contribution of small growers to tea production is more than 20 percent[125] and the big gardens purchase a major part of the green leaf production of the small tea growers. Using clone varieties of tea seedlings on small holdings, these small and marginal farmers are dependent on their crop as the main source of income. Although these farmers are challenged by low farm gate prices, limited market channels, poor access to credit and low levels of farmer organization, the positive aspect of lower production costs is what keeps them going. Some small tea growers have ventured into organic tea cultivation[126].

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AGRICULTURE ON THE *CHARS*

Brahmaputra valley

Vasudha Pangare

Chars or riverine islands formed by the braiding of the Brahmaputra river, keep changing in shape and size due to the effect of floods and erosion

CHARS OR riverine islands formed by the braiding of the Brahmaputra river, keep changing in shape and size due to the effect of floods and erosion. Many of the *chars* remain stable long enough for vegetation to grow and for settlements to establish. Islands which are stable for a decade or more are generally utilized for growing horticulture and plantation crops, and islands which are relatively less stable are used for growing short duration seasonal crops such as vegetables. A majority of these *chars* remain fallow and unutilized. Even in the case of *chars* used for cultivation, agricultural land keeps changing during the entire crop cultivation season from sowing to harvesting.

The total area of vegetative *chars* has increased in the past three decades in the Brahmaputra Valley and approximately 146 thousand hectares area[127] of *char* lands have been stable for the past ten years. Two crops are cultivated during the non-flooding months from November to April on *chars* in the Lower Brahmaputra Valley. Crop cultivation is almost negligible compared to the large size of the islands, in the Upper Brahmaputra Valley, as the *chars* here are less stable. In the Central Brahmaputra Valley, seasonal migration of *char* dwellers occurs for crop cultivation; *char* dwellers do not have settlements here.

Jamuna Basin

Kshirode Roy

CHAR LANDS of Bangladesh have a good potential for increasing agricultural production. The country has about nine million hectares of total cropped land, which is decreasing at the rate of 0.73 percent per year due to housing, roads, industries and other infrastructure development. On the other hand, the total area of *chars* of four big rivers Padma, Meghna, Jamuna and Brahmaputra and their 500 branch-rivers and tributaries is about one million hectares, and is increasing every year. The Bangladesh government has given special emphasis on increasing agricultural production in *char* areas to reduce the vulnerability of disadvantaged people living there. *Chars* in Kurigram, Jamalpur, Gaibandha, Bogra and Sirajganj districts have a population of about 6.5 million people of whom 2 million are extremely poor. In general, Kurigram district is considered as the poorest district of the country.

Char dwellers largely depend on crop agriculture, fishing and livestock-rearing for their livelihoods. *Char* soils are predominantly loamy sand, loam and sandy loam. These are deficient in most of the plant nutrients, have very low organic matter content and minimum water holding capacity. Generally local crop varieties having very low yield potential are cultivated in these areas, therefore, the average yields are lower than the national average yield. However, high yielding variety seeds of *boro* rice, wheat, maize, vegetables and some other crops are grown by many farmers.

Char lands of Bangladesh have a good potential for increasing agricultural production. Char dwellers largely depend on crop agriculture, fishing and livestock-rearing for their livelihoods

The main crops grown in the *kharif I* season (mid-March to mid-July) are *aus* rice, jute and sesame. In the *kharif II* season (mid-July to mid-November) *aman* rice is grown and in the *rabi* season, *boro* rice, wheat, maize, mustard, chilli, onion, groundnut, potato, sweet potato and vegetables are grown. The irrigation facilities in *char* lands are very limited and used mostly for *boro* rice and to some extent for wheat and vegetables. Generally electric connection is not available in those areas; farmers have to use diesel engines for operating pumps. The price of diesel in *char* areas is higher than on the mainland. Therefore, the cost of irrigation and ultimately the production cost in *char* areas is higher than on the mainland.

Common vegetables grown in the *char* lands are pumpkin, cucumber, radish, brinjal, and pointed gourd. Farmers can make more profits from vegetables than from rice, jute or sesame. Therefore, more farmers produce vegetables. Many of the farmers of the major milk producing district of Sirajganj are currently producing Napier grass along with vegetables. They grow this quick-growing grass for sale as well as for using it as feed for their cattle for increasing milk production and for fattening.

Flooding is a common phenomenon from mid-June to September. Late sown *aus* rice and *aman* rice are mostly affected by floods. However, due to huge sedimentation and carbon influx, flooded soils remain fertile. When devastating flood occurs, houses of

First year of agriculture on a newly formed char

Agriculture being stabilized on the char during the second and third year

Fully developed agricultural fields on the char after 5 to 8 years most *char* dwellers are damaged. Farmers living there have to take temporary shelter on unsubmerged roads and even have to move to slums of towns and cities and return after the flood recedes. Some of them taking shelter in towns and cities do not return to the *chars* and find new ways of earning their livelihood.

Farmers of *char* areas do not usually practice modern agricultural technologies like mainland farmers. Modern technologies need costly inputs like high yielding variety seeds, fertilizers of both macro and micro-nutrients, and pesticides, all of which poor farmers of *char* areas cannot afford. As most farmers cannot mortgage lands, they cannot get loans from banks. Because of transport problems, price of seeds, fertilizers, pesticides, etc. are costlier than the mainland. Farmers make very little profit from selling their produce because the input costs are higher. Primary education, health and agriculture extension services and support to cope with natural calamities, like flood and soil erosion are minimal.

To increase crop production in *char* areas, government and nongovernment organizations have implemented many programmes to increase annual incomes and improve the livelihood of farmers. These programmes include activities such as demonstration of modern agricultural technologies, training of farmers on improved crop production, primary education, health care, improvement of infrastructure, activities for the empowerment of women, all of which contribute directly and indirectly to agricultural and livelihood improvement. In recent years, research institutes have implemented many programmes to introduce high yielding varieties in *char* areas through on-farm demonstrations. Depending on agro-ecological zones, different technologies have proved appropriate in different *chars*, many of which have been adopted by farmers and increased crop production. For example, a farmer of the Brahmaputra Char has spent Tk 18,000 (approximately USD 212) on an average for cultivating pumpkin on 200 raised sandbars and sold them at Tk 42,000 (approximately USD 495.5). He made a net profit of Tk 24,000 (approximately USD 283) in one cropping season.

Hand percussion (sludger) or hand drilled shallow tube-wells are a common source of groundwater on the chars of Bangladesh

Many NGOs and international organizations have implemented programmes to support women's participation in agriculture development and have ascertained that women have increased their access to new knowledge on modern agriculture. Women who participated in these programmes are able to produce better quality products, maintain better quality seed through better storage facilities and have access to product marketing. As these women have increased monetary contribution in the family, they are able to provide better food and clothing to their children and invest in their education and health care. In general, the average benefit cost ratio of crop farming with GO-NGO supported programmes is more than that of un-supported programmes.

As an outcome of various programmes, agricultural production has increased, and livelihood has improved for *char* dwellers. These can further be improved if transportation and communication facilities are improved, government social safety net programmes are enhanced and compulsory primary education programmes for boys and girls are implemented.

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Hand-dug tube-wells

Md Hossain

HAND PERCUSSION (sludger) or hand drilled shallow tube-wells are common sources of drawing groundwater on the chars of Bangladesh. This technology can tap groundwater from a depth up to 7 meters below the surface and can be used effectively in soft sub-surface sediments comprising mostly of sand and clay.

Women who participated in these programmes are able to produce better quality products, maintain better quality seed through better storage facilities

A drilling derrick is constructed with local bamboos. The main crew continues the hand-chopping on the boring pipe, while other crews exert pressure on the boring pipe by means of a hand-driven lever, made of bamboos and/or pipes. A small pit is made near the derrick in which locally available clay and water is mixed to make drilling mud. Conventionally drillers used cow-dung, which is being strongly discouraged due to its impact on water quality. A steel pipe is used for the uppermost 2 meters section, on the top of which the hand pump is installed and the remaining portion consists of PVC pipe.

The diameter of the tube is most commonly 0.4 meters (1.5 inch). Number 6 Hand Tubewell, a lever operated suction pump, is generally used. Once the tube-well is installed, continuous pumping is done for a reasonable time so that the well becomes free from drilling mud. The cost of installation of a shallow tube-well of 100 meters depth, could be around 20 thousand Bangladesh Taka (approximately 250 USD).

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5. PEOPLE

One river, many cultures

Ganesh Pangare

Sanjoy Hazarika

Farzana Begum

Marc Foggin

Runa Khan

Pooja Kotoky

Ambuj Thakur

Manjil Hazarika

Gorky Chakraborty

Sushmita Mandal

Preetee Sharma

Yulha Lhawa

Xiawei Liao

Paresh Borah

Bushra Nishat

THE YARLUNG Tsangpo-Siang-Brahmaputra-Jamuna River is one river system that acquires various names along its journey, transcending three countries and three major faiths, and assimilating many local customs and practices along its flow. The banks of this majestic river have been dotted with settlements since time immemorial and many an ancient civilisation has flourished in its basin. The river has impacted and shaped the lives of people living on its banks, carrying with it numerous untold and re-told myths, stories that have shaped and continue to shape various customs and traditions as well as progress and development. As Sanjoy Hazarika says, this river system encompasses "Asia in Miniature". While the geography and fractured frontiers of the basins and sub-basins of the river system are fascinating in themselves, it is the population that holds even more interest: the cultural diversity and shared history. Straddling the ages and the mountains, the people of this winding trail form an anthropological bridge between South and Southeast Asia.

YARLUNG TSANGPO BASIN

Tibetan Nomadic Pastoralists

Marc Foggin

Straddling the ages and the mountains, the people of this winding trail form an anthropological bridge between South and Southeast Asia

THE TIBETAN PLATEAU constitutes the world's largest and highest mountain region, covering nearly a quarter of China's land area. At over 2.5 million square kilometers and averaging around 4,500 meters above sea level, it is mostly inhospitable for crop cultivation. Over vast areas of the plateau, therefore, only nomadic pastoralism can be practiced, a livelihood that is contingent on substantial flexibility and adaptability by herders to respond to harsh, often changing, and generally unpredictable climatic conditions. The environmental situation also has traditionally necessitated seasonal mobility to ensure survival of domestic livestock and their herders with the very limited productivity of the grasslands during the short annual productive growing periods.

From recent archaeological research, it appears that hunter-gatherers lived permanently in the cold-harsh environment of the Tibetan plateau from at least 8,500 to 7,400 years ago, and possibly as early as 12,700 years ago[1]. Some ecological studies suggest an anthropogenic creation of pastoral landscapes by early livestock holders, by removing trees to create or promote pasture lands, may have begun as early as 8,800 before present (BP), during the mid-Holocene climatic optimum[2]. Others, however, suggest that such human-modified environments appeared only later, c. 5,900 BP[3]. Genetic data on early domestication of yak also provide estimates ranging from c. 10,000 BP[4] to c. 5,000 BP[5].

Whatever the exact timeframe of the arrival of the first hunter-gatherers and pastoralists in the highlands, as d'Alpoim Guedes and Aldenderfer[6] point out, it is clear that when farmers first arrived from surrounding lowlands to the margins of the plateau, possibly as early as 10,000 BP, even as they brought new crops and new agricultural technologies, "they did not move into a void but rather a land that was full of other people." Beyond livestock and their many milk products, the most common staple food that is eaten by both farmers and pastoralists is barley, which was most likely introduced into southern Tibet between 4,500 and 3,500 BP[7]. Roasted barley flour or *tsampa* has always been a convenience food – versatile, long-lasting, portable – and thus a predominant part of people's fundamental diet. As such, *tsampa* may even be recognized as a core element in Tibetan identities[8].

Livestock on the Tibetan plateau include sheep, goats, yak, and horses. But amongst these, the yak epitomizes best Tibetan pastoralism, as life on the plateau would

Marc Foggin

simply not be possible without it. In many ways, the yak is to Tibetan pastoralists what fields of barley and other crops are to Tibetan farmers – or, as Robert Ekvall[9] aptly wrote in regard to livestock kept by Tibetan *drokpa*, or "high-pasture people":

> *Many dwellers of the Tibetan plateau… develop and tend other fields, not of the soil, but better adapted to the harsh ecology of that bleak land… livestock, which are the ample base of a vastly different economy… Within the production cycle of a subsistence economy, "fields on the hoof" occupy the place in nomadic pastoralism that soil fields occupy in sedentary agriculture… It is the care of these livestock which makes nearly half of the Tibetan people "pastoralists"; and because what they own, tend, and harvest is on the hoof [i.e., livestock] in wide pastures that require much movement, they are also "nomadic."*

Horses also play a very important role in Tibetan pastoral areas, even though smaller in economic impact, with horsemanship being a highly regarded skill and much praised especially through horse races and other contests at annual festivals, testing both horsemen and horses' performances to the maximum[10].

Globally, rangelands occupy about 40 percent of the earth's total land surface. For its part, the high Tibetan steppe extends around 3,000 kilometers from east to west and 1,500 kilometers from south to north. With a strong continental climate and very high elevations, this ecoregion also comprises the headwaters of many major Asia rivers, including the mighty Yarlung Tsangpo, better known downstream as the Brahmaputra River[11]. In the highlands, the Yarlung Tsangpo flows through both agro-pastoral and crop-based livestock production systems, with the former most prominent in the higher altitudes of the western region, also recognized as the cool semi-dry agropastoral ecological zone[12].

The yak epitomizes best Tibetan pastoralism, as life on the plateau would simply not be possible without it

Traditionally, at least until a few decades ago, there were three main groups of people present in the Tibetan rangelands: hunters, nomadic pastoralists, and crop farmers. The latter two groups have always maintained particularly close ties, to mutual benefit, exchanging meat and other livestock products for barley in autumn, in order to sustain themselves through the long winters. Tibetan hunters, on the other hand, always have depended on wildlife, often migratory, and therefore had to move seasonally according to natural patterns[13]. Large populations of wildlife were decimated, though, especially from the 1950s through to the end of the 1970s, and now wildlife populations persist only in substantially lower numbers. Fortunately, with improved legislation as well as greater public awareness about conservation and the development of a regional network of protected areas, much Tibetan wildlife is now recovering, hunting as a livelihood is now gone, with most former hunters now practicing pastoralism, raising livestock in combination with a range of other socio-economic activities.

Overall, Tibetan pastoralists today are less 'nomadic' than they once were, due largely to recent government policies that have encouraged varying levels of sedentarisation along with relocation and urbanization of herders and intensification of production systems, sometimes leading to fairly challenging scenarios of *nomads without pastures*[14]. Such rapid changes also have given rise to some concerns over people's sense of identity[15], which has been demonstrated, for example, amongst many First Nations in Canada to be highly and consistently correlated with people's sense of wellbeing and hope for the future[16]. At the same time, encouraging developments also are arising in China, such as with large-scale conservation endeavours including the creation of a new national park system[17] in which more participatory and inclusive approaches are now being trialled and progressively adopted, particularly through a model of community co-management in China's newest protected areas[18].

Today, for those who identify with being *drokpa* – i.e., Tibetan nomadic pastoralists, the high-pasture people – whether or not they still engage exclusively in livestock herding, or engage in herding at all, is beside the point. In either case, their sense of identity broadly remains closely tied to the grassland where they grew up, to their yak and other livestock, to their long and rich cultural heritage as well as the surrounding natural heritage – a land in which the wildlife is and always has been, in their words, the "jewels of the land".

Building and strengthening partnerships that include traditional knowledge of the long-standing custodians of the land, will support the collective interest of all stakeholders

With new and rapidly changing circumstances largely brought about through increased connectivity, or globalisation, with a virtual shrinking of the world, two responses are needed: first, a major re-thinking about whether or not food systems and people's livelihoods should even be subject to the criterion of specialisation-for-efficiency[19], considering the many non-monetary values of yak, grasslands, and pastoralist livelihoods; and secondly, in the interim, novel approaches must also be found whereby sustainable development may be promoted, with equity, across economic sectors and all the varied segments of the population. Toward this end, different models of rural development are being explored, ranging from the development of community cooperatives, associations, and social enterprises to value-add projects centred on wool processing and handicrafts, to individuals' pursuit of higher education for achieving personal dreams for business, art, research, civil service, etc. Through the latter, it should be possible in the future for more local perspectives, for the voices of the high-pasture people, to be more resonantly heard, adequately considered, and integrated into planning and action for a more sustainable future for all.

As outlined by UN Food & Agriculture Organization already many years ago, but still very relevant today[20], there are many profound changes taking place in the Tibetan plateau region, with both negative and positive impacts on the fate of the grazing lands and on everyone who depends on them. These changes include major infrastructure developments and market reorientations within pastoral systems, policies to settle pastoralists and reduce their traditional mobility, significant expansion of protected areas, promotion of crop production where previously good pastoral land was used by herders, and, not least, climate change with alterations in precipitation and temperature and increasingly frequent natural disasters (such as snowstorms and drought). Building and strengthening the right partnerships to address these issues, inclusive of local and traditional knowledge and of the long-standing custodians of the land, will support the collective interest of all stakeholders affected by the state of the environment on the Tibetan plateau – from the local pastoral communities, living in the remote, high-altitude Yarlung Tsangpo headwaters, to the herders, farmers, forest dwellers and town dwellers living far downstream.

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Linguistic Diversity on the Tibetan Plateau

Yulha Lhawa

ASIA IS the most linguistically diverse continent in the world and is home to almost a third of global language hotspots, clusters of endangered languages in small geographic regions. Thus, the region carries a significant weight of global linguistic diversity. A common misconception, in both popular and academic representations, is that Tibet is a monolingual region. However, a growing body of research attests that Tibet is linguistically diverse[21]. This aligns with both global and national patterns of linguistic diversity in low latitudes and rugged terrains with high biodiversity like the Tibetan Plateau, especially in the eastern part.

Minority languages on the Tibetan Plateau are languages that are linguistically distinctive from Tibetic or Sinitic (Chinese) languages. These minority languages are often unrecognized by the state and within Tibetan communities, under the assumption of a one-to-one relationship between language and ethnicity. The persistent emphasis on learning written Tibetan is also another major reason why there is little room for Tibetan minoritized languages within Tibetan communities and Tibetan literature even.

Asia is the most linguistically diverse continent in the world and is home to almost a third of global language hotspots, clusters of endangered languages in small geographic regions

Approximately 230,000 of the 6.2 million Tibetans in China speak one of these minority languages other than the three acknowledged tongues: Amdo, Kham and U'tsang. In 2018, Roche and Suzuki[22] identified up to sixty minority languages spoken both by Tibetans and other ethnic groups. In 2019, Suzuki and Tashi Nyima[23] identified four additional languages, so the latest estimate is sixty-four languages in total. There is a common saying across Tibet that every valley has its own tongue, which hardly seems like an exaggeration.

These minority languages are spoken by small populations and are only transmitted to the next generations orally. Many are endangered based on the UNESCO 9-factor framework for language vitality, mostly due to pressures coming from both increasing integration into the modern Chinese state and standardization of Tibetan language and culture. People are traditionally farmers and nomads, and these minority languages are only spoken in these villages with no media or school usage.

Standard Tibetan is the prestige language in Tibetan society. Social attitudes regarding Tibet's minority languages also typically undermine their vitality. Tibetans are known to use pejorative terms to refer to the minority languages of Tibet. These include the Tibetan terms *'dre skad* 'ghost language' and *log skad* 'backwards language', and the Chinese term *niaoyu* 'bird language'. These languages are identified with ethnicity; and in general, speakers of minority languages tend to have a negative attitude towards their own languages. In recent years, there has been a wave of interest in learning written Tibetan among many minority language speaking communities.

The number of identified minority languages might expand as more and more research is being carried out in less-investigated geographical areas. Regardless of how many languages are spoken in Tibet, it is certain that there will be fewer languages in 50 years' time if we do not actively preserve them. Recognizing and describing the region's minority languages is an essential step towards preservation of individual languages and providing data for further research and revitalization work. If this is done well, we might be able to avoid a fate which seems to await most of Asia, the world's most linguistically diverse continent.

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Yak: the treasure of the highland[24]

Xiawei Liao

THE YAK is a unique cattle species that lives in the high mountain grasslands of the Himalayas and the Qinghai-Tibetan Plateau, at altitudes between 3,000 to 5,000 meters. These mammals live at the highest altitudes in the world and can withstand severe cold temperatures of minus 30 degrees to minus 40 degrees centigrade.

The wild yak is a protected animal in China. There are more than 14 million yaks in the world, 90 percent of which are distributed in the high and cold regions of China's Qinghai-Tibetan Plateau at an altitude higher than 3,000 meters. Among them, 3.9 million yaks are found in Tibet, accounting for 30 percent of the total and ranking second only after the Qinghai province of China, which is home to 4.9 million yaks.

Yaks can adapt to the ecological environment of high altitudes, low atmospheric pressure and low oxygen content. The length and thickness of their fur vary with the seasons. In the cold season, yaks have thick hair under their chest to protect the chest, internal abdominal organs, external reproductive organs, breasts and joints from freezing. They also have small skin surface areas and extremely underdeveloped sweat glands to prevent from losing heat. Yaks have wide mouth and flexible lips so that they can eat the short grasses. On average, one yak can eat 26 to 30 kilograms of fresh grass per day.

Three types of yaks are found in Tibet: alpine yaks, Pali yaks and Sibu yaks. Tibetan alpine yaks are of two types: mountain yaks and grassland yaks. Alpine yaks are mostly black and are similar to wild yaks. The famous Jiali yaks are a type of alpine yak that live in the Jiali County in the Nagqu Prefecture. Pali yaks live in the alpine meadow grassland, subalpine (inter-forest) grassland, swamp meadow grassland and mountain shrub grassland in the Pali Town of the Shigatse prefecture. Pali yaks are mainly black, and a few are pure white.

Yaks can adapt to the ecological environment of high altitudes, low atmospheric pressure and low oxygen content

They usually have a wide head, flat forehead, and a slightly concave face, with round eyes, thin noses and large ears. The distance between the two horns of Pali yaks is large, which is one of the main characteristics of Pali yaks. Sibu Yaks are located in the Lhasa River Basin, close to the Shannan prefecture in the south in a transition zone from agriculture to animal husbandry. Sibu yaks graze all year around in the Sibu Valley, at an altitude of 3,789 to 4,200 meters.

Livestock on the Tibetan plateau include sheep, goats, yak, and horses. But amongst these, the yak epitomizes Tibetan pastoralism, as life on the plateau would simply not be possible without it. Yaks are one of the most important domestic animals in most of the pastoral area on the Tibetan plateau. Nomads place so much value on the yak that many refer to them as 'nor', which also means 'precious gem' or, more generally, 'wealth'. The yak, in many ways, defines nomadic pastoralism across most of the plateau. Yaks provide milk and milk products, meat, hair, wool and hides. They are also used as draught animals and for riding. Yak dung is an important source of fuel in an area where firewood is not available. The yak makes life possible for people in one of the world's harshest environments. There is little doubt that the presence of wild yaks, and their later domestication, was the single most important factor in the adaptation of civilization on the Tibetan plateau.[25]

BRAHMAPUTRA BASIN

Asia in Miniature

Sanjoy Hazarika

THE STRETCH of the Far Eastern Himalaya from Sikkim, India, eastward is significantly different from the rest of the mountain range. The reach of the Ganga plains, of Hindu ethos and historical Moslem influence, is much more muted here. If anything, many of the animistic hill tribes have gone the other way by embracing Christianity. Unlike the cultures of the faraway flatlands, these eastern communities are more directly linked to the Tibetans of the north, or the Indo-Chinese of the south and east.

The region is also unique in its geography. Although part of the same Himalayan range, these southern latitudes nurture a lush tropical landscape drenched by one of the highest precipitation rates in the world—strikingly different from the high desert of Ladakh or the dry terraces of west Nepal. The High Himalaya itself is lower at these extremities; with the peaks descending eastward from Mount Everest (8,848 meters) in the Khumbu, to Kanchenjunga (8,598 meters) at the Nepal-Sikkim border, to Namcha Barwa (7,756 meters), standing guard as the great bend of the Tsangpo. About here, the Himalaya breaks southward into Burma and dwindles away eastward into hills of the Hengduan mountains of Sichuan-Yunnan.

While the geography and fractured frontiers of this region are fascinating in themselves, it is the population that holds even more interest: the cultural diversity and shared history

The western part of the Himalayan range is neatly packaged into a progression of states from Pakistan to Nepal to Bhutan. But here in the east the range becomes a geopolitical jigsaw, crossing national frontiers with impunity. The rectangle of the Far Eastern Himalaya is broken up among five nation states, little Bhutan, the Northeast of India, the Chittagong Hill Tracts of Bangladesh, the Arakan region of northern Burma, the southeastern tip of Tibet and the hills of Yunnan. While the geography and fractured frontiers of this region are fascinating in themselves, it is the population that holds even more interest: the cultural diversity and shared history.

The babel of languages heard along this Himalayan flow includes the guttural Tibetan and its offspring Dzongkha, the sweeter Assamese in the Brahmaputra valley, and the lilt of Tibeto-Burman tongues in the hills of Nagaland, Manipur and Mizoram. This region is Asia in miniature, a place where the brown and yellow races meet. Taking a south-north transect, for example, you encounter the Bengali migrants in Assam, Tibeto-Burmans in the Himalayan mid-hills, and the Khampa of the high plateau. Going west to east, the spectrum is even more diverse from the people of Tibetan stock, the Bhutia and Lepcha of Sikkim and the Ngalong Dzongkha-speaking people next door in Bhutan, the population takes on Tibeto-Burman hues with the Sarchop

of eastern Bhutan. Eastward, the communities become progressively less ´Tibetan´ and more ´Burman´. The variety is outstanding.

Straddling the ages and the mountains, the people of this winding trail form an anthropological bridge to Southeast Asia, where the roots of many still lie. The Khasi of Meghalaya are believed to have come from Kampuchea and still speak a form of Mon-Khmer, although because of British missionary influence they use the English alphabet. The Thai Ahom migrated from Thailand to Assam 600 years ago and settled in a land they reported was as valuable as gold.

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Archaeology and prehistory

Manjil Hazarika

WHO WERE the first inhabitants of the Brahmaputra basin? When did they start living in the basin? From where did they arrive in the valley? How did they start cultivating rice in the valley? Who built the brick and stone temples, stupas, sculptures, ramparts seen in the valley? How did the cultural development and assimilation take place? These are some questions that boggle our mind when we think of the history of the people residing in the extensive fluvial landscape of the Brahmaputra basin with so much of ethnic, linguistic and cultural diversities. To seek the answers, one may look into the archaeological remains spread across the river basin and its tributaries and the associated historical events.

Manjil Hazarika

Rock cut votive stupas at Sri Surya Pahar Archaeological Site in Goalpara

India is often considered as a major crossroad of movements of prehistoric ancestors from Africa, the cradle of humankind, to the Far East. While discussing the dispersal routes of these early humans through South Asia, the Brahmaputra basin and its surrounding hill tracks is considered as a narrow strategic corridor between the gigantic high Himalaya in the north and Bay of Bengal and the Indian Ocean in the south. However, it may be noted that the sub-recent alluvial deposits

Manjil Hazarika

A fine rock-cut sculpture of Bhogasanamurti of Vishnu on the bank of the river Brahmaputra in Manikarneswar in North Guwahati

of the Brahmaputra valley may not give fruitful results for such an antiquity of around 2 million years before present. Vigorous sedimentation might have covered earlier deposits bearing artefacts and fossils or been washed away, if there ever were any. The fluvial activities of over-flooding and changes in the course of the river Brahmaputra and its tributaries have also affected many of the ancient and early medieval archaeological sites in the region. Moreover, frequent earthquakes have brought down majority of the structures and temple complexes built during the ancient and medieval period.

For understanding the earliest remains of human habitation in the Brahmaputra valley, one needs to look at the surrounding hilly areas which has produced some important prehistoric sites. Many Stone Age sites dating back to the Palaeolithic hunter-gatherer period have been recorded from the uplands of Garo-Khasi-Jaintia Hills, Naga Hills, Manipur and Tripura. Many of these stone artifacts have been equated with the Hoabinhian or similar industries of Southeast Asia that fall within the Late Pleistocene/Early Holocene geological period. Hoabinhian is a technological tradition of prehistoric hunter-gatherers-fishers that existed approximately during the last 43,000 to 7,000 years before present in a broad region from southern China, northern Vietnam, Malaya, Thailand, Laos, Cambodia, Sumatra, Taiwan and northeast India.

The next important phase is the Neolithic period starting at around 4,500 years before present. During this phase the inhabitants of the Brahmaputra basin and the surrounding hilly tracts started making polished and chipped stone axes, adzes and other utilitarian tools, handmade pottery of either plain or cord-impressed varieties. They settled in the foothills and uplands, exploited the aquatic natural resources and forest products and cultivated food crops like rice in the uplands as well as in the nearby marshy areas. This coincides with the advent of the various

Austro-Asiatic and Tibeto-Burman language speaking groups from neighbouring Southeast, East and South Asian regions. These assumptions are based on available archaeological, historical, linguistic and human genetic data. Slowly they expanded in population size and intensified the agricultural activities in certain fringe areas of the valley. They used large stones to erect burials in memory of the deceased and for commemorating certain events and demarcating boundaries. This tradition known as megalithic has persisted until today among various ethnic communities. Iron was a precious metal smelted by the late Neolithic communities.

Chieftain groups based on ethno-linguistic and cultural background emerged, slowly leading to the formation of petite kingdoms occupying the hills. Exchange of ideas, development of trade and commerce among them and arrival of newer groups of people from the Gangetic valley in the last part of the first millennium BC led to the rise of smaller principalities in the Brahmaputra basin and its tributaries.

Intermittent trade between India and China through the valley and surrounding areas provided a base for these earliest state formations. The Brahmaputra river system acted as a thoroughfare for the hinterland trade networks. The lower reaches of the Brahmaputra which joins the Padma (Ganga) in Bangladesh, is another important cultural zone of ancient Bengal where Buddhism flourished in the early centuries of the Common Era.

Areas like Goalpara in the confluence of Krishnai-Dudhnoi-Brahmaputra Rivers, the regions in and around Guwahati popularly known as ancient Pragjyotishapur, Dhansiri-Doiyang valley were some of the key areas of historical development since the beginning of the early centuries of first millennium AD. Mention may be made of the site of Sri Surya Pahar in Goalpara having evidence of three Indian religious sects of Buddhism, Jainism and Hinduism, which is often equated with Ellora of Maharashtra. Excavation at the site of Ambari in the heart of Guwahati city yielded evidence of cultural materials dating back to the Sunga-Kushana period. The Varmans of ancient Pragjyotishpura-Kamarupa had close ties with the Guptas ruling in a large part of north, central and east India. With a more organised way of administration, trade, cultural exchange reflected in the inscriptions, coins, pottery, stone sculptures, brick and stone structures, most areas of the lower and middle Brahmaputra valley were brought under a more homogenised cultural and political structure during the nineth to twelfth centuries AD under the Pala dynasty.

The Brahmaputra river system acted as a thoroughfare for the hinterland trade networks. The lower reaches of the Brahmaputra is another important cultural zone of ancient Bengal where Buddhism flourished

The Tai-Ahoms entered the upper Brahmaputra valley in the beginning of the thirteenth century from the kingdom of Pong in the upper Irrawaddy basin, a polity that straddled a part of upper Burma and the adjacent portion of the Chinese province of Yunnan. It gave rise to the Ahom kingdom, assimilating many of the petite kingdoms in the area. The six hundred years of their long rule witnessed a well-organised political and administrative structure supported by systematic agricultural practices, construction of roads, ramparts, forts, besides secular and religious monuments, and giant burial mounds known as the *Moidams*, mostly in the upper and middle Brahmaputra valley. The *chowkis* (military check posts) along the courses of the rivers and the battles of Saraighat near Guwahati fought by the Ahoms against the invading forces are testimonies of their naval warfare. Similarly, the Koch kingdom flourished in the lower part of the valley and shaped the cultural sphere of western Assam. Another notable feature of the medieval period is the rise of the Vaishnavite sect propounded by Saint Srimanta Sankardeva and his disciples. The *Satras* (monasteries), *Naamghars* and *Kirtanghars* (prayer halls) spread through the entire length and breadth of the valley, including the famous island of Majuli in the middle of the Brahmaputra are some important contributions of the Vaishnavite movement.

Throughout the history, the people living in the plains of the Brahmaputra and the surrounding hill tracts had close cultural and societal ties. This is easily observed in their customs, tradition, folklores, culture and mode of subsistence. This symbiotic

cultural milieu in a strategic geo-political setting covering a wider area of undivided Assam has shaped the cultural identity of the Brahmaputra basin. Influences of topography, environment and ecology are well reflected in the cultural traits among the people inhabiting the Brahmaputra basin in the past as well as in the present.

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Ancient fluvial trade route

Preetee Sharma

THE HISTORICAL period begins in the Brahmaputra valley from the mid-fourth century Common Era (CE) onwards. We do get a lot of references about the *Kamarupa-Pragjyotisha* or ancient Assam region in literature such as the Ramayana, Mahabharata, Kalika Purana and so on. These literatures mostly talk about the mythical king *Naraka*, the first king of *Pragjyotisha*, in great detail. But historically this information could not be verified with any other reliable sources such as inscriptions. The first three historical dynasties of the region of Brahmaputra Valley are the Bhauma-Varmana (mid-fourth to mid-seventh century CE), Salastambha (mid-seventh to tenth century CE) and the Palas of Kamarupa (tenth to thirteenth century CE) as reflected in the epigraphic sources.

The river played a very significant role in binding the entire length of the valley by providing ease of economic transactions and transportation which in turn led to homogenisation of culture

This period in the history of the valley from fourth till the first quarter of the thirteenth century CE is also referred to as the Pre-Ahom period, which as a term was popularised by historian Nayanjot Lahiri through her work "Pre-Ahom Assam" published in 1991. In the region of the Brahmaputra valley, the coming of the Ahoms into the valley in 1226 CE from beyond the Patkai range is considered a major break in the historical processes of the region. Historians also consider the coming of the Ahoms as the beginning of the medieval era in the region, just like in the Indian subcontinent the coming of the Sultanate rulers is the marker of medieval times. Historians also intermittently use terms such as Ancient Assam and Early Assam to refer to this period where the latter term is the most popular one.

In the historical processes of the valley the river Brahmaputra played a central role which is reflected in the way most archaeological sites of importance are located in the fluvial zone. Sites such as Ambari at Guwahati, Suryapahar at Goalpara have yielded very rich cultural metrial reflecting the larger connections within the Brahmaputra valley and also beyond. In fact, at Ambari a substantial amount of turquoise glazed potsherds, whose origin is traced to the Arab domain, have been found which shows Ambari was connected to the Indo-Arab trade network of the early medieval times. Also, at Ambari the discovery of Chinese Celadon potsherds shows the region's connection with China in the early medieval period. And most of these networks and connections seem to have been maintained through the fluvial

route of Brahmaputra as it was the most convenient and faster transportation route. A very significant historical source for studying about Early Assam are the epigraphic sources. A total of 32 inscriptions have been found in the region belonging to this period. Most of these inscriptions are records of land grants made by the kings of the three dynasties. Thus, these inscriptions provide a lot of information about places where villages were settled; information about the social groups and the hierarchies within; religious preferences; and crucial insight into the economic life of the Brahmaputra Valley in the Pre-Ahom times. In an eleventh century CE land grant we find the mention of different categories of boatmen: namely *Candenauki, Daksinapatinauki* and *Sadhavanauki*. The emphasis on segregating the boatmen plying on the *Lauhitya* or Brahmaputra on the basis of the area of operation or distance covered or goods transported by the boats within these historical records shows the crucial role played by the river Brahmaputra. The river played a very significant role in binding the entire length of the valley by providing ease of economic transactions and transportation which in turn led to homogenisation of culture and other social practices in the historical times.

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Tai-Ahoms of Assam

Ambuj Thakur

THE TAI-AHOMS of Assam are a branch of the great Dai race of Southeast Asia that came from Mung-mao, the present-day Ruili area in Southwest China's Yunnan province, in the early part of the Thirteenth Century CE. According to the *Deodhai Asam Buranji* (the Ahom Chronicles) their leader, Chao-lung Siukapha (1189

– 1268 CE) through his grit and determination, rallied his 9,000 camp followers and 300 war horses to establish a powerful kingdom on the verdant plains of the Brahmaputra valley in Upper Assam after subjugating the various local kingdoms including the Chutiyas, Barahis, and Marans. Interestingly, Chao-lung Siukapha entered this valley through the Tipam area, bound on the one side by the Patkai Hills, and the Buri Dihing River, on the other. True to their traditions of being valley people settled beside water courses, Siukapha also tested his luck along the courses of both the Brahmaputra and its major tributaries like the Buri Dihing and

the Dikhou, to establish his foothold in the 'Land of Golden Gardens' or *Mung-Dun-Chun-Kham*. The capital was finally chosen near Simaluguri, adjacent to the Naga Hills, and named Che-Rai-Doi or Charaideo, meaning the 'City of the Sacred Hill'. Ever since then, it became the royal burial ground with almost all of Siukapha's descendants interred in mounds, called the *Maidams*, akin to the Pyramids of Egypt, but rarely explored until now.

Assam, or ancient Kamarupa, has a glorious history since the days of the Bhauma-Naraka dynasty finding mention even in the epic Mahabharata. It reached its apogee during the days of Kumara Bhaskaravarman, a contemporary of Harshavardhana of Kannauj, when the Chinese traveller Hieuen-Tsang visited the capital city

Pragjyotishpura, or City of Eastern Lights, in the Seventh Century CE. But it was under the stable leadership of the nearly six-hundred year old Ahom rule that it emerged as a cohesive socio-political and cultural unit. In the period from 1228 to 1826 CE, the Brahmaputra valley witnessed an immense churning within, withstanding and adapting to numerous external stimuli, which gave shape to the greater Assamese identity. Siukapha and his successors, managed to do what few dynasties have seldom achieved in history, being conquerors, they assimilated their customs and traditions with the local populace thereby blending into a unique synthesis of ideas and emotions.

One of the major achievements of the Ahoms lay in building up a durable economy under the rubric of the *Paik* system, which was a system of corvee labour and had parallels in Southeast Asia like the *Prai* system in Thailand, amongst others. In a non-monetised economy, human labour was invaluable and this system catered well in administering the country. First reorganised during the reign of Siusengpha or Pratap Singha (1603 to 1641 CE), by the astute Momai Tamuli Barbarua, father of the famous general Lachit Barphukan, it followed the decimal system in organising the officers of state administration. Each individual was considered a *paik* and four of them formed a *got*. Land was state-owned and these *paiks* were assigned fallow land to cultivate in lieu of paying a part of the produce as tax. They also had to render services to the state and the royalty in various forms such as military service, construction works, royal household duties.

Another important innovation of the Ahoms was the introduction of wet-rice cultivation in Assam. The very reference of Mung-Dun-Chun-Kham alludes to their instant likeness for the golden paddy and oilseed fields of the Brahmaputra valley

Both Shihabuddin Talish, the Mughal chronicler (*Tarik-i-Asham*) accompanying his master Mir Jumla, and later Aurangzeb's general Ram Singh have attested to the dexterity of this system and sang paeans to the fastidiousness of the people of Assam for the love of their motherland, in their accounts in the mid-seventeenth century CE respectively. Later on, the system saw further modifications during the reign of Siurempha or Rajeswar Singha (1751 to 1769 CE), when the numbers of the *got* were reduced to three. The various officers commanding the *paiks* were the *Bora* (20 men), *Saikia* (100 men), *Hazarika* (1,000 men), and *Phukan* (6,000 men). The commanders-in-chief of Upper Assam and Lower Assam, the *Barbarua* and the *Barphukan* had 12,000 *paiks* with them. However, due to the depredations of the Moamaria rebellion and the Burmese invasions towards the end of the Ahom monarchy, this system declined.

Another important innovation of the Ahoms was the introduction of wet-rice cultivation (*Sali*) in Assam. The very reference of *Mung-Dun-Chun-Kham* alludes to their instant likeness for the golden paddy and oilseed fields of the Brahmaputra valley. Their agrarian character was suitably put to test in the regions' fertile alluvial soil and multiple varieties of paddy like *Ahom Sali*, *Khampti Sali*, *Pakhi Sali*, *Aanki Sali*, *Kar Sali* were cultivated using improved water conservation techniques. Later on, in the early nineteenth century CE, British officials like Francis Buchanan Hamilton noted that the paddy constituted about three quarters of the agrarian produce of the kingdom. Sir Edward A. Gait also wrote in his *A History of Assam* that the local people lived in ease and comfort with every article of domestic consumption produced in their own fields, something that Shihabuddin Talish had also spoken about a hundred and fifty years earlier.

The Ahom rulers were master builders and the palaces like the *Karengghar* and *Talatalghar*, in the old capitals of Garhgaon and Rangpur, are living examples of refined architectural styles. The great reservoirs like the *Borpukhuri*, *Joysagar* and *Rudrasagar* besides the numerous temples along their banks, as well as the sports pavilion, *Rangghar*, are testimonies of their interests in leaving their mark in the region's history. These tanks were designed in such a way that the water levels have never receded to this day even during dry seasons. A special type of cementing glue, *Koraal*, made of materials such as lentils, fish, river sand, honey, and lime, was used in construction activities, which gave the walls of these buildings not only durability, but also strength. It should be noted that most of these buildings have survived till date in this highly seismic zone, including the great earthquakes of 1897 and 1950 CE.

The Brahmaputra valley is a densely populated region. Considered to be the heart of Assam. The different communities of the valley have brought colour and vibrancy to the state's landscape

The Ahom coins were also fine specimens of currency which had a very high silver content of about 94 percent, with denominations ranging from the gold mohur to one-thirty-second of a rupee. Octagonal in shape, they had the names, regnal years and salutations to deities like Vishnu, Shiva, Shakti on the obverse and the reverse sides, besides the royal dragon symbol. While gold was sourced from the rivers of Assam, with special guilds called the *Sonowals* assigned to the task, silver was supplied from the faraway mines of Yunnan through the Southern Silk Route (*Nanfeng Sichou Zhilue*). As late as 1809 CE, British officials noted that the kingdom had a brisk annual trade amounting to a hundred thousand rupees along this route including commodities like horses, silver, cowries, lac, and silk.

The Ahoms were warriors and repulsed as many as fourteen invasions from the western side, including the Mughals. The Ahom victory in the Battle of Saraighat (1671 CE) still echoes in the hearts and minds of Assamese people. They had not only a strong infantry, but also a powerful navy consisting of different types of canoes and boats required for navigating the treacherous channels of the Brahmaputra and its tributaries. Experts in constructing earthen forts and embankments, the Ahoms used natural vegetation to their advantage in defending their realm. However, towards the late eighteenth and early nineteenth centuries CE, religious strife and political disunity sapped the vitality of the administrative system, paving the way for the British to finally annex the kingdom in 1826 CE after signing the Treaty of Yandabo with the Burmese. However, the Tai-Ahoms still remain an influential community in Assam today and their past achievements cannot be allowed to fade away in the mists of history.

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Cultural landscape

Farzana Begum

THE BRAHMAPUTRA valley is a densely populated region. Considered to be the heart of Assam, the valley stretching from Sadiya in the east to Dhubri in the west is the cradle of bustling cities and towns, bucolic villages and hamlets, serene *chars* and *chapories* (sand bars), and picturesque islands inhabited by diverse communities. The valley is the meeting ground of numerous linguistic and racial groups and is a treasure house to the anthropologist. Presently, Assam is home to communities belonging to different tribes, castes, languages and religions. These communities have been living in close proximity over a long period of time, which has led to intermixing of racial and cultural elements. The different communities of the valley have brought colour and vibrancy to the state's landscape.

A unique feature of the state is the presence of a large number of tribes, comprising 12.41 percent of the state's population. Many of the tribes have common ancestry but also distinct cultural traits, which distinguish them from one another. Through

Tai Phake

A small ethnic group residing in Assam radiant with it's own culture and tradition.

Tai Phakes migrated to the north eastern part of India from the Howkong valley of Myanmar in 1775.

historical records the origin of the tribes can be traced back to 800 years ago, but studies of their migration stories, folklores, and songs indicate that the tribes have a long existence preceding the historical period. A majority of the tribes belongs to the Mongoloid group and are members of the Tibeto-Burman language family. The Bodos form the largest tribal group in terms of population, followed by the Misings. Other tribes like the Rabhas and Karbis also have sizeable populations.

The Bodos also known as Boro or Boro Kacharis are regarded as one of the earliest settlers of this region, their main concentration is now on the northern bank of the river Brahmaputra from Dhubri in the west to Dhemaji district in the east. The Misings are the second largest scheduled tribe in Assam in terms of population. The word 'Mi' means man and 'Shing' means water/river. Therefore, Mising means the tribe living by the side of the water or river. The socio-economic and cultural life of the Misings is closely linked to life on the riverbanks. They construct their houses on piles. They are expert swimmers and use boats and rafts for transport. Years of living on the riverbanks have taught them to cope with the floods that occur every year. The intimate relation of the Mising tribe with the river is an accepted truth and the saying – *Noi Suwani Miri* which means that the river is made beautiful because of the Miri (Mising)- reflects this sentiment.

The Rabhas are believed to have come to Assam from Tibet at different stages of time in waves of migration. They have close linguistic and cultural affinity with the Bodo and Garo tribes. The Garos and Karbis reside in both the hills and plains of Assam. The Garos call themselves as *Achik Mande* meaning 'Hill Man'; they follow the matrilineal family structure and trace their lineage through females. The Karbis call themselves as '*Arleng*', meaning man. Some authors opine that '*Arleng*' also refers to "slope dwellers"[26].

The Tiwas living in the plains are settled cultivators and the Tiwas living in the hills practice *jhum* (shifting) cultivation. The Tiwas living in the plains have assimilated the Assamese way of life and have been deeply influenced by Vaishnavism. The hill Tiwas have maintained their traditional culture. The unique *Jon Beel mela*, which is an annual event during the month of January, provides an opportunity to witness the ancient traditional barter system practiced among the different ethnic communities.

The Kacharis who used to collect gold or '*son*' from the bank of the Subansiri River came to be known as Sonowal Kacharis. The people of the tribe are deeply influenced by Vaisnavism, but traditional *Bathou Puja* (worship of Lord Shiva) is observed with sacrifice of animals. The Dimasa Kachari consider themselves the descendants of the Brahmaputra; the tribal meaning of the word 'Dimasa' is 'son of a big river'. '*Di*' means 'water', '*Ma*' means 'big' and 'Sa' means 'son'.

The word 'Mi' means man and 'Shing' means water/ river. Therefore, Mising means the tribe living by the side of the water or river

The Ahoms belong to the Tai ethnic group of the Mongoloid race. They came to Assam during the early part of the thirteenth century. The kingdom which Sukapha, the first Ahom king of Assam established in 1228 continued till 1826, leaving behind a rich legacy in the history of this land.

The Deoris is another riverine community of Assam. The term '*Deori*' means the 'offsprings of God and Goddess. The Deoris also known as *Jimochanya* functioned as the priests of the Chutiyas of Assam[27]. Originally from the banks of the river Kundilpani at Kundil, presently known as Sadiya, the Deories traveled along the Brahmaputra river and initially took shelter in the sand bars.

Also nestled in small pockets are found several communities including the Tribes who follow the Buddhist religion and inhabit the upper region of Assam. The Tai Khamtis are said to have migrated to Assam from Bar Khamti (Khamti Lung) in Burma during the eighteenth century. The Tai Phakes are the descendants of the Tai royal officials and had a principality of their own in Hukong valley in the Patkai range of mountains. In 1777, they arrived by boat at Kokilamukh and later settled in Naharkatiya. The Tai Aitonias and the Tai Turungs have also migrated from Burma.

The Singpho tribe believes that they migrated to this region through the Brahmaputra via the Sampo River between 800 and 700 B.C. Although these tribes have over times developed their own individual identity, there are many traits, which they share in common. Racially they belong to the Tibeto Mongoloid races and trace their origin from Myanmar or Burma. They came to this region in series of migration from ancient times. All are followers of the teachings of Buddha. They share similarities in food, clothing, economic activities, religious rites and festivals. These small but ethnically rich Buddhist tribal groups have made the landscape of the state more brilliant and colourful with their presence. They practice agriculture; rice cultivation is the primary occupation. They are also expert horticulturists. The women in all the tribes are expert weavers.

Amidst the diversity in society and culture, there are many commonalities, which bind the people of Assam. Rice, fish, the use of *Khar*, (Alkaline) and *Tenga* (Sour) in their curry are loved by all the communities. An upper and lower wrappers are the traditional attire of a woman of Assam, and each tribe/non-tribal community has a different name for it in their language, Bihu the festival associated with the seasons and agriculture is celebrated by all people from different religions, castes and tribes. These are only a few of the attributes that unite the people of the hills and plains of Assam. These are examples of harmony and inclusiveness imbibed in the society and culture of the land of the Brahmaputra.

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The Char people

Gorky Chakraborty

CAN A piece of land 'float' in water of a flowing river? If it floats, will it 'flow' with the river? Does such a 'flowing-float' sustain life and livelihood for the humans? If it does, how does one categorise it: as land, water, or both, or none! Well, these were the puzzles which were explained to me by my fellow traveller in a city bus in Guwahati, until an argument picked up regarding the 'quality' of the currency note provided by him as fare. The conductor reacted with a 'slur', soon followed by few other passengers, ultimately resulting in his forced de-boarding from the bus. In utter bewilderment, I too went out, as if to continue our conversation which got interrupted abruptly. The man was shivering in fear, an accumulated rage within made him angry too, unable to speak properly and sobbing intermittently, he tried telling me that he hailed from the *char* areas of the river Brahmaputra in Assam. I tried consoling him feeling bad at his hapless plight, followed by loss of words and silence, until he asked me "will you come to our place?" and went further with his invitation saying "what I had been narrating to you so far will be in front of your eyes, and you, yourself can make out what is a *char*: land, water, both, yet none! My tryst with *chars* thereby began on the roads of Guwahati, the largest and fastest growing urban agglomerate in northeast India. The search for academic literature

Can a piece of land 'float' in water of a flowing river? If it floats, will it 'flow' with the river?

on these areas left me depressed as they were almost non-existent. But the incident in the bus, the slur, the land that floats and flows yet sustains life and livelihood albeit temporarily and questions about his identity agitated me until I decided to study these areas applying academic lenses.

Under colonial rule, in-migration of the traditionally skilled cultivators from the populous districts of neighbouring Bengal to the wasteland of the Brahmaputra valley, was encouraged to meet the rising food grains requirement of the state and also satisfy the ever-increasing demand for raw jute from the mills in Bengal, thereby adding to the revenue generating capacity of Assam. The Census Report of 1911 mentions large scale movement of people from East Bengal to Assam, mainly to the Goalpara district. What started flowing in trickles soon transformed into waves and till the end of the colonial era, the migrant people constituted about one-tenth to one-sixth of the state's population, settled in more than 6,213,000 acres of wasteland, increasing the cropped area from 2.40 million acres to 4.79 million acres in Assam. While this heralded a sea change in the agricultural scenario in the Brahmaputra valley, increasing enormously the acreage, yield and productivity of a wide variety of crops along with revenue, it also changed the socio-cultural profile of the state.

Large scale anthropogenic settlements were established on the chars of the Brahmaputra valley. The 1992-93 survey reveals that there were 2,089 char villages in the Brahmaputra

Large scale anthropogenic settlements were established on the *chars* of the Brahmaputra valley as many of these farm-settlers from East Bengal chose to live on the *chars*. A large section of these migrants was already used to living and cultivating in fluvial plains in East Bengal and thereby could negotiate the Brahmaputra flood plains. Interestingly, as the *chars* were within the river, they were geographically exclusive, as a result, the settlers remained outside the mainstream population groups which had settled in far-off areas from the river. The *chars* were thus both the geographically 'other' and the settlers became the socio-culturally 'other' in terms of their identity.

After more than four decades into the post-colonial era, the state undertook a socio-economic survey of the *chars* of the Brahmaputra, to assess the life and livelihood patterns of its dwellers. The first survey was conducted in 1992-93 followed by another in 2003-04; till date they remain the only source of macro data concerning these areas. The 1992-93 survey reveals that there were 2,089 *char* villages in the Brahmaputra, where Barpeta district (351) in lower Assam had the highest numbers followed by Dhubri district (313), which borders Bangladesh. In the 2003-04 survey, the data shows a different trend, more villages in Dhubri than in Barpeta, indicating the change in the fluvial regime of the Brahmaputra.

These surveys revealed that the *chars* constitute 4.60 percent of the total land in the state and 4 percent of its cultivable land and are inhabited by 9.37 percent of the state's population. Evidently, there is excessive pressure on land for survival, land which is impermanent and prone to regular flooding and recurrent erosion. As a result, the density of population in these areas is more than double (690 persons per square kilometer) compared to the state average (340 persons per square kilometer). More than 81 percent of the population in the *chars* is illiterate, perhaps one of the largest illiterate population groups in India. The findings of these surveys may be summed up by quoting the poverty estimates. The population living below the officially determined poverty line increased from 48.89 percent to 67.89 percent from the survey period 1992-93 to 2003-04.

Due to these abysmal conditions, migration remains an important 'escape' route for the *char* dwellers. These impermanent *chars* when eroded, migrate downstream. They re-appear, of course if not fully eroded, through accretion towards the tail. The *char* dwellers exhibit different patterns of migration: moving to central locations within a *char* from the eroding peripheries; migrating to a more stable *char* usually nearer to the banks; shifting to relatively stable places within the riverine flood plains; migrating to urban locations seasonally; and if possible, to urban places for good.

Despite producing a diversified crop profile and exhibiting a higher crop intensity compared to the mainland, impermanence of land, lack of legislative and revenue safeguards along with abysmal conditions of health and literacy entwined in skewed income and land occupancy, the *chars* remain the most impoverished and neglected areas in Assam. Where the *char* dwellers are caught in a bind of uncertainties: the river fosters the uncertainty of life and livelihood, land and water, and migration to the mainland ushers in the uncertainty of identity.

As per local literary records and folklore, Majuli has existed for more than five hundred years. There is evidence that the Ahom kings also consolidated their rule on the island

Majuli Island

Sushmita Mandal

MAJULI, OR "land locked between two parallel rivers" is the world's largest inhabited river island located in the middle course of the Brahmaputra river in the state of Assam in India[28]. The island is a conglomerate of 248 cadastral villages spread over an area of roughly 487.55 square kilometers[29]. However, the true extent of the island today is unknown due to the shifting nature of the river that constantly erodes the riverbanks and reshapes it. Islets (locally known as *chaporis*), *beels* or wetlands, ox-bow lakes and streams cover 14 percent of the total geographical area of the island[30], making it an ideal habitat for birds (both resident and migratory) and aquatic diversity.

As one de-boards at Majuli's Kamalabari Ghat, the new sediment deposited from the last monsoon greets you. Further ahead there are concrete structures that lie along the banks of one of the streams. Referred to as porcupine structures in

engineering terms, they are a silent testimony to the efforts ongoing in Majuli to arrest the eroding banks from being further eaten away. But as one sees, these efforts have been futile in the face of a raging river. The shrinking of Majuli is documented from the colonial era. A map prepared by A J Mefat Mills of the British East India Company in 1853 shows Majuli's land mass at 1,246 square kilometers. The 1993 maps prepared by the Brahmaputra Board show only 880 square kilometers as the total landmass. However, after the monsoons of 2001, the recorded land area of Majuli was approximately 425 square kilometers. The river takes away earth but also creates new land masses. In these newly formed sand bars (locally called *chapori*) animals and humans live, not knowing when they will be again washed away by the devouring river. The memory of this shifting relationship between land and water is etched on the eroded banks. The loss of land in Majuli has meant a loss of both homestead and land for farming. Erosion and accretion are a distinct feature of braided river systems and while people have been juxtaposed between the two, life in Majuli progresses from day to day, negotiating such paradoxes.

Life on Majuli Island

As per local literary records and folklore, Majuli has existed for more than five hundred years. There is evidence that the Ahom kings also consolidated their rule on the island. The remnants of an erstwhile fort that was built on the island are a testimony to that. The key point of Majuli's transition into a unique cultural landscape was seeded in the setting up of *Sattra* (Vaishnavite monastery) in the fifteenth century. The Assamese Bhakti saint, Srimant Sankardeva came to the island and imparted teachings of Lord Krishna through performing arts. He used innovative methods of communicating spiritual teachings that included music, dance and theatre, most of which exist till this day. It was Sankardeva along with his successor Madhavdeva, who set up several monastic institutions called *sattras*, where monks spend their lives in reading scriptures, engaging in performing arts and devoted to the worship of Lord Krishna.

It is believed that as many as 65 *sattra*s existed in Majuli at the turn of twentieth century, but due to the floods coupled with erosion, several of these have shifted base to the mainland. Currently about 22 *Sattra*s exist in Majuli. It is a major seat of Vaishnavite culture in Assam and is much revered and worshipped by locals. The *sattriya* culture is the mainstay of local tourism in Majuli and figures prominently in the itinerary of any devout Vaishnav in Assam wishing to visit the seat from where it spread across the state.

Majuli is juxtaposed between the impermanence of a shrinking landmass and a continuing cultural-religious heritage. The cultural-religious component is intangible and the physical component in the form of the *sattras* are continually relocated and hence reconstructed. History is written in Majuli with water; it eludes the usual frameworks for measuring heritage. In 2006, Assam passed the Majuli Cultural Landscape Region (MCLR) Act, aimed at "prevention of loss of value and authenticity of the cultural landscape of Majuli" and established the Majuli Cultural Landscape Management Authority (MCLMA). This institution is entrusted with implementing an inclusive management plan, involving local stakeholders in an integrated effort to protect the unique heritage of the island.

The rhythm of life on this island is clearly guided by the seasons; summer is the season of high activity when roads and embankments are repaired/fortified for the ensuing monsoons that would again take away some life and livelihood. Soon after the flood waters recede, the wetlands are teeming with fresh stock of fish that the river brought along with it. The new sediment deposited in the fields is ready to be ploughed and planted with a variety of paddy, vegetables, and oil seeds. Winters are a time of tending the crops, harvesting ones that are ready and spending some time at leisure as well. People's reverence to the Gods is best expressed through their regular visits to the *naamghar* (village level religious institution), each morning and evening. Festivals like the *Bhaona* festival are an opportunity for the villagers to

congregate and enjoy the traditional theatre form known as *mukha bhaona*, which evolved as part of the *Sattriya* culture and uses *mukha* (masks) of mythological characters for storytelling.

Mask making as an art form is closely linked to Vaishnavism. The Chamaguri Sattra in Majuli has traditionally been known for making the masks used in the traditional theatre; it is a hereditary skill passed on from generation to generation. But over the years this art is dying as the youth have demonstrated little interest in keeping it alive. We had the privilege of meeting Kosha Kanta Deva Goswami, Sattradhikari(head) of Chamaguri Sattra, master mask maker, whose family is devoted to mask making. He and his family have been engaged in various outreach activities and have held trainings to pass on the knowledge so that the art form can survive. In 2003 Kosha Kanta Deva Goswami was recognized for his contributions by the Sangeet Natak Academy. His family besides making the big masks used in *mukha bhaona* also makes small replicas that have found ready takers among tourists who find it convenient to carry them as mementos from Majuli.

Majuli reveals itself as a vast mosaic of paddy and mustard fields crisscrossed with wetlands and streams, with concrete bridges in some places and rickety river bridges at others

Locally available materials like bamboo, cane, clay, cow dung and vegetable dyes are used in making these masks. The framework is made by weaving spliced strips of bamboo or cane into a loose structure, over which cloth (now paper is also used) is pasted using a light mixture of clay and water. This is sun dried, after which the features are carved out using a mixture of three parts clay to one-part cow dung. After these dry, the mask is painted using vegetable dyes. Accessories such as hair are stuck using locally available materials like jute. A mask takes anything between 12 and 15 days to complete. The masks portray characters from Indian mythology, including gods and goddesses, demons, birds and animals.

Majuli reveals itself as a vast mosaic of paddy and mustard fields crisscrossed with wetlands and streams, with concrete bridges in some places and rickety river bridges at others. The idyll that it symbolizes is far from reality for its residents. Limited connectivity to the mainland is one of the main concerns. Aspirations, especially of the youth coalesces around the idea of a bridge that would connect the island to the mainland. Given that infrastructure like embankments have provided little relief, the bridge promises much more, such as connectivity, and access to emergency medical facilities, and markets. But the tricky terrain is a cruel pin sticking into such bubbles of hope. The alluvial flood plain of Brahmaputra is unstable and will only support vast quantities of water passing over it, but not permanent concrete structures.

Impermanence is the only way of life in Majuli. People anchor themselves into their cultural way of life and build their hopes around a stable and yet elusive future. Uncertainty looms large, floods and erosion have become more pronounced in recent years due to changes in the climate[31]. Plans are afoot to conserve this largest inhabited river island in the world, declaring it a no-plastic zone, exploring traditional methods of arresting erosion, developing an integrated conservation

plan for the island with extensive consultations[32]. People are moving towards an unknown future, where things operate beyond their powers and make them helpless. From climate change to embankment politics, to floods and lives washed away by the Brahmaputra, Majuli could have been a sad and poetic tale of loss. But it is not. Because in their transient world, people of Majuli have devised ways of living with water. It is this spirit of the people and their way of life that deserves to be protected. It is the "Majuli way of life" that merits a heritage label.

❄

Tea tribes

Pooja Kotoky and Paresh Borah

ASSAM THE "land of Red River and Blue Hills" is known around the world for its tea[33] and has been a major industry contributing to the economy. The backbone of the tea industry is the labour provided by tribal communities who were brought to Assam nearly 200 years ago to work in tea plantations. The tribals who settled in the tea plantations over the years were identified as Tea Tribe (collectively) or *Cha Jana Jati*. Today this community represents 20 percent (6.5 million) of Assam's total population[34] and is composed of Santhal, Munda, Khond, Kharia, Ho, Gond, Bhumij, Kurukh and 112 other tribes.

In the face of acute shortage of manpower to clear forests and expand plantations, The Assam Tea Company began to bring in labour from outside the state. The labourers were brought to Assam from Bihar & Jharkhand (Ranchi, Hazaribagh, Chaibasa and Dumka); Bengal (Santhal Parganas, Bankura, Birbhum and Midnapur); Orissa (Sambalpur, Balasore, Cuttack and Koraput); Madhya Pradesh and Chhattisgarh (Raipur, Balghat, Bhandara, Bundelkhand, Ghazipur and Gorakhpur). And a small number were brought in from South India and Maharashtra.

In late nineteenth century several natural calamities like earthquake, drought, flood, famines, epidemics and poverty gripped millions of lives in north-west provinces, Orissa, north Bengal and central India. Poor peasants and landless labourers who were victims of exploitation and indebtedness to *zamindars* or landlords, fell into the traps of contractors' false assurances of better and easier work opportunities, higher wages and land for cultivation in Assam.

In order to recruit labourers two main systems of recruitment were followed; Contractor System (1859 to 1915) and Sardari System (1870 to 1959).[35] Contractors were the licensed people whose ultimate objectives were to collect as many people as possible to work. Without any restrictions, contractors adopted all kinds of fraudulent methods and transported labourers to Calcutta depot on foot, trucks and goods trains, then to Assam in most inhumane and inhospitable conditions. It will not be wrong to say that they were literally uprooted from their existence, heritage and culture to an unknown new world on false hope and deception to work as 'indenture labours'. The transportation journey became complicated during the rainy season because of the strong velocity and current of the Brahmaputra. It took 135 to 140 days to reach Sadiya from Calcutta.

Letters of communication between the Company and Government have revealed that streamer boats were introduced in the eighteen sixties exclusively to transport labourers from Calcutta depot to Assam

Letters of communication between the Company and Government have revealed that streamer boats were introduced in the eighteen sixties exclusively to transport labourers from Calcutta depot to Assam[36]. Because of the inhospitable journey, many lost their lives due to sickness and unavailability of treatment before reaching the different tea estates in Assam, where living conditions were overcrowded and hazardous. They were not permitted leave from duty during sickness and did not have guarantee of personal freedom and liberty. The labourers were imposed with draconian rules to live and work; any violation of rules resulted in flogging, beating, and at times were brutally killed. Female labourers were pressurized to increase the birth rate and abortion was strictly prohibited to create 'future' generation of labourers.

Post Indian Independence, with the implementation of the Plantation Labour Act of 1951 the basic standards of living for plantation workers improved. About 3 to 4 million labourers belonging to the tea tribes work in the tea industry. Today the tea tribes comprising of 96 ethnic groups, have no connections with their original homes. Since the colonial period, tea tribes have remained cut-off from the other

indigenous groups of the state and have formed a unique identity bearing the historical impression of colonial plantation life. Having no connections with their places of origin and intermingling with various cultures in the plantation setting of Brahmaputra valley, the tea tribes have developed a composite community culture in which the elements of the tribal culture of the Jharkhand region are predominant.

The present generation in the tea plantations is looking beyond life in the tea gardens. They are aspiring to create a separate identity from their parents; some are now first-generation graduates, and some are taking up skill development programs provided by the Government and private organizations and getting recruited as teachers, nurses, and mechanics.

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Boat clinics: ships of hope

Pooja Kotoky

THE BRAHMAPUTRA valley has a network of 2,500 river islands known as *chars or saporis* which are home to 2.5 million people. Most of the islands lack basic infrastructure and services like health care, schools, roads, electricity and drinking water and sanitation. During monsoon there is no accessibility and communication between the mainland and the river islands. Most men from these marginalized communities migrate to the mainland for work, leaving behind vulnerable women and children.

In June 2004, the Centre for North-Eastern Studies and Policy Research (C-NES), under the leadership of Sanjoy Hazarika, launched a unique initiative to bring mobile relief and health care facilities by boat to these marginalized communities. In the same year (2004), C-NES won the World Bank's India Marketplace competition for the innovative concept of "A Ship of Hope in a Valley of Floods", and the prize money of USD 20,000 (about ₹1.37 million now) led to the construction of the first boat clinic. Named *Akha*, which means hope in Assamese, the first boat clinic was built with local raw material with the help of boat-builder Kamal Gurung. Made of wood, the boat is 65 feet in length and equipped with an out-patient department, a laboratory, cabins, toilets, water supply and a power generator. Fourteen more have been added since. The mobile health services were first started in partnership with the district administration in Dibrugarh. Later the services were expanded to Dhemaji and Tinsukia districts.

In August 2008, as the waters raged around Lamba *Sapori,* an island home to the Mishing community in Dhemaji, a couple, Punyadhar and Oiphuli Morang, watched helplessly as their two-year-old daughter, Moina, suffered an acute asthmatic attack. Having seen the boat clinic pass by the *sapori* several times, they had some idea of its schedule. So Punyadhar stood atop his house and waved vigorously to the *SB Shahnaz*, which was plying these waters. The team spotted the couple and made its way to their home, where medication was administered, and the child recovered. This is just one incident out of hundreds which demonstrate the importance and value of the boat clinics.

"A Ship of Hope in a Valley of Floods". The boat clinics are at work 24/7, 365 days a year

After being proven as an effective and successful model the National Rural Health Mission (NRHM), Government of Assam proposed collaboration and signed a unique private-public partnership in 2008. As of 2019 the Boat Clinics are working in 13 districts. Each boat has 2 doctors, one or two auxiliary nurses, a lab assistant and a pharmacist. These boat clinics provide curative care, reproductive and childcare, family planning services, basic laboratory services, emergency services and care during pandemics, epidemics, disasters and public health emergencies. Awareness programmes are also carried out on family planning, health and hygiene, nutrition and sanitation. The boat clinics are at work 24/7, 365 days a year.

One of the special highlights of the project is the Brahmaputra Community Radio Station (BCRS) popularly known as Radio Brahmaputra established at Dibrugarh with the aim to target tea garden labourers and most remote islands. Currently, the radio reaches 14 islands, 30 tea plantations and more than 180 villages and three districts along and across the Brahmaputra on FM 90.4.

Till March of 2019, over 2.7 million people have received basic health care services. Annually 3,40,000 cases are handled by the Boat Clinics in all the 13 districts in the Brahmaputra valley. In 2020, the Boat Clinics became the main catalyst during the spread of the novel coronavirus disease. They launched awareness campaigns in the islands about the newly emerged disease and advocated the need for social distancing and carrying out community surveillance and testing.

❄

Runa Khan

JAMUNA BASIN

FRIENDSHIP hospital ships

Runa Khan

EIGHTEEN YEARS ago, while visiting a *char* (island) on the River Jamuna, I was invited into the home of a family I had met by the riverbank. It was a humble hut made of straw and living within it was a family, along with the one cow they possessed and the entirety of their belongings. Families like theirs barely have enough to eat two meals a day, yet I saw the wife feeding their sick child the

Runa Khan

second meal of the day, just before dusk fell. It was only rice with a little onion. I asked the mother. 'Why do you not feed her a little later so that she will sleep at night, contented?' Perplexed, she looked at me with disbelief in her eyes. 'What an extravagance!' she exclaimed. 'One taka (1 cent) of kerosene to light a lantern so they could eat after dark! If the child falls asleep now, she will not know that she is hungry at night.'

Another mother came with a baby who was suffering from cerebral palsy and asked me, 'doctor (the village quack) said that there is nothing to be done for my child. Should I kill her?' A handicap, another mouth to feed, social ostracism, and a pain watching the child suffer daily.

A reverberating shock, pain, anger at the injustice broke my heart and led me to look for any solution I could find. These were areas where even the trawlers for passenger transport used to stop plying at dusk due to remoteness and insecurity. Where the nature of the land and climate eclipsed the possibility for any permanent infrastructure. These were the *chars* of the Jamuna: silted, nomadic islands formed and broken upon the river's whim. Access to any basic services be it roads, electricity, schools, hospitals, shops, police were totally unheard of. Millions lived on such *chars* all over the country.

In the strife towards saving lives FRIENDSHIP started the first hospital ship on these shores. Now we could even deliver tertiary care to their doorsteps! The Lifebuoy Friendship Hospital was followed by the Emirates Friendship Hospital on the Jamuna, and now five new hospital ships are on the verge of being launched on the Jamuna, Padma (Ganges) and other rivers of Bangladesh.

As the Lifebuoy Friendship Hospital ship brought much needed healthcare, I realized just a ship was not enough! What would happen to the patients we were leaving behind? Those needing simple contraceptives or surgical follow ups? Thus, FRIENDSHIP developed a three-tier healthcare system, the first of its kind in the world, so no one would be left behind. 1st Tier: Ship Hospitals; 2nd Tier: Satellite Clinics, where healthcare teams set up bimonthly medical camps in communities around the hospital giving primary care and follow ups. 3rd Tier: Friendship Community Medic-Aides: community women to take healthcare to the doorstep of every family. To link the three tiers, we used mHealth, a software that would assist to diagnose, treat and refer patients. This way, we provide free and comprehensive care to 6.5 million people a year, 60 percent of whom are women.

FRIENDSHIP developed a three-tier healthcare system, the first of its kind in the world. Integrating our work with lessons learnt from nature, we have made a most robust global healthcare system

But Saving Lives, needed global healthcare and comprehensive interventions. For poverty alleviation could not be ignored if that child was to eat three meals a day. Empowerment for the communities and to reach the services, climate action was needed. Schools, trainings, access to finance and preparedness and support, even linkages through to governments were created. Every solution and step built on mobility and innovation.

The rivers change daily. Erosions, floods, tropical tornados, famines today have become unpredictable and extreme. Integrating our work with lessons learnt from nature, we have made a most robust global healthcare system. As the land and people move, so could the solutions. FRIENDSHIP's integrated approach spanning over 18 years has rendered more than 36.25 million services for these climate-impacted migrant communities.

Once upon a time, our very culture and life was ingrained and inseparable from the rivers and nature. Now, most of us reside within the secured glass bubbles of our cities and societies, so sheltered from nature's wrath and generosity. Many of us have moved far away from designing our services geared to the one thing we cannot fight: nature and the environment. Humanity's greatest challenges will come from nature in the coming years. Those who live in harmony with nature and the environment will know how to cope and survive. And it is only by respecting the environment and working alongside it, can we find the solutions in regions such as these *chars* of the *Jumna*.

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Langalbandh festival and fair

THE LANGALBANDH fair or Gur-Pukur's fair is one of the major religious festivals of the Hindu community in Bangladesh. The festival occurs on the eighth day of the lunar month which coincides with the Bengali month of *Chaitra*. During the festival also known as *Astami snan* or holy bath Hindu devotees take a bath in the Old Brahmaputra river, the channel that flows through Jamalpur, Mymensingh and Langalbandh. There are a number of *ghats* (steps leading to the river) or bathing places by the river, but Langalbandh and Panchami *ghat* on the west bank of Brahmaputra, are considered to be most sacred.

The belief of the devotees is that the holy or sacred bath will please Lord Brahma, provide salvation and mental purification. Thousands of people, both from the country and abroad, visit the place every year for the holy bath. The fair is also a major tourist attraction. The fair lasts for three days, beginning on the day before the holy bath and ending in the day following the bathing festival.

Sheikh Rokon

Bard of the Brahmaputra: Bhupen da Hazarika

Sanjoy Hazarika

TO MILLIONS he was simply 'Bhupen *da*', a legend recognized and honored in India and Bangladesh.

While India posthumously gave him the Padma Vibhushan (he had earlier been awarded the Padma Shri and Padma Bhushan civilian honors), his stature in South Asia was demonstrated when Dhaka honoured him with the *Muktijoddha Padak*, the country's highest civilian award. Indeed, he was cherished in Dhaka as much as he was in Guwahati. His song on the war of Bangladesh's freedom, *Joi Joi Nobo Joto Bangladesh* (hail the newborn Bangladesh), is a stirring marching tune, which was on every Bengali's lips during those harrowing days as that momentous struggle for liberation gathered strength and inspired the battle for freedom. And when Bangladesh was born, he was welcomed there like a hero. His songs were not limited to Assamese and Bengali, and his rich baritone was equally at ease in Hindi, Urdu and English.

The waterways of Assam were the source of inspiration for his lyrics. 'The Brahmaputra is the lifeline of Assam,' he said. One of his notable collaborations for Doordarshan was Luit Kinare (by the banks of the Luit), a mosaic of ordinary tales that was both cheerful and poignant. Perhaps the best example of the humanistic ideals that imbue his works is *Manuhe Manuhar Babe* (For mankind), composed in 1964. 'If we do not care for our fellow human beings, who will?' sings the bard. It is a song that needs to resound across Assam and the north-east at times of strife.

The waterways of Assam were the source of inspiration for his lyrics. The Brahmaputra is the lifeline of Assam, Bhupen da said

He was without doubt one of the greatest living cultural communicators of the region, swaying millions with the power and passion of his voice, and the message of universal brotherhood and humanism. He had a genius for weaving a magical tapestry out of traditional Assamese music and lyrics. In the process, he breathed new life into the language, synthesizing old and new strands of music, and instilling a sense of pride in the Brahmaputra valley. Bard of the Brahmaputra. But he was more than that: he was a passionate fighter for rights, for the poor (his early and later songs drive home the messages of equality, humanity and brotherhood especially in times of pain and tragedy) and who believed in the importance of means over ends.

It was because of his persistence as head of the Sahitya Kala Parishad that the *Satriya* dance, performed originally in the *satras* or Vaishanvite monasteries, is today recognized as one of India's 'national' dance forms. Bhupen Hazarika was at the confluence of these great streams, bringing them together in his unique way, with humanity and equality as his principles and symbols.

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Atisha Dipankar Srijnan (or Srigyan)

Bushra Nishat

"He crossed the mountain
Covered with perilous frost:
He is the Atish of Bangla
Who lit the light of learning in Tibet"......

REGARDED AS the most enlightened and outstanding Buddhist scholar and philosopher, Atisha Dipankar Srijnan was born near the Padma in Bangladesh and breathed his last on the banks of the Yarlung Tsangpo near Lhasa in Tibet. Born to a royal family as Chandragarbha, he was given the title named Dipankar Srijnan meaning the 'one who has the lamp of wisdom in his hands' after initiation into Buddhism. Invited by the king, he travelled to Tibet in 1042 where he received the name of Atisha, a Tibetan reference to peace.

Atisha had a lengthy career as an academic at the Buddhist monastry, Vikramasila (in Nalanda, Bihar, India), travelled and lived in Sumatra, Indonesia for over a decade but it was in Tibet where he found his final calling in life[37]. It took Atisha and his companions almost two years to travel on foot from India to Tibet across mountainous terrains of the Himalayas amidst climatic hazards and also attacks by dacoits. The main route was from Palpa in Nepal to Manas Sarover[38]. In Tibet, Dipankar reformed Buddhism; he refined, systematized, and compiled an innovative and thorough approach to *bodhichitta* known as "mind training" (*lojong* in Tibetan). Atisha also wrote on engineering and agriculture and devoted more than a decade of his life for the well-being of the Tibetan people. He employed his engineering skills for construction of a dam in western Tibet for protecting communities from floods and helped in setting up an irrigation system by digging canals which led to boosting of agricultural productivity[39].

Dipankar wrote, translated and edited more than two hundred books, which helped spread Buddhism in Tibet. Tibetans revere Dipankar, granting him a rank second only to Gautam Buddha and refer to him as *Jobo Chhenpo* (a great God)[40].

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6. HARNESS

Tapping the River

Xiawei Liao

Uttam Kumar Sinha

Qu Bin

M Niamul Naser

Minakshi Bora

RTI International & ELMS

Ganesh Pangare

Shanaj Laila

THE YARLUNG Tsangpo Brahmaputra Jamuna river system provides water for irrigation, and domestic use along the entire length of the river system, supporting the water-dependent livelihoods of riparian communities such as agriculture and fisheries. In some sections of the river system, water is used in industries and for power generation as well.

Infrastructure systems, such as hydropower stations, inland waterways, and ports have been gradually developed to harness such benefits provided by the river

In the Yarlung Tsangpo basin, recent trends show increasing water usage for industrial and domestic purposes. Due to a small population and limited development in the Tibetan region of China, water quality is relatively pristine in the upper reaches of the river system while the water quality can be seen to deteriorate downstream with increasing human activities. In the Brahmaputra and Jamuna basins, the river also provides a wide range of other benefits that are important to riparian social economies, such as inland water transport. Hydropower production is gaining increasing appreciation in the upper hilly regions. Most of the water withdrawn from the river in Brahmaputra and Jamuna basins is used for agricultural purposes.

Infrastructure systems, such as hydropower stations, inland waterways, and ports have been gradually developed to harness such benefits provided by the river. While the river presents a natural barrier for connectivity between two banks, the acceleration of bridge building has overcome such barriers and significantly increased the connectivity in the basin, which also plays a fundamental role in the social and economic development of the riparian communities.

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Water uses for irrigation, industrial and domestic purposes

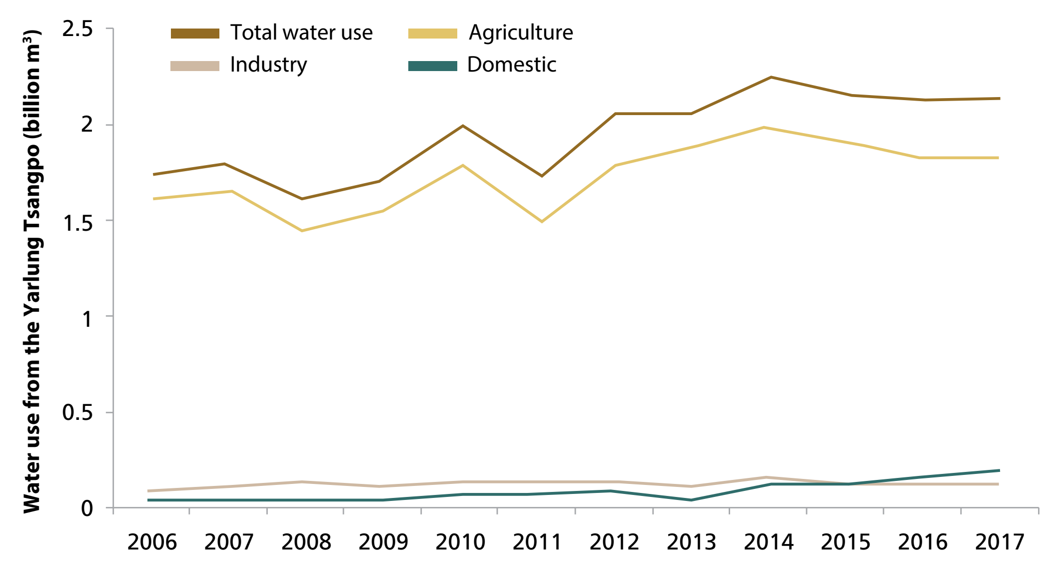
RTI International & ELMS[1]

YARLUNG TSANGPO River is an important source of water for the Tibetan Region in China. Water supply from Yarlung Tsangpo on average makes up about 60 percent of the total water supply in the Tibet Autonomous Region, rising from 40 percent in 2008, indicating the increasing importance of the river to the social economy of Tibet.

Even so, water use from the upstream Yarlung Tsangpo remains low compared to the volume of water available from the river. From 2006 to 2017, total water use increased from 1.76 billion cubic meters (bcm) to 2.14 bcm, peaking at 2.25 bcm in 2014. (Figure 1). Although agriculture is the largest user of water, the share of agricultural water use has decreased from over 92 percent in 2006 to just above 85 percent in 2017. Domestic water use has increased by the largest margin, by over 230 percent, from 2006 to 2017, compared to 60 percent for industrial water uses and only 12 percent for agricultural water uses.

The share of industrial water uses increased from 5 percent in 2006 to over 8 percent in 2011 and then decreased and stabilized at around 5 to 6 percent in recent years. The share occupied by domestic water uses have almost tripled from 3 percent to nearly 9 percent during the last decade.

Figure1: Historical water use change in the Yarlung Tsangpo from 2006 to 2017[2]



In the Brahmaputra and Jamuna basins, surface water irrigation is mainly confined to the flat and fertile lands of the valley, though small-holder irrigation also occurs in the hilly upstream terrain of the Brahmaputra and Teesta basins. Large-scale irrigation is supported by several barrages, including India's Teesta Barrage, which regulates the discharge for nearly 1 million hectares in India and about 150,000 hectares in Bangladesh. This infrastructure could irrigate 750,000 hectares in Bangladesh[3]. Surface water irrigation in these zones is highly water intensive and three rice crops are commonly grown (*aus, amman*, and *boro*); the first two depend heavily on floods, while the *boro* crop, which achieves by far the highest yields, is planted as floods recede. Risks of crop failure during the early monsoon are highest; a large flood event can destroy those crops and does so with regularity. In the Jamuna basin, some 80 percent of irrigation originates from groundwater, particularly for the cultivation of *boro* rice[4], which has been an important driver for attaining food self-sufficiency in Bangladesh in the last two decades.

Currently, there are more than 1,270 Flood Control Drainage and Irrigation (FCDI) schemes in the country, developed by the Bangladesh Water Development Board (BWDB) and the Local Government Engineering Department (LGED) and covering more than 6 million hectares. From 1995 to 2015, LGED developed around 720 small-scale water resources sub-projects that improved water management for around 450,000 hectares of land. In addition, there are four barrages across the Teesta, Tangon, Buri-Teesta, and Manu rivers, which are used as diversion structures for supplementary irrigation. Irrigation development, accompanied by high yielding value crop development, particularly *boro* rice, and making use of the abundant groundwater resources, has shown spectacular results in the country.

Irrigation development, accompanied by high yielding value crop development, particularly boro rice, and making use of the abundant groundwater resources, has shown spectacular results in the country

Due to climate change and unregulated groundwater use, less water is available for irrigation during the dry season in a large part of the Jamuna basin. Therefore, a well-planned irrigation management system is essential for gradually increasing crop intensity as well as yield. Irrigation efficiency needs to be improved with modern water management technologies to enhance food productivity through optimal use of available water resources. As part of the climate change strategy, creation of water reservoirs and rainwater harvesting in rain-fed/coastal/hilly areas will be encouraged, and small-scale water resources systems may be developed.

Domestic and industrial water uses in the Jamuna basin are mostly derived from groundwater sources. The pumping of groundwater has increased with increasing population in the basin. As a result, land subsidence has become a growing concern, and has pushed urban water managers to more strongly consider a substantial switch to surface water sources. Owing to concerns about water quality, such a switch would require higher water treatment costs, and could exacerbate the competition for water in the dry season, inducing tradeoffs with agricultural and navigational water uses. More targeted and managed groundwater recharge during wet periods could help offset these rising pressures but has not previously been practiced in a systematic way.

The importance of water resources for the industrial sectors in Bangladesh, an important engine for the country's growth during the last 10 to 20 years, is growing rapidly. Whereas water demand is still low compared to the agriculture sector, industrial use is expected to grow by 440 percent by 2050. Water resources are particularly important for the textile, fertilizer, and leather industries, both in terms of consumptive needs and in view of the pollution pressures caused. Water is also used in thermoelectric power generation both as a cooling agent and for steam generation used for power generation. The textile sector accounts for more than 85 percent of all export earnings, more than 10 percent of GDP, and provides direct employment to more than 4 million workers. Both textile and leather sectors have high growth rates projected for the next 20 to 30 years.

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WATER QUALITY

Yarlung Tsangpo river

Qu Bin

GENERALLY, THE Yarlung Tsangpo had an alkaline aquatic environment: pH in the Yarlung Tsangpo basin was between 8.3 to 9.0 with an average of 8.8. TDS (total dissolved solids) varied greatly from 66 mg L-1 to 265 mg L-1 with an average 157 mg L-1 in the mainstream channel, which was higher than that of the world average. The water chemical characters of the Yarlung Tsangpo vary along the whole river system, and are significantly shaped by the different geology, meteorological and anthropogenic conditions within the river basin[5].

The water chemical characters of the Yarlung Tsangpo vary along the whole river system, and are significantly shaped by the different geology, meteorological and anthropogenic conditions within the river basin

The Tibetan Plateau is the youngest and highest plateau in the world, where weathering and physical erosion take place at a fairly high rate[6]. Solutes in the Yarlung Tsangpo river waters have multiple sources, deriving from physical, chemical and biological processes in the drainage basin such as weathering of rocks, groundwater supplication, precipitation transportation, and as well as anthropogenic input[7]. It has been proposed that the majority of the dissolved solids in the Yarlung Tsangpo are mainly derived from various rock weathering (namely, carbonates, evaporates, silicate) as well as numerous geothermal springs and mineral-rich alpine lakes distributed in the Sothern Tibetan Plateau[8].

Major ions (Ca^{2+}, Na^+, K^+, Mg^{2+}, Cl^-, HCO^{3-}, SO_4^{2-}) in the mainstream of Yarlung Tsangpo fluctuated but with a general underlying steady trend from the source to the downstream. When compared with other rivers in the world, concentrations of most ions in the mainstream of the Yarlung Tsangpo were higher than the world average. For instance, concentration of SO_4^{2-} in the mainstream of Yarlung Tsangpo was 37.4 mg L^{-1}, almost four times higher than that of the global average (Figure 2).

Besides the precipitation and weathering supply, the evaporation along the upper reaches of the river basin significantly exceeds rainfall because of the abundant annual global radiation[9], both of which could lead to the high ion concentrations (e.g., Ca^{2+}, Na^+, Mg^{2+}, HCO^{3-}, SO_4^{2-}) in the Yarlung Tsangpo. Differently, ions K^+ and Cl^- in waters of the Yarlung Tsangpo had a lower concentration than the world average level.

It is claimed that K^+ in waters of the global river is primarily from the silicate minerals leaching, and in small amounts from other sources that often include one or more among evaporite minerals, fertilizers, rain waters and the decay of land plants[10]. Therefore, with few fertilizers or decay land plants along the Yarlung Tsangpo basin, the concentrations of K^+ presented relatively low levels. It has been widely accepted that Cl^- in surface waters of rivers contributed by the cyclic salts is expected to decrease with increasing distance from the sea[11].

With the major contribution of the rainfall during the monsoon season to the annual discharge of the Yarlung Tsangpo[12], water chemistry is inevitably affected by the precipitation which is dominated by the India monsoon. However, as the roof of the world, the high elevation Himalaya blocks most of the water vapor flux from the Indian Ocean to the Tibetan Plateau and declines the precipitation in this area[13]. As a result, the concentration of Cl^- in the Yarlung Tsangpo was lower than most rivers in the world.

Majority of the dissolved solids in the Yarlung Tsangpo are mainly derived from various rock weathering as well as numerous geothermal springs and mineral-rich alpine lakes

Figure 2: Average concentrations of major cations of the mainstream of the Yarlung Tsangpo and rivers in the other regions in the world. (Modified from Qu et al.[14])

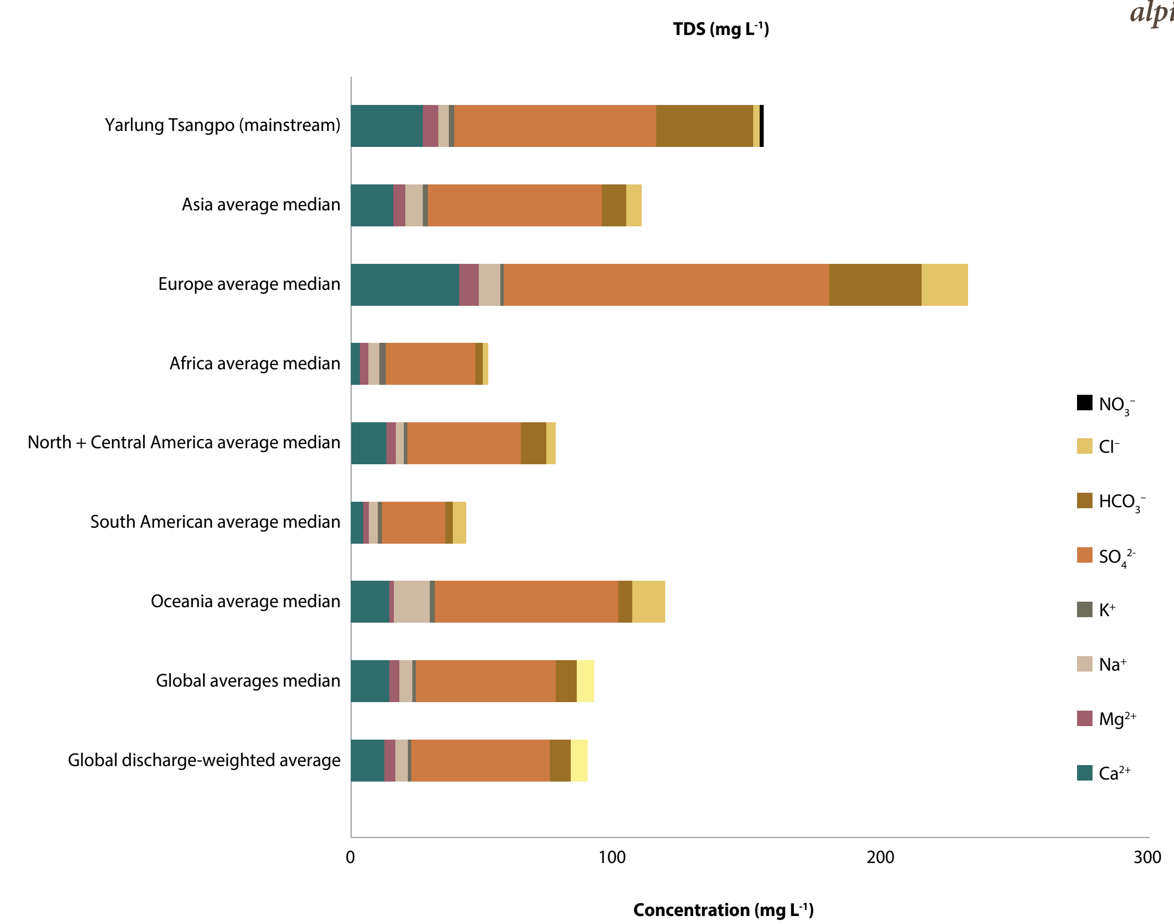

Table 1: Chemicals of health significance as described by international guideline (WHO) and China national guideline (GB) for drinking-water quality. Concentrations in Yarlung Tsangpo were presented in range and average, repectively

Parameter	Unit	Concentrations in Yarlung Tsangpo[15]	WHO[16]	Remark	GB5749[17]	Remark
pH		8.3-9.0, 8.8		Optimum: 6.5–8	6.5–8.5	
TDS	mg L^{-1}	66-265, 157 [18]	NA	Optimum: <1200	1000	
Turbidity	NTU	14.2-62.4, 26.1	5		NA	
Aluminum	µg L^{-1}	3.1-128.8, 43	200		200	
Antimony (Sb)	µg L^{-1}	1.7-18.4, 4.8	20		5	
Arsenic (AS)	µg L^{-1}	0.2-80.2, 20.2	10			
Barium (Ba)	µg L^{-1}	5.6-28.7, 15.1	700		700	
Bicarbonate (HCO_3^-)	mg L^{-1}	28.1-92.1, 68.0	NA	Optimum: <600	NA	
Cadmium (Cd)	µg L^{-1}	0.2-14.2, 2.7	3		5	
Calcium (Ca^{2+})	mg L^{-1}	12.3-46.3, 27.5	NA	Optimum: <250	NA	
Chlorine (Cl)	mg L^{-1}	0.4-5.8, 2.3	5 (C)	For total chlorine	4	For total chlorine
Chromium (Cr)	µg L^{-1}	0.2-4.1, 3.3	50(P)	For total chromium	50	For Cr(+6)
Copper (Cu)	µg L^{-1}	0.3-7.4, 2.2	200		100	
Fluorine (F^-)	mg L^{-1}	0.1-0.2, 0.16	1.5		1	
Potassium (K)	mg L^{-1}	0.2-1.2, 0.9	NA	Optimum: <250	NA	
Lead (Pb)	µg L^{-1}	1.6-55.7, 12.4	10		10	
Magnesium (Mg^{2+})	mg L^{-1}	1.3-12.5, 4.7	NA	Optimum: <150	NA	
Manganese (Mn)	µg L^{-1}	0.8-265, 40.7	400(C)		100	
Molybdenum (Mo)	µg L^{-1}	0.6-2.0, 1.3	70		70	
Nitrate (NO_3^-)	mg L^{-1}	0.1-2.9, 1.1	10	For nitrogen (N)	10	For nitrogen (N)
Sodium (Na^+)	mg L^{-1}	1.2-9.1, 5.2	NA	Optimum: <200	200	
Sulfate (SO_4^{2-})	mg L^{-1}	11.0-112.8, 38.7	NA	Optimum: <500	250	
Uranium (U)	µg L^{-1}	0.7-4.2, 2.2	30 (P)		NA	
Zinc (Zn)	µg L^{-1}	2.2-60.6, 17.0	NA	Optimum: <3	1	

Note: NA= no health based guideline value is provided; According to WHO Drinking-water Quality 4th edition (2011):
A = Provisional guideline value because calculated guideline value is below the achievable quantification level;
C = Concentrations of the substance at or below the health-based guideline value may affect the appearance, taste or odour of the water, leading to consumer complaints;
D = Provisional guideline value because disinfection is likely to result in the guideline value being exceeded;
P = Provisional guideline value because of uncertainties in the health database;
T = Provisional guideline value because calculated guideline value is below the level that can be achieved through practical treatment methods, source protection, etc.

Most of the concentrations of the elements are at low level in river waters of the Yarlung Tsangpo compared with the global average[19]. It should be noted that high concentrations of manganese (Mn), copper (Cu), cadmium (Cd), lead (Pb) and zinc (Zn) were found in parts of the socio-economically developed regions in the Yarlung Tsangpo river basin. The trace element in waters of the Yarlung Tsangpo are mainly governed by the weathering of bedrocks followed by up-concentration due to high aridity, human activities might also have an effect on the water chemistry over the region. Notably, in the Yarlung Tsangpo near the Yangbajing, high levels of arsenic (As) were observed, which is mainly due to the distribution of arsenic-rich springs within the basin[20,21,22].

Watercourse within the Yarlung Tsangpo River can be generally considered pristine

River water chemistry is highly variable by natural environment conditions such as basin lithology, hydrology and climate. Based on the pH and ions study, waters in the Yarlung Tsangpo river basin were characterized by high alkalinity due to the high concentrations of Ca^{2+} and HCO_3^-. TDS was ~157 mg L^{-1} in the basin fluctuated from 66 mg L^{-1} to 265 mg L^{-1}, which was in a common level compared to other rivers in the world. The ionic characteristic study of river water chemistry of the Yarlung Tsangpo was mainly controlled by natural processes, such as weathering of carbonates, silicates, and evaporites, and drainage from geothermal waters and saline lakes. By comparison with the standards from WHO and GB for drinking water, all ions were within the maximum desirable limits and concentrations of most elements were under the guideline of WHO. Watercourse within the Yarlung Tsangpo River can be generally considered pristine.

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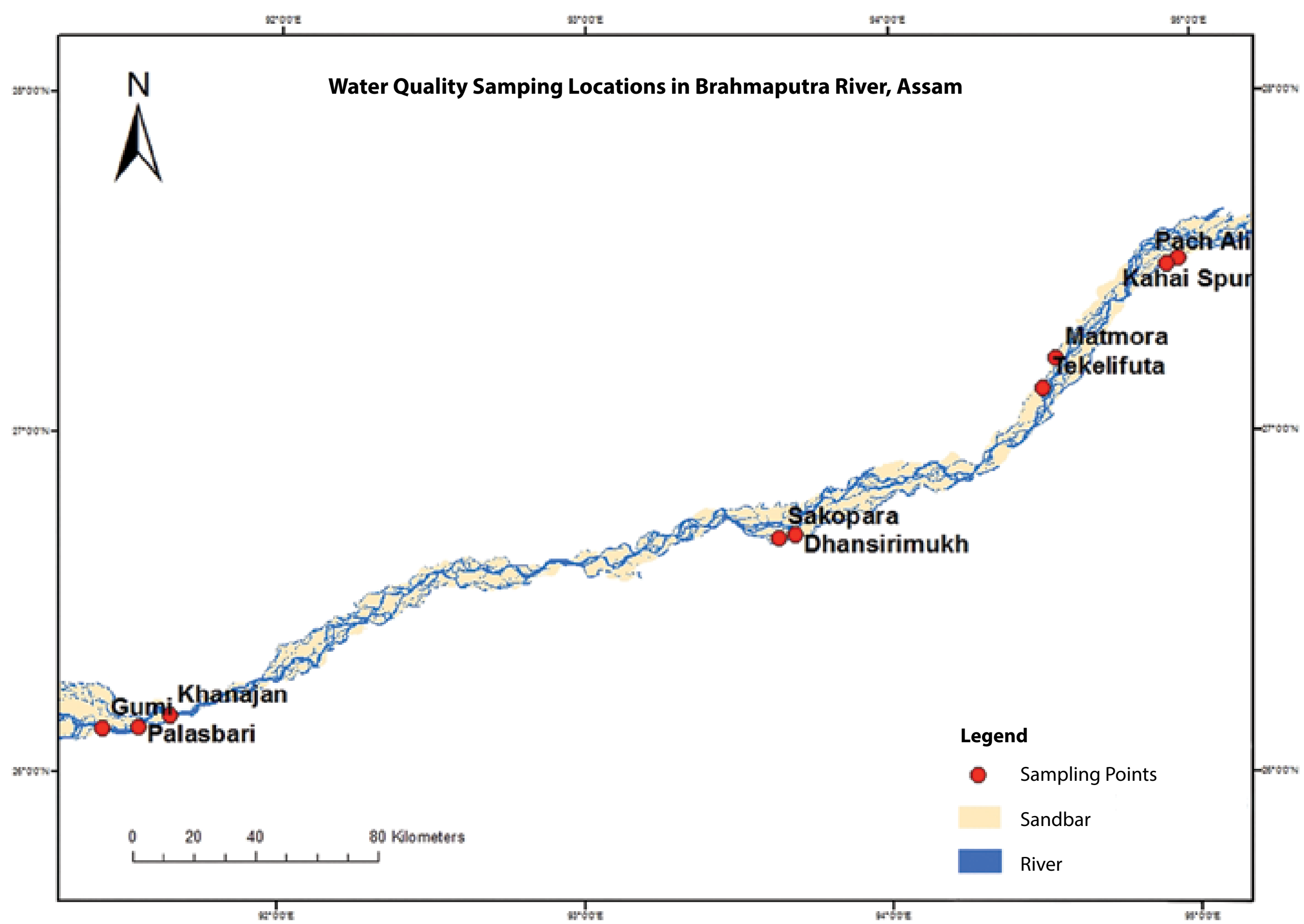
Brahmaputra River

Minakshi Bora

BRAHMAPUTRA RIVER plays an important role in the life and livelihood of the riverine population apart from supporting unique watershed ecology and therefore its water quality assessment is pivotal. Unfortunately, proper water sampling and laboratory-based water quality assessment covering the entire length of the river is largely missing in case of Brahmaputra River. Hence, the establishment of a detailed and scientific field-based water quality database for the river is very much essential for deploying and strengthening a proper water quality management plan. An attempt has been made to analyze an already existing database procured by Prof Dulal C Goswami under the Northeastern Integrated Flood and Riverbank Erosion Management project (Assam) sponsored by Asian Development Bank during the year 2007[23]. Unlike other water quality studies done so far on the Brahmaputra, the advantage of this study is that it covers the entire length of the river in Assam in the upper, middle and lower reaches

Figure 3: Map showing the sampling sites



Like all other Indian rivers, coliform contamination is considerably high in the Brahmaputra river along major locations at the vicinity of human habitation

each with multiple sampling points. The sampling sites are namely Pach Ali, Kahai Spur, Matmora, Tekelifuta, Dhansirimukh, Sakopara, Khanajan, Palasbari and Gumi (Figure 3).

A total of 24 different water quality parameters viz. color, odour, temperature, pH, electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), total hardness, calcium, magnesium, Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), chloride, sulfate, nitrate, ammonical nitrogen, phosphorus, arsenic, iron, manganese, lead, fluoride, total coliform and fecal coliform were analyzed by following the standard protocols given by Trivedy and Goel[24] and APHA[25]. Based on the collected data an overview of the water quality status has been obtained and the results are presented in Table 2 given below and are discussed in the subsequent paragraph.

Table 2: Water Quality of Brahmaputra River at selected sampling sites

Parameters	Kahai Spur	Pach Ali	Matmara	Tekelifuta	Dhansirimukh	Sakopara	Khanajan	Palasbari	Gumi
Color	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless	Colorless
Odor	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
Temperature	20	18	22	20	21	22	24	22	19
pH	7.5	5.8	7.4	6.2	7.1	6.9	6.7	6.7	7.7
EC	3400	800	2000	1800	2400	2600	3100	3000	3600
TSS	172	189	137	169	180	197	193	183	229
TDS	13.6	15.7	12.9	12.1	14.2	17.1	17.4	16.9	18
Total Hardness	64	42	46	50	52	42	52	48	50
Calcium	12.02	14.43	12.83	16.83	13.6	14.4	13.07	12.02	15.23
Magnesium	51.97	27.572	33.18	33.17	38.4	27.6	38.93	35.98	34.77
DO	6.49	8.91	8.91	12.16	8.1	9.7	7.41	9.73	10.54
BOD	4.2	4.6	3.6	3.9	4.2	3.2	3.46	3.25	3.96
Chloride	34.02	25.56	22.72	29.82	27.4	24.1	27	27	26
Sulphate	7.44	4.69	10.78	12.11	6.7	8.4	10	10	10
Nitrate	3.91	4.32	4.21	2.76	2.3	1.8	3.14	3.26	BDL
Ammoniacal Nitrogen	3.8	4.5	1.2	1.8	3.1	2.8	2.8	2.4	2.1
Phosphorus	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Manganese	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Iron	0.87	0.9	0.91	0.86	0.76	1.12	1.84	1.12	0.9
Fluoride	1.4	1.07	1.33	1.6	1.4	1.07	1.27	1.46	1.37
Arsenic	0.002	0.003	0.01	0.012	0.002	0.001	0.004	0.001	0.002
Lead	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL	BDL
Total Coliform	9	12	7	9	9	11	9	9	11
Fecal Coliform	1	2	1	1	1	0	1	0	1

N.B: All the parameters are in mg/l except temperature (˚C), pH, electrical conductivity (µS/cm) & Arsenic (ppb); BDL-Below Detection Limit

Source: Field monitoring and analysis done by Department of Environmental Science, Gauhati University

Out of the 24 parameters examined, six parameters, that is, pH, electrical conductivity (EC), magnesium, fluoride, iron and coliform count were observed to have crossed either the desirable or the permissible limit given by various standardization agencies such as BIS and ICMR. The survey indicates that surface water quality of the Brahmaputra River is acceptable in terms of mineral content and organic matter. However, like all other Indian rivers, coliform contamination is considerably high in the Brahmaputra river along major locations at the vicinity of human habitation. River Bharalu, a tributary of Brahmaputra which drains through the Guwahati

city reports very high coliform count in the recent past (Central Pollution Control Board report). Notably, bacteriological quality of the Brahmaputra River water is generally worst during May and June when a lot of surface runoff occurs during the early monsoon outbreaks.

Besides, another water quality parameter, that is, turbidity, which was not monitored during the present study, is also of major concern in the river. According to a report by East Siang Public Health Engineering Department during the year 2017, turbidity level as high as 425 NTU was recorded in the Siang river which is a major contributor of the Brahmaputra river. The excessive suspended sediment load during rainy seasons is responsible for the high turbidity levels in the river water. Excessive turbidity of the Brahmaputra river in the recent times is also related to the geological instability of the region. As the river valley and its adjoining highlands lies in geologically unstable and seismically active Eastern Himalayan belt, it experiences frequent earthquakes. These earthquakes trigger massive landslides and the debris thus generated in turn increases the turbidity of the river water[26].

Excessive turbidity of the Brahmaputra river in the recent times is also related to the geological instability of the region

Furthermore, in order to attain a broader perspective about the overall water quality status, a water quality index (WQI) calculation was also performed using *Weighted Arithmetic Index method*[27]. WQI aims at assigning a single value to the water quality of a source by translating a list of parameters and their concentrations present in a sample into a single value[28]. A pioneer work by Brown *et al*[29] stated that according to the range of WQI values, five water quality status categories can be classified: 0 to 25 is *excellent*; 26 to 50 is *good*; 51 to 75 is *poor*; 76 to 100 is *very poor*; and finally, above 100 is *unsuitable for drinking and fish culture*. The WQI values calculated in the current study ranged from a minimum of 29.8 to a maximum of 74.5. Out of nine sampling sites, four sites, namely, Pach Ali, Tekelifuta, Sakopara and Palasbari exhibited good water quality status with WQI values less than 50. While the remaining five sites, Kahai Spur, Matmora, Dhansirimukh, Gumi and Khanajan, exhibited poor water quality status with WQI values ranging between 50 and 75. Proper treatment is suggested prior to any use of the water falling under poor category.

Fortunately, direct pollution sources are mostly absent in the Indian stretch of the Brahmaputra River channel and moreover, owing to the huge amount of water discharge carried by the river, the pollutants added to it easily gets dispersed or diluted with time and space. However, a concerning fact about the overall water quality of the Brahmaputra river is that some of its tributaries like Dibru, Bhugdoi, Dhansiri, Gelabil and Bharalu are considered to be very polluted which in turn are contaminating the otherwise pristine water of the Brahmaputra river to a great extent. The present set of data will provide valuable insights in designing a suitable and holistic water quality management scheme in the Indian part.

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From a river to a drain: the Bharalu river

Shahnaj Laila

Originating in the Khasi Hills of India's north-eastern state of Meghalaya, the nearly 13 kilometers long Bharalu river starts off as the Bahini/Bihini near the Basistha Ashram at its foothills. According to Puranic legends, Lord Brahma's son, the great sage Basistha, meditated at this very site to rid himself of a curse given by one King Nimi. On Lord Vishnu conferring him with a boon of salvation, the sage brought down the three streams (Tridharas) of the celestial Ganga, namely, Sandhya, Lalita, and Kanta, to this point and absolved himself of all sins by taking a ritual bath there. Herein, the combined tridharas came to be known as the Basistha Ganga. On the banks of this river sprang up an ashram attributed to sage Basistha and is both a holy place as well as a popular picnic spot today. In 1764 C.E., the Ahom King Rajeswar Singha built the Jogeswar Shiva Temple within the ashram complex, surrounded by the Garbhanga Reserve Forest which is a rich elephant habitat.

A few kilometres from this point, the river bifurcates into two rivulets – the Basistha flowing towards the Ramsar site, Deepor Beel (Beel is an Assamese word for a lake); and the Bahini, meandering through Guwahati city before emptying into the Brahmaputra at Bharalumukh (mouth of the Bharalu literally).[30] It flows through areas like Beltola, Ganeshguri, R.G Baruah Road, before taking a sharp turn from the Assam State Zoo, whereon it comes to be known as the Bharalu. The river passes through some of the densest population clusters of the city including Ulubari and Sarabhatti before it meets the Brahmaputra.[31]

Historically, riverine transport was the preferred medium of movement of people and goods in Assam since it was inexpensive and the topography difficult. With the establishment of British rule in 1826 C.E., the necessity of an all-weather road for the purpose of facilitating military transport was strongly felt by 1836 C.E. By 1865 C.E., some steps were taken to construct such a road.[32] In order to sustain a large workforce, supply chains had to be maintained, especially the supply of firewood for fuel. With a sanction from the Bengal government in 1872 C.E., the Bhoraldhap forest area near Rani, adjacent to the Deepor Beel, was identified as a suitable site for felling timber, from which the tree-logs would be floated to Guwahati by the river Bharalu.[33] This is one example of the use of the Bharalu as a waterway.

However, this entire stretch of the river has been polluted today due to rampant urbanisation and the unchecked disposal of waste into its waters, rendering it unfit for human consumption. It has become a sewer and sections of it are known as the Mora Bharalu (Mora is Assamese word for dead), with putrefying stench wafting through the air. The river's catchment areas of central Guwahati are urban sprawls, and the prescribed width of its channel (40 feet) has been reduced to only 5-10 feet at many points due to encroachment. The Bharalu has been named as one of the 71 most polluted rivers in India by Central Pollution Control Board. Such problems have led to flash floods inundating many areas annually during monsoon. Moreover, the dangerously high levels of diarrhea causing fecal coliform bacteria make the water unsafe for drinking.[34]

In 2013, the Pollution Control Board of the Government of Assam, following the guidelines of the National River Conservation Directorate of the Ministry of Environment and Forests, Government of India, came up with a Detailed Project Report to clean up and restore the Bharalu.[35] A Feasibility Report of the Guwahati Development Department of Assam Government has also listed the Bharalu as one of the priorities of Guwahati Smart City development project involving a number of measures. It remains a mammoth task and needs proper planning and execution.[36]

Jamuna River

M Niamul Naser

THERE ARE quite a few cities and urban areas situated on the banks of the Jamuna and its tributaries, but there are no major industrial zones along the river. Pollution usually originates from domestic waste and agricultural sources along the river. The water quality parameters are within national standards as can be seen from Table 3 and water quality improves during monsoon as any pollution is flushed away by the river.

Table 3: Physicochemical condition of the Brahmaputra and Jamuna river system of Bangladesh

River System	Year	pH	DO mg/l	BOD mg/l	TDS mg/l	Chloride mg/l	References
Brahmaputra R	2016	7.18-7.78	5.8-7.6	1.0-2.2	52.2-168.0	4.0-12.0	DOE 2017
	2012	6.63-8.1	5.4-9.4	2.0-4.2	71-163	2.0-8.5	DOE 2014
	2010	6.82-7.28	4.0*-6.6	1.8-12.4*	62-120	4-8.5	DOE 2012
Jamuna R	2016	6.76-8.19	6.4-8.5	1.2-4.2	62.2-125.3	4.0-10.0	DOE 2017
	2012	7.2-8.46	5.9-8.5	2.8-11.0*	63.1-165.6	1.5-8.5	DOE 2014
	2010	6.16*-8.7	4.6*-7.4	2.0-5.0	66.0-170.0	3.0-14.5	DOE 2012
Meghna R	2016	6.08-7.09	0.8*-7.1	0.2-8.4*	28.1-228.0	2.0-30.99	DOE 2017
	2012	6.24*-7.6	5.2-7.2	0.3-3.4	45.0-150.0	3.0-11.0	DOE 2014
	2010	6.75-7.3	5.0-12.0	6.9*-20.2*	26.0-195.0	2.5-18.0	DOE 2012
Tista	2016	7.24-7.54	6.45-7.55	1.9-3.2	65.0-255.0	NA	DOE 2017
EQS** values for Bangladesh		6.5 – 8.5	≥5	≤6	1000	150-600	DOE 2017

** Values indicating the anomalies from EQS given by Department of Environment (2017)*

*** EQS, Environmental Quality Standard of Department of Environment (2017)*

Comparing the river water qualities, in 2010, 2012 and 2016, the total dissolved solids (TDS) and chlorides content were in good values of ranges for the DOE (2017) environmental quality standards (EQS). The pH, dissolved oxygen (DO) and Biological Oxygen Demand (BOD) have always been a challenge for the rivers of Bangladesh (see * values). In 2010, the pH values of Jamuna and in 2012 in Meghna fell slightly below the standard values. The slight alkalinity of water could be due to soil pH or for domestic and agricultural wastes disposed in the banks of the river. The DO, in 2010, falls slightly below the EQS values in Brahmaputra and Jamuna rivers, while in 2016, it was far below in Meghna river system. For the Brahmaputra and Jamuna rivers this may be due to low water flow and for Meghna river due to industrial effluents in the lean water flow period. The BOD indicates that the sewage contamination was earlier due to sporadic issues in both Brahmaputra and Jamuna rivers; but common in Meghna river system. Looking at the values of the upper riparian segments of Teesta river along with the Brahmaputra and Jamuna rivers, the northern rivers are in good aquatic state, especially for fishes. Further, the downstream Meghna river water quality is recently getting altered. There is a lack of detailed biological productivity and elements like plankton and benthos in the river ecosystem.

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NAVIGATION

Inland navigation

Uttam Kumar Sinha

Yarlung Tsangpo river

In a region where water is predominantly used for irrigation and with seasonal variation in rainfall, along with higher level of urbanization, maintaining channels for navigation is inherently difficult. Frequent flooding during the monsoons makes inland navigation more arduous. However, if the policy directive is to maximize broader social, economic and environmental benefits, then the inland navigation projects could not only support greater and faster economic growth but also lead to higher cooperation among the riparian countries. Navigation channels on the rivers as they flow and cut across the territorial boundaries in the region should be designed to become "pathways for prosperity" by interfacing with the social and economic needs of the riverine communities rather than being narrowly implemented for transportation utility by moving large containers from one river port to another. The emphasis on transboundary river cooperation cannot be less highlighted. For example, careful site-selection and constructing more storage dams in the upper reaches of the rivers could provide the twin benefits of flood management and adequate water flows for navigation in the downstream plains. Upstream-downstream cooperation on inland navigation is not unique as such arrangements are witnessed in several basins like the Nile, Amazon, Rhine and the Danube with discernable social and economic benefits including mechanisms to protect the environment and ecology of the rivers.

China has the largest network of waterways and the highest inland waterways cargo movement (one tonne over one kilometre) in the world

Inland navigation on the Yarlung Tsangpo is not a priority for China like, for example, the Yangtze river, winding through 9 provinces from east to west, which is regarded as an economic super-zone or more commonly as the 'golden waterway' generating 40 percent of China's GDP. China has the largest network of waterways and the

highest inland waterways cargo movement (one tonne over one kilometre) in the world. It considers inland port infrastructure critical to its global trade growth and has targets to improve the waterways with calls for strengthening shipping capacity, expanding roadway and railway networks, and building large-scale logistics centres. Even on the Mekong River, China plans to develop 500 tonnes shipping navigation capacity along the 630 kilometers stretch of the river from Yunnan province to Luang Prabang in Laos.

The middle reach of the Yarlung Tsangpo River is about 100 kilometers and the elevation changes from 3,993 to 2,780 meters above the sea level, with an average gradient of 0.13 percent. Annual precipitation in the middle reach of the Yarlung Tsangpo river decreases dramatically from 60 millimeters in Nyingchi, to 43 millimeters in Lhasa, to 28 millimeters in Gyantze. There are no significant inter-annual precipitation changes. Precipitations are concentrated from June to September, making up 90 percent of the annual total. The inflow of the middle reach of the Yarlung Tsangpo river mainly depends on precipitation, ice melting and groundwater recharge. Inter-annual flows are relatively stable[37]. Since 1962, there have some been short-distance transport around the Milin County. However, due to the large elevation change and high altitude, the potential for inland waterway development in Tibet has largely remained unutilised.

River transportation

Along with the development of modern infrastructure such as roads and railways, the river system is still a major mode of transportation for goods and people in India and Bangladesh. Waterways can be a cost efficient, environment-friendly mode of transport with huge potential to enable diversion of traffic from over-congested roads and railways.

Brahmaputra River

India, on the other hand, has 14,500 kilometers of recorded inland waterways. As compared to other means of transport, inland waterways are the least capital-intensive and with relatively low infrastructure costs, it is best suited to carry over-dimensional cargo (ODC). Despite such advantages, waterways trade in India constitutes less than 4 percent of the total inland cargo movement.

At various stages in the history of the Indian sub-continent's economic growth, waterways helped to create economic wealth. In probably the most authentic physical account of the Indian frontier, the *Imperial Gazetteer of India* (1909) describes the Brahmaputra basin as the "great highway" of the Himalayas from the plateau of Tibet to the plains of Assam. Like the Indus in the north-west, the bend of the Brahmaputra

Inland waterways are the least capital-intensive and with relatively low infrastructure costs, it is best suited to carry over-dimensional cargo

enfolds the Himalayas in the south-east and as the *Gazetteer* notes, "This magnificent natural outlet of the glacier and snow-fed drainage of the north is still a matter of speculative interest to geographers, although enough of it is known to justify the expectation that it may yet be recognized as one of the world's highways."

Romesh Dutt, the eminent economic historian had expressed, "Nature had provided India with great navigable rivers which had been the high roads of trade from ancient times. And the system of canals, fed by these rivers, would have suited the requirements of the people for cheaper although slower transit, and would have at the same time increased production, ensured harvests and averted famines." He went on to describe how narrow commercial considerations prevented the state's involvement in river navigation, while road and rail enjoyed continuous state support during the British rule. Despite extension of the Assam-Bengal Railway from Guwahati to Tinsukia in 1902 and to Lumding and Dibru-Sadiya in 1903; 98 percent of the weight of the trade was carried by the Brahmaputra in the Assam valley during the time.

With the partition and the ensuing politics, the significance of inland waterways in the stream of development thinking remained much neglected in the region since 1947.

This is fundamentally changing now with the realisation that waterways can be a cost efficient, environment-friendly mode of transport with huge potential to enable diversion of traffic from over-congested roads and railways. In 2016, through an Act

History of inland water transport on the Brahmaputra[38]

Brahmaputra in Assam has served as a means of transport and communication of merchandise and people from and to Assam. Long before the advent of the railway system into Assam, the river maintained the link with other parts of the country through the network of its waterways and hundreds of boatmen were employed in its services. It was the lifeline of Assam.

The modem steamship service between Assam and Calcutta was first introduced by a Calcutta-based British-owned river transport company, the India General Navigation and Railway Company Ltd, which was founded around 1844. Another British-owned company which started operation was the River Steamer Company that was founded in 1867 and subsequently renamed as River Steam Navigation Company. Later on, both these companies came to be known as the Joint Steamer Companies. In 1967 the Central Inland Water Transport Corporation, a Government of India undertaking, became the legal successor of the joint steamer companies, in Calcutta. The river service was well organized, an infrastructure developed on the riverine route, and it became one of the world's most flourishing internal trade routes.

The river was the bulk carrier of Assam's tea and jute to Calcutta, two of the country's most valuable foreign exchange earners. The steamer services from and to Calcutta were finally closed down during the Indo - Pakistan conflict of September 1965 and the century old, checkered history of the inter-state trade and commerce came to an end.

The main exports of Assam, tea, leather, and jute have to find their way to Calcutta for internal distribution in India and export overseas. These have necessarily to be carried by the inland waterways. Tea has to be carried by the river route not only because the railways cannot carry the entire traffic, but because the waterway is quicker than by rail and the tea warehouses in Calcutta are so located that they can mostly be used in conjunction with water transport." Imports into Assam from Calcutta were food grains, foodstuffs, salt, mustard oil, iron and steel materials, cement, cloth, textiles, etc.

Bangladesh has over 24,000 kilometers of rivers, rivulets and canals of which one-fourth are navigable during the monsoon and nearly one-sixth during the dry periods

of Parliament, India designated 111 rivers as national waterways and signalled a strong stake in harnessing its network of rivers for inland navigation.

In addition to the 111 rivers already identified for development of waterways, there are about 116 rivers, that can provide 35,000 kilometers of navigable stretches. By overlooking these natural waterways, the logistics cost in India today runs very high at about 18 percent. Comparatively in China it is 8 to 10 percent and 10 to 12 percent in most European countries. Inland waterways transport is cost effective when compared to rail and road transport. Calculations suggest that the cost of transporting cargo by waterways is one-fourth the cost of transport by rail and one-sixth the cost of transport by road. In an age of environmentally sound approaches, trade on waterways leaves a small carbon footprint. Estimates suggest that 1 horsepower can carry 4,000 kilograms load in water but only 150 kilograms by road and 500 kilograms by rail. One litre of fuel can move 105 tons weight per kilometer by inland waterways but only 85 tons per kilometer by rail and 24 tons per kilometer by road. India has a vision plan on the Brahmaputra section of the river called the National Waterways 2 (NW2) and is currently focused on the route from Dhubri to Sadiya in Assam.

Jamuna River

Bangladesh has over 24,000 kilometers of rivers, rivulets and canals of which one-fourth are navigable during the monsoon and nearly one-sixth during the dry periods. About 50 percent of Bangladesh's cargo traffic moves through these waterways along with nearly one-quarter of all the passenger traffic. Most of the freight transported by waterways in Bangladesh is bulk cargo including construction materials, petroleum products, fly-ash, fertilizers and food grains. There are over 22,000 registered vessels engaged in trade and passenger movement. In addition, there are more than 750,000 local or country boats for transport of goods and people. These are the lifelines for the poorest communities. Bangladesh is emphasizing strongly on regional inland waterways transport with its Connectivity Project Phase 2. The focus of these initiatives will be largely on long-distance trade and transport, bulk cargo, connecting the sea ports and the National Waterways 1 (NW1) to National Waterways 2. It is developing large number of waterways as a national priority. Some of them will connect with those in India to facilitate transboundary navigation.

The Bangladesh Inland Water Transport Authority (BIWTA) established 21 inland river ports and 380 landing stations in the country through 2014. In 2013–14, BIWTA recorded 87.40 million passengers and 35.18 million tons of cargo for the nine major river ports. Inland water transport is mainly used for the transport of bulk, dry bulk, and liquid bulk of construction materials, food grains, fertilizer, clinker, petroleum products, and other products. A large fleet of about 10,000 inland vessels are engaged in the carriage of goods and passengers. There are also approximately 750,000 boats powered by pump engines operating mainly in the rural waterways.

BIWTA's ongoing activities include dredging of waterways, procurement of dredgers and ancillary crafts, development of an inland container terminal at Ashuganj, improvement of inland ports and landing stations, development of landing stages in rural areas, and development of waterways around Dhaka city. An inland container terminal has been developed through a joint venture project of BIWTA and Chittagong Port Authority with an annual handling capacity of 116,000 TEUs[39], which is to be followed by another four inland container terminals under construction by the private sector.

About 50 percent of Bangladesh's cargo traffic moves through these waterways along with nearly one-quarter of all the passenger traffic

Despite being the cheapest mode of transport, the popularity of inland waterways transport as a mode of passenger and cargo transportation has been declining. The modal share of inland waterways transport fell from 16 percent passenger and 37 percent cargo in 1975 to 8 percent passenger and 16 percent cargo in 2005[40]. Much of the competition came from the road transport system. Inland waterways transport has suffered because many rivers of the country have been deteriorating both from natural, morphological processes and from withdrawal of water from the rivers causing decreased dry season navigability. This was further aggravated by poor or no maintenance of navigability, weak regulations and safety standards, low allocation of budgetary funds, and general under-investment by both public and private sectors. Tables 4 and 5 below illustrate the declining share of inland-water transportation (passenger and cargo) from 1975 to 2005, and Table 6 shows that almost all the existing routes fall in the basin area.

Table 4: Modal share of passenger and cargo

	Passenger Traffic (billion passenger-km)						
	Total	Road	%	Rail	%	IWT	%
1975	17.0	9.2	54%	5.1	30%	2.7	16%
1996	66.0	52.0	79%	3.9	6%	10.1	15%
Annual Growth 1996-2005	7.1%	6.6%		0.7%		1.3%	
2005	111.5	98.4	88%	4.2	4%	8.9	8%

	Cargo Traffic (billion ton-km)						
	Total	Road	%	Rail	%	IWT	%
1975	2.6	0.9	35%	0.7	28%	1.0	37%
1996	10.7	6.9	63%	0.8	7%	3.0	30%
Annual Growth 1996-2005	6.9%	8.6%		0.8%		0.1%	
2005	19.6	15.7	80%	0.8	4%	3	16%

Source: World Bank (2007)

Table 5: Employment in Inland Water Transport (IWT)[41]

IWT Employers	Employed	IWT Employers	Employed
Public Sector		Private Sector	
Bangladesh Inland Water Transport Authority	4,000	Landing Stations	668,000
Bangladesh Inland Water Transport Corporation	5,000	Inland Vessels	75,000
Department of Shipping	60	Dockyards	101,000
		Country boat and Mechanized country boat	5,500,000
		County boat yard	10,000
Total	6,363,000		

Table 6: Existing Navigation Routes in Bangladesh

Route	Length (km)	Remarks
Alaipur-Raita-Laxmipur	32	During lean period the minimum depth remains 1.5 m
Paksey-Lauskandi-Ghoramara	7	
Talbaria-Shantigram-Sengram	25	
Sengam-Habaspur-Stabaria	3	
Nazirganj-Durgapur	6	
Padma-Jamuna confluence	14	
Sub total	87	
Alaipur-sarda	14	Hydrographic survey never carried out
Sardu-Rajshahi	15	
Premtali-Godagari	6	
Sub total	35	
Total	122	

Source: Mishra et al. 2012[42]

Sand quarrying

Sand quarrying is an important source of livelihood in India and Bangladesh; but needs to be monitored in order to alleviate the negative impacts

International navigation

Uttam Kumar Sinha

INLAND WATERWAYS transport on the Brahmaputra is particularly promising between India and Bangladesh. The protocol agreement between these two countries remains a stable framework for transit and trade. The Bangladesh-India joint communiqué, published in January 2010 during the visit of the Prime Minister of Bangladesh to India, showed that an understanding had been reached to introduce transit trade through Bangladesh to connect mainland India and its northeast. This was considered as a breakthrough attempt to re-align Bangladesh's long-term development strategy with neighboring India. The India-Bangladesh Protocol on Inland Water Transit and Trade (PIWTT) signed in 2015 allows for inland vessels of one country to transit through specified routes of the other country with each country providing facilities of 'ports of call'.

The waterways connectivity presents to Bangladesh an opportunity to sell its commodities like garments, pharmaceuticals, and leather to India, Bhutan, and even Nepal

The following year, a vessel from Kolkata traversed Bangladesh to the north-eastern Indian state of Tripura highlighting the value of the protocol routes in boosting the isolated markets of northeast India and allowing the region access to the industrial and market centres in India and Bangladesh. The 19th PIWTT Standing Committee meeting between the two countries in 2018 significantly improved the protocol routes with the inclusion of Rupnarayan river (NW-86) and expanded the number of 'ports of call' from five to six on each side by including Kolaghatin in West Bengal and Chilmari in Bangladesh. Standard-operating procedures for movement of passengers and cruise vessels on the inland routes were also agreed. Combining the services of the 1,620 kilometers NW-1 on the Ganga-Bhagirathi-Hooghly river system and the 891 kilometers NW-2 on the Brahmaputra between the town of Dhubri on the Bangladesh border and Sadiya in Assam and the 71 kilometers NW-6 on the Aai river in Assam (through Bangladesh) will open up greater economic benefit in the region benefiting the Indo-Gangetic plains, Bangladesh and the north-eastern states of India, which suffer from huge logistic cost of essential supplies.

The waterways connectivity presents to Bangladesh an opportunity to sell its commodities like garments, pharmaceuticals, and leather to India, Bhutan, and even Nepal. Currently Bangladesh sources less than 10 per cent of import from India, and less than 1 per cent of exports. A situation that will rapidly change for the better as the navigational routes are further developed.

Table 7 shows that all inland water transportation protocol routes either origin or terminate in Chandpur, which is within the greater Ganges-Brahmaputra-Meghna basin with river ties to the entire Brahmaputra River system.

Table 7: Description of Protocol International Routes with India

Route			Shoal			Year of Survey
Name	Class	Distance (km)	#	Length (km)	Min. depth (m)	
Raimangal-Chandpur route						
Raimangal-Chalna	II	119	2	1.7	1.6 and 2.2	2010
Chalna-Mongla	I	16	1	0.5	2.1	2010
Mongla-Ghasiakhali	I	31	1	20.0	0.5	2010
Ghasiakhali-Chandpur	I	200	-	-	-	2004
Chandpur-Daikhawa route						
Chandpur-Aricha	II	119	-	-	-	2006
Aricha-Sirajganj	II	92	6	6.0	(-)1.3-(+)1.8	2010
Sirajganj-Bahadurabad	II	88	5	5.0	(-)1.3-(+)1.0	2010
Bahadurabad-Chilmari	II	62	5	5.0	(-)1.2-(+)2.2	2010
Chilmari-Daikhawa	II	37	3	3.0	0.1 -1.5	2010
Chandpur-Zakiganj route						
Chandpur-Bhairab Bazar	I	123	NA		-	2002,2006
Bhairab Bazar-Madna	III	63	1	10.0	1.2	2010
Madna-Ajmiriganj	III	47	1	23.0	(-)1.0	2010
Ajmiriganj-Sherpur	III	71	-	-	-	2010
Sherpur-Zakiganj	III	115	1	1.5	1.5	2010

Source: Mishra et al. 2012[43]

In addition, Bhutan is also benefitting. Landlocked Bhutan can finally find access to the sea through downstream India and Bangladesh. For the first time in July 2019, using the Brahmaputra waterways from Dhubri in Assam to Narayanganj in Bangladesh, Bhutan was able to ship stone aggregates using India as a transit. The cargo was first transported by land routes from Phuentsholing in Bhutan to the Dhubri jetty covering a distance of 160 kilometers and thereon by ship to Narayanganj. The cargo capacity was 1,000 MT equivalent to 70 trucks on road. The development of Jogighopa in Assam as a logistics hub for movement of cargo to and from the north-eastern states and Bhutan gives fillip to the development of inland waterways on the Brahmaputra.

The bilateral approach with India and Bangladesh on the Brahmaputra continues to outline its engagement. In the context, therefore, the lower-riparian cooperation on the Brahmaputra is of greater value. The sub-regional platforms like the Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) which has transport and communication as one of the 14 sectors of cooperation and the Bangladesh-Bhutan-India and Nepal (BBIN) initiative to enable people and cargo movement across borders can act as a catalyst for cooperation on inland waterways.

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Enhancing navigation

Uttam Kumar Sinha

HAVING UNDERSTOOD the overall benefits of inland waterways and factored the cooperating actors in the equation, the question of how to enhance the scope of the Brahmaputra waterways becomes pertinent. The Brahmaputra has enormous potential to capture the regional aspiration but before it is fully realized it has a serious challenge to overcome and that being ensuring adequate water flows particularly during the dry months.

Storage dams: Building storage dams in the upper reaches of the Brahmaputra basin can provide multiple benefits notwithstanding the negative social and ecological impacts of building such structures. A cost-benefit analysis suggests that some of the negative impacts can be off-set by the positive gains.

For one, the storage dams will result not only in a perennial and reliable inland waterways transport but will also bring higher availability of water in the dry months for drinking water supplies, irrigation and industrial and commercial use. Second, it will enhance flood management capabilities leading to lower social and economic costs of floods and third with an all-season water transportation, climate change mitigation efforts will be strengthened.

It is estimated that for every tonne per kilometer of transportation on water GHGs emission is calculated to be 25 percent of that of transport by road. Fourth, development of water storage dams would require long-term planning, financial capabilities, sub-regional cooperation among the Brahmaputra-basin actors like Bangladesh and Bhutan and above all provincial or intra-state understanding in the north-eastern region of India. As a spin-off the overall benefits and gains from inland waterways transport can encourage water use efficiency in the water sectors. Significant water savings could further result in enhanced flows during dry season.

River dredging: Bangladesh has also taken a decision to dredge its rivers, and it will be advantageous for India to extend dredging services to Bangladesh. In fact, dredging work on Ashuganj-Zakiganj section on the Kushiyara river and Sirajganj-Daikhowa section on the Jamuna has commenced with India providing 80 percent of financial contribution. Once the work is complete, the river route, it is expected, will become navigable all year round for cargo vessels boosting further the connectivity and economic gains in the region.

As a spin-off the overall benefits and gains from inland waterways transport can encourage water use efficiency in the water sectors

Navigation services: Night navigation services for safe shipping and navigation between Pandu-Silghat stretch of the NW2 near the Bangladesh border has already been implemented and such systems and technologies like the river navigation information system or the differential global positioning system that India has installed at various locations on the NW2 should be offered to Bangladesh.

The technical and infrastructural advancement of the NW2 is driving hydrographic surveys and feasibility studies, many of them already completed, on a number of rivers meandering the north-eastern states. The total navigational length calculated is 1,213 kilometers of which the prominent ones connected to the Brahmaputra are the Subansiri (NW95), Dhansiri (NW31), Lohit (NW62), Aai (NW6), Beki (NW73), Dehing (NW30), Kopili (NW57) and Puthimari (NW82). The Aai and the Beki along with the Drangme Chhu or the Manas and the Mo Chhu or the Sankosh flow from Bhutan and empties into the Brahmaputra in Assam while the Wang Chhu confluences with the Brahmaputra in Bangladesh after traversing through West Bengal.

Inland water transport infrastructure: Particularly for Assam, the development of the inland waterways transport cannot be more critical. A vast populace both urban and rural need transport facilities and rely on small ferry services for their daily activities and livelihood. There are, however, operational limitations to these services.

The World Bank-funded Assam Inland Water Transport Project is a timely venture to help modernize the waterways transport services by building terminals, installing night navigational aids, connecting more areas and ensuing easy accessibility in all seasons. This has the potential to spur economic trade at one level and at another to facilitate education and health services to the riverine communities.

Furthermore, as Bangladesh is a cornerstone to enhancing inland waterways and any plans to expand India's ambitious national waterways will have to include trade to and through Bangladesh, given the recent traction in the bilateral relations Bangladesh is seeking Indian investment in almost 100 special economic zones (SEZs). India could take advantage of the proposal particularly in constructing cargo terminals, which are in shortage in Bangladesh. Additionally, Bangladesh could consider allowing Indian vessels to load/unload at all designated ports of call, a courtesy that India offers to Bangladeshi vessels, and adopt improved vessel standards.

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Bridges and connectivity

Xiawei Liao

BRIDGES CREATE connections. They allow safe passage where previously was not possible or was much more difficult. While the River and its tributaries are full of difficult topographies, many bridges have been built. A selection of the bridges in the basin is listed and illustrated here in this section.

Yarlung Tsangpo river

Qushui Bridge: The first modern highway bridge in Tibet
Qushui Bridge is located in the Qushui County in Tibet, 60 km to the Southwest of Lhasa. As the first modern highway bridge in Tibet, it entered into operation on August 1st in 1966. The bridge is 300 meters long and 10 meters wide.

Yarlung Tsangpo Bridge: The longest bridge on the Yarlung Tsangpo
The Yarlung Tsangpo Bridge, also called Cross Yarlung Tsangpo Bridge, is the longest bridge on the Yarlung Tsangpo until now. The construction started in April 2003 and started being used in August 2005. The bridge is 12 meters wide and 3,797 meters long with 108 openings. Each opening spans across 35 meters. The bridge is built on a total of 216 pile foundations.

Liuwu Bridge: The first multi-bridge flyover on the Lhasa River
Liuwu Bridge is the first modern flyover in Tibet located on the Lhasa River. Its construction was completed in 2007. The whole bridge is 29 meters wide and 1,660 meters long with the main bridge and two approaches, south and north. The design of the Liuwu Bridge has embodied many Tibetan cultural details such as the lotus shaped pier, which symbolizes luck.

Lhasa Bridge: The most scenic bridge on a tributary of Yarlung Tsangpo
Having been completed on July 1st, 2006, Lhasa bridge has become one of the most scenic spots in Tibet. The bridge is 940 meters long in total and located at an altitude of 3,700 meters above the sea level. It is only 2 kilometers from the Lhasa station and about 5 kilometers from the city center of Lhasa. The bridge is designed as flowy while *kha-btags* (traditional ceremonial scarf in Tibetan Buddhism) welcome guests from far away. The design also resembles snow mountains that are seen everywhere in Tibet.

Brahmaputra river

The mighty Brahmaputra river, flowing through the Assam valley is one of the longest rivers in India. Brahmaputra river is known as the lifeline of Assam state and separates the northeastern states from the rest of India. Six rail and road bridges have been constructed over the Brahmaputra in Assam and four new bridges are proposed.

Dholia Sadiya Bridge, Dhola Sadiya
Dhola Sadiya Bridge or Bhupen Hazarika Bridge across the mighty Brahmaputra river (Lohit River, a major tributary of the Brahmaputra River) at 9.15 kilometers, is the longest bridge in India and become operational in 2017. Prime Minister Narendra Modi inaugurated India's longest road bridge over Brahmaputra River on 26 May 2017.

Dhola Sadiya Bridge or Bhupen Hazarika Bridge across the mighty Brahmaputra river at 9.15 kilometers, is the longest bridge in India

A year after the Dhola-Sadiya Bridge was inaugurated, the Government of India announced plans for a longer bridge over the river Brahmaputra, which is likely to be completed by the year 2026-27. It will run between Dhubri in Assam and Phulbari in Meghalaya, close to the Bangladesh border. At 19.3 kilometers, the new bridge will be twice as long as the Dhola-Sadiya Bridge.

Bogibeel Bridge, Dibrugarh
Bogibeel Bridge across the Brahmaputra river in Dibrugarh is the longest road and rail bridge in India. The 4.94 kilometers long road-cum-rail bridge connects Dhemaji district and Dibrugarh district of Assam. This is also Asia's second longest rail-cum-road bridge, longest combined rail and road bridge in India and second longest bridge in Assam after Bhupen Hazarika bridge.

The Jamuna Bridge, also known as the Bangabandhu Bridge, is the longest bridge in Bangladesh. It has been named after the founder president of Bangladesh - Bangabandhu Sheikh Mujibur Rahman

Saraighat Bridge, Saraighat
Saraighat Bridge in Guwahati is the first rail-cum-road bridge over mighty Brahmaputra river in Assam. The Saraighat Bridge over the river Brahmaputra links the northeast region with the rest of the country.

Saraighat Bridge in Guwahati is the first rail-cum-road bridge over mighty Brahmaputra river in Assam

Kolia Bhomora Setu, Tezpur
Kolia Bhomora Setu (Bridge) is a 3.15 kilometers long road bridge over the Brahmaputra river near Tezpur, connecting Sonitpur with Nagaon. The bridge is one of the most important links between the northeastern states and rest of India.

Naranarayan Setu, Jogighopa
Naranarayan Setu is another important road-cum-rail bridge over the Brahmaputra river in Assam, connecting Jogighopa with Pancharatna. The 2.284 kilometers long double deck bridge is listed as one of the most impressive rail-cum-road bridges of India.

New Saraighat Bridge, Guwahati
The 1.49 kilometers long new Saraighat Bridge over the Brahmaputra river near old Saraighat rail-cum-road bridge was inaugurated in 2017. This is the second bridge on Brahmaputra river at Saraighat.

Jamuna river

The 18.5 meters wide and 5.63 kilometers long Jamuna Bridge, also known as the Jamuna Multi-Purpose Bridge, or the Bangabandhu Bridge, was opened in 1998 and is the longest bridge in Bangladesh. It has been named after the founder president of Bangladesh - Bangabandhu Sheikh Mujibur Rahman. The bridge connects the district of Bhuapur on the east bank of the river to the town of Sirajganj on the west bank. The bridge carries both road and rail traffic, as well as gas, electricity and telecommunications and was designed to bring the north-west region of Bangladesh into the country's mainstream economy and make inter-regional trade easier. It is part of the Asian Highway and the Trans-Asian Railway establishing a strategic link between the eastern and western parts of Bangladesh[44].

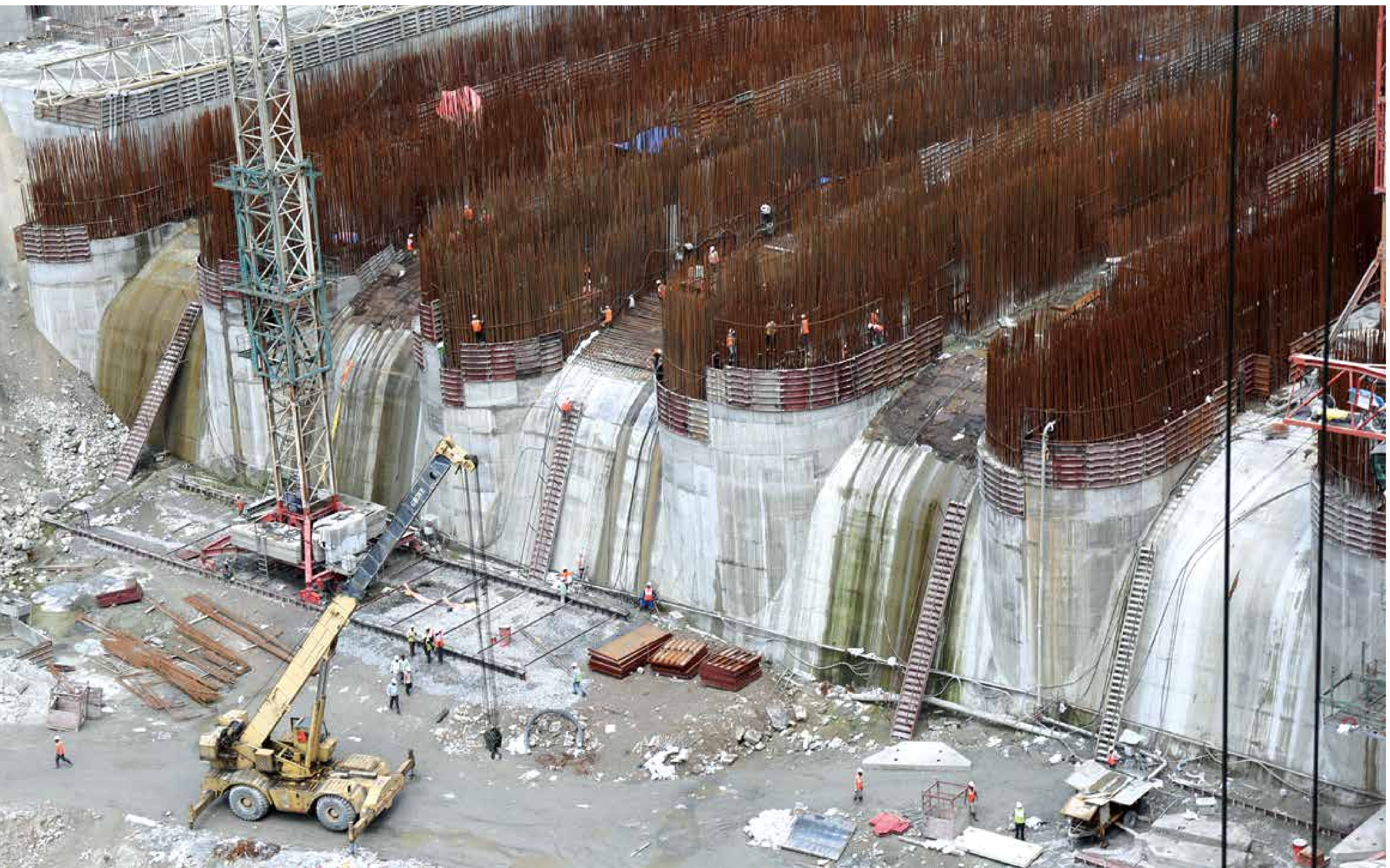
Using water power to make incense

Incense sticks are an important component of worship in Tibetan culture. Incense sticks are lighted in temples, homes, place of work and business and are an essential part of daily life. These pictures depict the process of using the power of flowing water to turn the wheels of the grinders for making a paste of the fragrant wood which is used to make the incense sticks.

Hydropower production

RIT International & EIMS

THE YARLUNG-Brahmaputra-Jamuna Basin has the potential for power generation from large storage dams as well as run-of-river and micro-hydro installations. Despite unmet demand for energy in the region, only a limited number of projects have been implemented to date[45]. The most important include the Zangmu Dam and several other storage projects in China[46], the aforementioned Teesta Barrage (which has a capacity of 67.5 MW), two other Teesta dams under construction in India (Low Dam III and IV), and several mid-sized structures on tributaries of the Brahmaputra in Bhutan.



Bhutan has seen improvements in development outcomes through investment in hydropower production and export. Analyses show that control infrastructures in this basin mainly advance energy production, except for the Teesta Barrage, which is mainly for irrigation. Dams far upstream in the basin may provide only limited flood protection due to modest storage-to-flow ratios and their inability to buffer against the heavy monsoon rainfall that falls in downstream portions of the basin[47]. Upstream dams, however, could have a major influence on augmenting dry season flows.

The Yarlung-Brahmaputra-Jamuna Basin has the potential for power generation from large storage dams as well as run-of-river and micro-hydro installations

The Zangmu hydropower station at the middle reaches of the Yarlung Tsangpo started operating in 2015. It is located next to the southern Tibetan county of Gyaca, which has a population of around 17,000. Located in a V-shaped valley at 3,200 meters above sea level, the Zangmu hydropower station is regarded as the highest in the world. The 510-MW plant is the largest in Tibet and equivalent to the entire existing hydropower-generating capacity of Tibet[48].

The Siang River is also endowed with rich hydropower potentials, amounting to more than 46 GW[49]. But it has been seen that hydropower development depends on various factors which include technical difficulties and political

The Brahmaputra basin provides scope for mutual benefit of the stakeholder countries with respect to energy generation

opposition, dearth of adequately investigated projects, land acquisition problem, environmental concern, regulatory issue, long clearance and approval procedure, the dearth of good contractor, and sometime law and order problem are the cause for the slow development of hydropower.

Although Assam has one of the lowest hydropower potentials in India's northeastern states, it has harnessed the maximum hydropower potentials in the region. Among all the northeastern states in India, Assam has harnessed maximum hydro potentiality, 55.14 percent, followed by Sikkim 15.6 percent and Meghalaya 11.78 percent. Currently, Assam has a capacity to produce 680 MW of hydro power, with another 275 MW capacity unexploited[50].

The Brahmaputra basin provides scope for mutual benefit of the stakeholder countries in respect to energy generation. India and Bhutan have hydropower potential, and both these areas have a list of planned hydropower plants. Bhutan and

India have already signed agreements for distribution of power. Currently with only one hydropower plant of 230 MW, Bangladesh is yet to take part in the negotiations. Possibilities for inclusion for Bangladesh exist, as the country is already allowing India for trans-shipment of goods between Assam and Meghalaya and the Kolkata port of India.

India and Bhutan have enjoyed long and fruitful collaboration in the hydropower sector by providing clean electricity to India, generating export revenue for Bhutan, and further strengthening the bilateral economic linkages.[51] The two countries have successfully concluded several power sharing agreements. In 1961, India and Bhutan signed the Jaldhaka agreement, constructing the Jaldhaka project situated on the Indian side of Indo-Bhutan border in West Bengal. A major part of the power produced at Jaldhaka hydropower plant was exported to southern Bhutan. In 1987, Bhutan's first mega power project, the 336-MW Chukha Hydropower Project (CHP) was fully funded by the Government of India with a combination of grant and loan.

The sale of hydropower accounted for the largest share of Bhutan's GDP. It is also the most important export item contributing about 40 percent of Bhutan's total exports

Subsequently, the two countries also signed the Agreement on Cooperation in the Field of Hydroelectric Power (HEP) in July 2006, which outlines the framework for cooperation in the field of Hydropower. In 2008, the two countries further signed the Protocol to the 2006 Agreement and agreed to increase the export of electricity from Bhutan to India from 5,000 MW to 10,000 MW by the year 2020. Of these, three projects totaling 2,940 MW (1,200 MW Punatsangchu-I, 1,020 MW Punatsangchu-II and 720 MW Mangdechu HEPs) are under construction.

The sale of hydropower accounted for the largest share of Bhutan's GDP. It is also the most important export item contributing about 40 percent of Bhutan's total exports. India finds her interests fulfilled in alleviating their power deficiency by supporting Bhutan and Bhutan in turn finds an opportunity to optimize its national income through power exports to India.

In addition to hydropower, sources of cooling water are going to be a major issue for large-scale thermal power plants. Water is required in various processes at thermal power plants, primarily for cooling purposes. Significant volumes of water are used to cool down the steam exiting the steam turbines to dissipate the residual heat. Air cooling tower technology could be a solution if adequate water cannot be arranged from the respective rivers.

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7. GOVERN

Framework for co-operation

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Bushra Nishat

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INTRODUCTION

Ganesh Pangare and Bushra Nishat

ACROSS THE globe, investments in infrastructure development such as roads, embankments, dams, barrages, diversions, irrigation schemes and power facilities, while bringing visible benefits at the local and national level, are also creating multiple burdens and risks to the river and millions of people who are dependant for their lives and livelihoods on the rivers, associated wetlands and aquatic resources. In the case of international/transboundary rivers like the Yarlung Tsangpo-Brahmaputra-Siang-Jamuna, these risks and burdens are made more complex by sovereignty implications and geopolitical dimensions. Countries and governments need to move towards a perspective of shared opportunities for positive regional benefits, while keeping in mind national and local needs and interests. Transboundary water management needs to harmonise water policies and standards and brings into focus issues at different levels and across sectors, encompassing not only technical but also social and economic implications. This is the reason it is important to understand, national as well as regional arrangements of all countries in a basin.

There are 263 transboundary water sources in the world that straddle or cross political boundaries of one or more sovereign states, constituting over 80 percent of worlds fresh water sources – rivers and aquifers

Development in the Basin has historically been piecemeal and undertaken on a project-by-project basis at the country level. Agreements between riparian countries in the region are mostly bilateral and may or may not have a holistic approach to water resources management. The complex geopolitics between riparian countries has been amplified by an incomplete basin knowledge base, the varying professional water resources management and technical capacities of the basin countries, and power asymmetry among the riparians. The absence of a basin-wide cooperative framework has translated into missed opportunities for regional economic growth, including in agriculture, hydropower development and trade, inland water transport, and disaster risk reduction.

Rustam Vania

This section is an inventory of the water management institutions, policies and transboundary agreements for the riparian countries of the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna basin – China, India, Bhutan and Bangladesh and also looks at challenegs and opportunities in the region.

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International[1] and policy framework for transboundary water management

China

Taylor W. Henshaw

CHINA SHARES about 40 major transboundary watercourses with Afghanistan, Bangladesh, Bhutan, Cambodia, India, Kazakhstan, Kyrgyzstan, Laos, Mongolia, Myanmar, Nepal, North Korea, Pakistan, Russia, Tajikistan and Vietnam. Most transboundary waters are located in the southwest area of the country (including: Yarlung Tsangpo-Siang-Brahmaputra-Jamuna; Shiquan/Indus; and Lancang/Mekong). Among these transboundary rivers, 12 originate in China. China is located upstream on most of its shared transboundary rivers.

Transboundary water management needs to harmonise water policies and standards and brings into focus issues at different levels and across sectors

China was one of three countries to vote against the 1997 Convention on the Law of the Non-Navigational Uses of International Watercourses (UN Watercourses Convention). Although China is not a party to Multilateral Environmental Agreements on water, it supports the principle of exchanging data and information with its neighboring riparian states[2].

According to Feng and He[3] – "trans-boundary water is mainly the responsibility of Ministry of Foreign Affairs because it relates to the relationship among the riparian countries. Yet given that Ministry's lack of specific knowledge of water resources, it must always be assisted by other ministries related to water issues", most importantly Ministry of Water Resources (MWR), Ministry of Ecology and Environment (MEE), National Development and Reform Commission (NDRC), National Energy Administration (NEA) as well as Energy State-owned Enterprises (SOEs) who are involved with hydropower development on international rivers.

The leading unit, Division of International Rivers is set up under the Department of International Cooperation, Science and Technology of MWR whose mandates include:

"In charge of foreign affairs related to international rivers, research and formulate related policies, organize and coordinate negotiations related to international rivers."

Furthermore, in accordance with the 2002 Water Law, revised from the 1988 Water Law, which stipulates that "the state shall exercise a water resources management system of river basin management in conjunction with jurisdictional management". the South-western rivers, including the Yarlung-Tsangpo, sit under the jurisdiction of the Changjiang Water Resources Commission. To summarize, within the MWR, Changjiang Water Resources Commission has the mandate to manage domestic issues with respect to the Yarlung-Tsangpo River as a River Basin Organization, while the Department of International Cooperation, Science and Technology has the mandate to manage international/transboundary issues related to the Yarlung-Tsangpo.

In addition those two departments, China Renewable Energy Engineering Institute under the MWR and the National Energy Administration are involved in Hydropower Development Planning along international rivers; Ministry of Emergency Management, Department of Flood and drought prevention (MWR) and Department of Water Project Operation Management (MWR) are involved with dam operations along the international rivers; Bureau of Water Transport of the Ministry of Transport is responsible for transport activities on international rivers.

Although transboundary rivers seem to be not of major concern to China's water policy makers, since it is hardly discussed or seen in China's policies, reports, governmental mandates and so forth, China has a record of (mostly bilateral) formal institutions with its neighboring countries regarding all different aspects related to transboundary river cooperation, for example, hydrological data sharing, navigation, fisheries, water sharing, economic cooperation. It should be noted that China's transboundary river cooperation institutions are primarily bilateral and less multilateral and most of them

do not focus exclusively on transboundary watercourses but on a broader cooperation agenda. In the north, a number of Sino-Russian transboundary water accords are in place (including the 2008 China-Russia Agreement Concerning the Reasonable Use and Protection of Transboundary Waters). The least formal arrangements are in place with South Asian countries regarding especially the Indus and Yarlung Tsangpo - Brahmaputra river basins. However, there has been a long history on transboundary water cooperation between China and India, which dates back to the 1950s and the process is summarized by Feng et al[4] as below in Table 1.

Table 1. China-India cooperation on transboundar rivers[5]

Year	Events	Cooperation
1950	Diplomatic ties established in 1950; the prime ministers visited each other in 1954	Provisions of discharge data in 1955, and of hydrologic information (discharge, rainfall, and water level) in 1957.
1984	Agreement on trade in 1984. Indian prime minister visited China in 1988	In 1993, agreement on environmental cooperation signed, along with gradual restoration of Sino-Indian relations
1997	Protocol on Cooperation	In 2002, MOU and the Implementation Plan on the Yarlung-Tsangpo/Brahmaputra
2003	Declaration on the Principles of Relations and Comprehensive Cooperation in 2003; Joint Declaration in 2005	MOU in 2005 and Implementation Plan in 2008. The Expert Level Mechanism on Trans-border Rivers (ELM) established in 2006, and the Work Regulation in 2008. MOU in 2008 and Implementation plan in 2010.
2010	Joint Communique	MOU in 2010 and Implementation Plan in 2011 on the Langqen Zangbo/Sutlej River.
2013	Joint Declaration; Agreement on Border Defence Cooperation.	MOU in 2013 and the Implementation Plans upon the Yarlung-Tsangpo/ Brahmaputra in 2013 and in 2014. MOU on Strengthening Cooperation on Trans-border Rivers in 2013
2015	Joint Declaration	In 2015, MOU upon the Langqen Zangbo/Sutlej River.
2018	Informal summit of the top leaders	In 2018, MOU and Implementation Plan upon the Yarlung-Tsangpo/ Brahmaputra; the 11th meeting of the ELM held; China notified of emergency information on a landslide on the mainstream to India.

China has reached memorandums of understanding with India and Bangladesh on flood control and sharing hydrological data on the river. In 2002 China agreed to provide flood season hydrological data (water level, discharge and rainfall) at three stations located on the river from June 1 to October 15 every year. The MOU expired in 2007. Similar five-year MOUs were reached in 2008 and 2013. In 2013, China agreed to provide an additional 15 days of hydrological data (May 15 to October 15) each year on the River. The parties agreed to "further strengthen cooperation on transboundary rivers, cooperate through the existing Expert Level Mechanism on provision of flood-season hydrological data and emergency management, and exchange views on other issues of mutual interest." Both sides recognized that transboundary rivers and related natural resources and the environment are "assets of immense value to the socio-

economic development of all riparian countries" and the "cooperation on trans-border rivers will further enhance mutual strategic trust and communication as well as strengthen the strategic and cooperative partnership." A revised implementation plan (containing technical details of provision of information, data transmission methods and cost settlement) was executed in June 2014.

An Expert Level Mechanism (ELM) was established in 2006 between China and India to discuss interaction and cooperation on the provision of flood season hydrological data, emergency management and other issues as agreed regarding transboundary rivers. The ELM has held 11 meetings since its establishment, and only one annual meeting cancelled, in 2017 because of the border conflicts. Normal issues discussed in the agendas include reviewing previous bilateral cooperation and utilization reports on the provision of hydrological information, and discussion of the MOUs and the relevant implementation plans. Other issues agreed on by both sides (but without detailed information) include strengthening cooperation, exchanges on the situation of the projects on the Yarlung-Tsangpo - Brahmaputra, notification on blockages of the mainstream, and so on[6]. In general, the ELM is the normal channel and a technical decision supporting organization between China and India to facilitate transboundary

water cooperation. But it has a limited working scope, and its effects are restricted by the broader Sino-Indian diplomatic relations.

China has also entered into comparable MOUs with Bangladesh in 2006 and 2008. In a 2007 Joint Communique, the countries agreed "to cooperate in the field of water resources, utilize and protect the water resources of transnational rivers in the region keeping in mind the principles of equity and fairness." In 2008, China entered into hydrological data sharing MoU with both Bhutan and Bangladesh, providing that in flood season, China will provide hydrological information to Bhutan and Bangladesh from three hydrological stations along the main stream of the Yarlung Tsangpo.

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India

Taylor Henshaw

INDIA HAS entered into a number of transboundary water agreements, ranging from water allocation to hydropower development, with Pakistan, Nepal, Bangladesh, Bhutan, China and Nepal.

India-China Agreements

India has reached MoU with China on flood control and sharing hydrological data in the Yarlung Tsangpo. In 2002 China agreed to provide flood season hydrological data (water level, discharge and rainfall) at three stations located on the river from June 1 to October 15 every year. The MOU expired in 2007. Similar five-year MOUs were reached in 2008 and 2013. In 2013, China agreed to provide an additional 15 days of hydrological data (May 15 to October 15) each year on the river. The parties agreed to "further strengthen cooperation on transboundary rivers, cooperate through the existing Expert Level Mechanism on provision of flood-season hydrological data and emergency management (see below), and exchange views on other issues of mutual interest." Both sides recognized that transboundary rivers and related natural resources and the environment are "assets of immense value to the socio-economic development of all riparian countries" and the "cooperation on trans-border rivers will further enhance mutual strategic trust and communication as well as strengthen the strategic and cooperative partnership." A revised implementation plan (containing technical details of provision of information, data transmission methods and cost settlement) was executed in June 2014.

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India-Bhutan Agreements

The 1949 (and updated in 2007) India-Bhutan Friendship Treaty provides for perpetual peace and friendship, free trade and commerce, and equal justice to each other's citizens. The Treaty is the basis for present-day joint hydropower plants on Brahmaputra tributaries in Bhutan.

India's Hydropower Partnership with Bhutan

Bhutan and India have a reciprocal arrangement that sees a power-deficient India supply technical and financial assistance to resource-rich Bhutan to develop numerous hydropower projects for the benefit of both countries Bhutan relies on the export of power (which accounts for about 20-25 percent of GDP) for sustainable development, while India acquires much-needed energy to drive its rapidly growing economy.

Since 2007, cooperation between Bhutan and India has been enhanced through agreements over long-term purchases and Indian financial support for hydropower projects in Bhutan, as well as the introduction of public-private partnership arrangements. India and Bhutan have signed memoranda of understanding to reach this installed capacity target. Ten hydropower projects have been planned for implementation over Bhutan's 10th and 11th Five-Year Plan cycles. The installed capacity additions by 2020 will tap a projected 42 percent of Bhutan's technically feasible hydropower resources.

In addition to hydropower development, India and Bhutan have cooperated to establish the *Comprehensive Scheme for Establishment of Hydrometeorological and Flood Forecasting Network on Rivers Common to India and Bhutan* (1979). This network consists of 35 hydrometeorological stations located in Bhutan. (These stations are maintained by Bhutan with funding from India). A Joint Expert Team (comprised of officials from both governments) tracks the progress of the network. The two countries have also formed a Joint Group of Experts on Flood Management. This entity discusses and assesses the probable causes and effects of the recurring floods and erosion in the southern foothills of Bhutan and adjoining Indian plains. It recommends remedial measures.

India-Bangladesh Agreements

India is not party to any agreements with Bangladesh on the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna.

The Teesta, a tributary of the Jamuna, has been a longstanding issue between India and Bangladesh since 1952. India has constructed the Teesta barrage at Gazaldoba, West Bengal, upstream of the India-Bangladesh border, to provide water to northern parts of West Bengal. In 2010, during the 37th Indo-Bangladesh Joint River Commission, Bangladesh proposed a draft "interim agreement" and India offered a "statement of principles" on sharing the Teesta waters. The two countries could not reach agreement in 2011. In March 2013 the President of India assured Bangladesh of India's commitment to a "fair, reasonable solution" on the Teesta and stated that consultations with stakeholders would take place.

India-Bhutan Agreements

An India-Bangladesh-Bhutan Working Group on Water and Power has been established for sub-regional cooperation on water resources management and hydropower development. The first meeting was held in April 2013. The parties agreed at that time to prepare a framework for trilateral cooperation. There has been no further reporting on the Working Group's progress.

An India-Bangladesh-Bhutan Working Group on Water and Power has been established for sub-regional cooperation on water resources management and hydropower development

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Bhutan

Taylor Henshaw

BHUTAN SHARES a 600 kilometer border with India on the east, south-west and west; and a 470 kilometer border with China on the north and northwest. Bhutan's international water agreements primarily focus on hydropower projects with India. The country also has flood forecasting and warning agreements with India and China. Ministry of Foreign Affairs (MOFA) is the designated ministry of the Royal Government of Bhutan which oversees the foreign relations of Bhutan. The Ministry has the Department of Multilateral Affairs which focusses on transboundary water management. As per Bhutan's National Water Policy[7]:

- Trans-boundary water issues shall be dealt in accordance with international laws and Conventions to which Bhutan is a signatory.
- Cooperation in information sharing and exchange, appropriate technology inwater resources development and management, flood warning and disastermanagement shall be initiated at the national, regional and global levels.

Bhutan was an absentee to the 1997 UN Watercourses Convention vote and has not ratified the Convention.

The Bhutan Water Policy recognizes the tremendous potential of hydropower for socio-economic development and export. The Policy states that transboundary water issues are to be dealt with in accordance with international law and conventions to which Bhutan is a signatory, while taking into consideration the integrity of the rivers and the legitimate water needs of riparian states. Cooperation in information sharing and exchange, appropriate technology in water resources development and management, flood warning, and disaster management are to be initiated at the national, regional, and global levels. The National Environment Commission is empowered to address matters of international water cooperation.

Flood Forecasting and Warning

In addition to hydropower development, Bhutan and India have cooperated to establish the *Comprehensive Scheme for Establishment of Hydrometeorological and Flood Forecasting Network on Rivers Common to India and Bhutan* (1979). This network consists of 35 hydrometeorological stations located in Bhutan. (These stations are maintained by Bhutan with funding from India). A Joint Expert Team (comprised of officials from both governments) tracks the progress of the network. The two countries have also formed a Joint Group of Experts on Flood Management. This entity discusses and assesses the probable causes and effects of the recurring floods and erosion in the southern foothills of Bhutan and adjoining Indian plains. It recommends remedial measures.

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Bangladesh

Taylor Henshaw

BANGLADESH HAS a dense network of rivers (about 405), *khals* (floodplain channels) and wetlands. The country shares 54 rivers with India and three rivers with Myanmar. The major rivers are the Ganges, Brahmaputra and Meghna (Nepal, Bhutan and China are also river system riparians). Bangladesh is downstream on all three major rivers. These rivers lead into the world's largest delta (and the Sundarbans mangrove forest).

Bangladesh has a dense network of rivers (about 405), khals (floodplain channels) and wetlands. The country shares 54 rivers with India and three rivers with Myanmar

Bangladesh voted in favour of the 1997 UN Watercourses Convention but has not ratified it.

The 1999 National Water Policy contains policy for fostering international cooperation in water management. These provisions are:[8]

(a) Work with co-riparian countries to establish a system for exchange of information and data on relevant aspects of hydrology, morphology, water pollution, ecology, changing watershed characteristics, cyclone, drought and flood warning, and to help each other understand the current and emerging problems in the management of the shared water sources;

(b) Work with co-riparian countries for a joint assessment of all the international rivers flowing through their territories for better understanding of the overall basins' potentials;

(c) Work jointly with co-riparian countries to harness, develop, and share the water resources of the international rivers to mitigate floods and augment flows of water during the dry season;

(d) Make concerted efforts, in collaboration with co-riparian countries, for management of the catchment areas with the help of afforestation and erosion control for watershed preservation and reduction of land degradation;

(e) Work jointly with co-riparian countries for the prevention of chemical and biological pollution of the rivers flowing through these countries, by managing the discharge of industrial, agricultural and domestic pollutants generated by human action; and

(f) Seek international and regional cooperation for education, training, and research in water management.

The Ministry of Foreign Affairs (MOFA) formulates and executes the foreign policy of the Government of Bangladesh and represents the State to foreign governments and international organizations. While MOFA maintains liaison for any bilateral or international issues, it is the relevant ministries that guide MOFA on technical matters, in case of of transboundary water, this is Ministry of Water Resources (MoWR). Any MoU related to transboundary water resources is also signed by MOWR, but treaties and agreements are dealt by the Prime Minister's office with support from MOWR and have to be approved by parliament. In case of issues like inland navigation and energy (hydropower) the main minsitries are Ministry of Shipping and Ministry of Power, Energy and Mineral Resources respectively, however MoWR participates in related meetings and is consulted in decision making. Under MoWR, JRC is agency that is responsible for transboundary water resources management.

Joint Rivers Commission Bangladesh (JRC)

The Joint River Commission is a bilateral working group established by India and

Bangladesh in the Indo-Bangla Treaty of Friendship, Cooperation and Peace that was signed on March 19, 1972 and came into being in November, 1972. As per the treaty, the two nations established the commission to work for the common interests and sharing of water resources, irrigation, floods and cyclones control. JRC's main activities include carrying out comprehensive survey of the river systems shared by the two countries, formulate projects concerning both the countries in the fields of flood control and to implement them, to formulate detailed proposals on advance flood warnings, flood forecasting, study on flood control and irrigation projects on the major river systems and examine the feasibility of linking the power grids of Bangladesh with the adjoining areas of India, so that the water resources of the regions can be utilized on an equitable basis for mutual benefit of the people of the two countries.[9] JRC is also responsible for dealing with riparian countries of Bhutan, China and Nepal.

Bangladesh-India Agreements

Cooperation between India and Bangladesh started with the first treaty 'India-Bangladesh Treaty of Friendship, Cooperation and Peace' signed in 1972. This paved the way for building further relations in various sectors including trade, water allocation and transportation. In December 1996 both the countries signed the *'Treaty on Sharing of the Ganges Waters'* at Farakka. The mutual agreement provided an arrangement for sharing of the Ganges waters at Farakka in a spirit of mutual accommodation and the need for a solution to the long-term problem of augmenting the flows of the Ganges. Additionally, there are around 100 MoUs between Bangladesh and India and some of

those relevant to the transboundary rivers. However, Bangladesh is not party to any agreements with India on the Brahmaputra-Jamuna River.

Indo-Bangladeshi Treaty of Friendship, Cooperation and Peace

Bangladesh and India signed the Treaty of Friendship, Cooperation and Peace in 1972 (consisting of a Preamble and 12 Articles), which provided a broad scope for bilateral relations. The Preamble specified "peace, secularism, democracy, socialism and nationalism" as the common ideals "to maintain fraternal and good neighbourly relations and to transform their border into a border of eternal peace and friendship". Over water resources, the parties agreed "to make joint studies and take joint action in the fields of flood control, river basin development and the fields of hydroelectric power and irrigation. While the Treaty's signature sparked other agreements, the governments declined to renegotiate or renew the Treaty when it expired in 1997.

In December 1996 both the countries signed the *'Treaty on Sharing of the Ganges Waters'* at Farakka. The mutual agreement provided an arrangement for sharing of the Ganges waters at Farakka in a spirit of mutual accommodation and the need for a solution to the long-term problem of augmenting the flows of the Ganges. Although this treaty focusses on the Ganges basin, this is considered as a milestone between the two contries.

Bangladesh and India have a long standing Protocol on Transit and Trade through inland waterways which was first signed in 1972

In Sepetember 2011, the "Framework Agreement on Cooperation for Development" between Bangladesh and India was signed by the two Prime Ministers. Article 2 states that "to enhance cooperation in sharing of the waters of common rivers, both Parties will explore the possibilities of common basin management of common rivers for mutual benefit". Article 2 of this agreement stipulates that "the Parties will cooperate in flood forecasting and control"; and "they will cooperate and provide necessary assistance to each other to enhance navigability and accessibility of river routes and ports".

Protocol on Inland Water Trade and Transit (PIWTT)

Bangladesh and India have a long standing Protocol on Transit and Trade through inland waterways which was first signed in 1972. It was last renewed in 2015 for five years with a provision for its automatic renewal for a further period of five years. The Protocol allows mutually beneficial arrangements for the use of their waterways for movement of goods between the two countries, one of the waterways being the Jamuna. Bangladesh and India developing two stretches of Bangladesh inland waterways on a 20:80 cost sharing basis[10].

Bangladesh-China Agreements

In 2008, Bangladesh agreed to a "Memorandum of Understanding upon Provision of Hydrological Information of the Yarlung Tsangpo - Brahmaputra River in Flood Season by China to Bangladesh", with China. This document provides that, in flood season, China will provide hydrological information to Bangladesh from three hydrological stations along the main stream of the Yarlung Tsangpo.

India-Bangladesh-Bhutan Working Group on Water and Power

An India-Bangladesh-Bhutan Working Group on Water and Power has been established for sub-regional cooperation on water resources management and hydropower development. The first meeting was held in April 2013. The parties agreed at that time to prepare a framework for trilateral cooperation. There has been no further reporting on the Working Group's progress.

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Multilateral cooperation in the region

OVER THE last couple of years, a new area of cooperation between the countries have emerged. The first regional body, South Asian Association for Regional Cooperation (SAARC) was established in 1985. Along with SAARC, other sub-regional institutions have materialized. While most of them are trade and connectivity oriented, the evolving institutional mechanisms and the growing political will offer opportunities to include critical water-energy-food issues.

The Bangladesh, Bhutan, India, Nepal (BBIN) sub-regional initiative is envisioned to improve economic cooperation and connectivity among the four South Asian countries

South Asian Association for Regional Cooperation (SAARC)

The South Asian Association for Regional Cooperation (SAARC) was founded in Dhaka as a vehicle for political and economic cooperation. Currently, the member countries are Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan and Sri Lanka. China is one of the nine observers at SAARC summits.[12] The SAARC maintains permanent diplomatic relations at the United Nations as an observer and has developed links with multilateral entities, including the European Union. The SAARC charter stipulates that decisions are to be unanimous and that "bilateral and contentious issues" are to be avoided.

The stated areas of cooperation of SAARC does not include water, and SAARC activities have been limited to 'soft areas of cooperation' such as holding seminars, workshops and trainings.[13] Although, SAARC Meteorological Research Centre and SAARC Disaster Management Centre (SDMC) promotes collective research on weather, meteorology and disasters (including floods).

Bangladesh, Bhutan, India and Nepal (BBIN) initiative

The Bangladesh, Bhutan, India, Nepal (BBIN) sub-regional initiative is envisioned to improve economic cooperation and connectivity among the four South Asian countries. This initiative allows to bypass some of the more complex political issues of SAARC and engage in direct discussions on connectivity in the four countries.[14]

The Initiative looks at land and inland waterways connectivity and energy, could be an effective sub-regional institutional mechanism for better water and hydropower cooperation. The first achievement of the BBIN initiative has been the Motor Vehicles

Agreement to make cross border trade and transport in and through the northeastern region of India to and from Bangladesh, Bhutan and Nepal more efficient.[15]

Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC)

The Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) is an international organisation of seven nations of South Asia and Southeast Asia that are dependant on the Bay of Bengal. The BIMSTEC member states are Bangladesh, Bhutan, India, Myanmar, Nepal, Sri Lanka and Thailand. This sub-regional organization came into being on 6 June 1997 through the Bangkok Declaration. The regional group constitutes a bridge between South and South East Asia and represents a reinforcement of relations among these countries. The objective of building such an alliance was to harness shared and accelerated growth through mutual cooperation in different areas of common interests by mitigating the onslaught of globalization and by utilizing regional resources and geographical advantages.

Unlike many other regional groupings, BIMSTEC is a sector-driven cooperative organization. Starting with six sectors—including trade, technology, energy, transport, tourism and fisheries—for sectoral cooperation in the late 1997, it expanded to embrace nine more sectors—including agriculture, public health, poverty alleviation, counter-terrorism, environment, culture, people to people contact and climate change, in 2008.[16] Compared to SAARC, BIMSTEC has greater trade potential. Given the fairly harmonious relationship among member states of BIMSTEC, improving its performance is an achievable goal. The success of BIMSTEC does not render SAARC futile; it only adds a new chapter in regional cooperation in South Asia. Two decades since its inception, however, BIMSTEC's successes have also been minimal.[17]

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The Bangladesh – China- India- Myanmar (BCIM) Forum

Ambuj Thakur

THE BCIM Forum is a Track II initiative that evolved out of China's need to open up its land-locked Southwest frontier provinces of Yunnan, Sichuan and Guizhou to the huge markets of South Asia through the warm water ports of the Indian Ocean Region. The principal mover has consistently been the Yunnan Provincial Government, along with the Yunnan Academy of Social Sciences (YASS) playing a seminal role. This coincided with India's weighing its various options in developing its own land-locked Northeastern Region under the ambit of its Look East Policy. Moreover, countries like Bangladesh and Myanmar also wished to join the bandwagon of these to economic giants to open up their economies for greater investment and looking out for markets to sell their products. It began to take shape on a preliminary conference on *Regional Development in India and China* in New Delhi on 19th-20th November 1998, where representatives from the two countries met to deliberate on a wide range of issues of mutual cooperation. The term 'Sub-Regional Cooperation Zone of China, India, Myanmar and Bangladesh' was explicitly mentioned by the senior YASS academic, Che Zhimin, with emphases on win-win cooperation, multi-lateralism, multi-polarity, and developing the periphery[18].

BIMSTEC has greater trade potential. Given the fairly harmonious relationship among member states of BIMSTEC, improving its performance is an achievable goal

With such a background, the first conference between Bangladesh, China, India and Myanmar was convened in Kunming, Yunnan, on 15th-17th August 1999, where a whopping ninety delegates from the Chinese side participated against a total of 39 combined from the rest three countries. The agreement to create a coordinating forum for such deliberations was agreed upon and it was christened as 'The Kunming Initiative'. From 1999 to 2019, a total of thirteen meetings have been held in all the four countries on a rotational basis, with a major focus on the three T's – Transport, Trade and Tourism, respectively. With time other issues like border trade and management, information technology, transnational crimes, illegal immigration, sports, to name a few, were also taken up. But the overt stress was always on improving connectivity networks by tapping into the United Nations Economic and Social Commission for Asia and the Pacific's (UNESCAP) decades-old proposals of linking Asia through its Pan-Asian Highway and Trans-Asian Railway networks respectively. It found echo it an earlier article in Beijing Review written in 1984 by Pan Qi, a former Vice-Minister for Communications of China, to open up Southwest China to the rest of the world by developing connectivity networks[19].

The joint statement reiterated the necessity for developing connectivity among the four countries through railways, air, waterways and roads, as also the digital and energy sectors

One of the major outcomes of these deliberations was the successful organisation and completion of the BCIM Car Rally from Kolkata to Kunming in February 2013, covering a distance of nearly 3000 kilometres and traversing through one of the sections of the old Southern Silk Route with cities like Jessore, Dhaka, Silchar, Imphal, Mandalay, Ruili, Dali on the way. Way back in 2009, then Chinese President had called upon promoting Yunnan as a bridgehead for the markets of China, South Asia and Southeast Asia respectively, and this rally could be seen as a step in that direction. By 2013, the term bridgehead was replaced by *Qiaotoubao* or 'Opening Up' to be in tune with China's official policy of peace and development.

Despite the institution of a Joint Working Group between the officials of the four countries and up-gradation of this initiative to an official Track I status, post-2013 it remained in cold storage for a long time due to the BCIM's coming under the ambit of the Belt and Road Initiative (BRI). It was only after the BCIM was dropped from the list of corridors in the Second BRI Meet in early 2019 that the decks were clear for the process to move ahead. In June 2019, on the sidelines of the 7th China-South and Southeast Asia Think Tank Forum and the South and Southeast Asia Commodity EXPO and Investment Fair in Kunming, the 13th BCIM Forum Meeting was held in the nearby city of Yuxi as a very low-key affair. The joint statement reiterated the necessity for developing connectivity among the four countries through railways, air, waterways and roads, as also the digital and energy sectors.

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PERSPECTIVES ON HYDRO-DIPLOMACY

Benefits from transboundary river cooperation

Ganesh Pangare and Bushra Nishat

COOPERATION OVER shared waters hinge on economics, legal frameworks, international law, international relations, geopolitics and hydrology. Transboundary water management is a long-term social, political and diplomatic effort and needs to be revisited and adapted according to the prevailing situation. Hydro-diplomacy could increasingly play an important role in strengthening and securing international relations and regional stability provided that it demonstrates concrete results on the ground; results for water, food and energy security, for a green economy, for healthy ecosystems and climate resilience, for people's health and well being and equity.

Agreements or treaties between riparian countries are mostly bilateral and may or may not have a holistic approach to river management. The conventional approach to hydro-diplomacy has been mostly focussed on negotiations on formulating a formal agreement or 'treaty' between two governments. The details of this agreement are usually prescribed by diplomats, government delegates and bureaucrats based on international conventions and standards. According to IUCN[20], this approach presumes hydro-diplomacy takes place under the authority of sovereign governments. While formal agreements at the official level are absolutely necessary, this approach often disregards that water resources are managed at multiple scales, thus for these agreements to work on the ground and to be acceptable at the national or country level, involvement of water users at different levels including local communities are also essential. A wide spectrum of formal and informal agreements, concentrating on concrete actions and sustainable solutions based on local priorities need to be in place. This means an all-inclusive approach with participation and involvement of a broad range of stakeholders including local communities, local governments, technical agencies, economic and private sectors. These agreements would then become the practical building blocks that augment and improve the potential for national governments to reach high-level agreements encouraging an operational roadmap for improvement in water governance towards sustainable development at the basin level[21]. Hydro-diplomacy approaches have the potential to play a facilitating and bridge-building role to support and enable these agreements to be put in place at different levels and between governments. Hydro-diplomacy starts with national interests and needs to be embedded in effective processes from the initial dialogue to being able to progress all the way to a constructive and enforceable agreement and its joint implementation at national and regional levels between riparian interests.

Hydro-diplomacy could increasingly play an important role in strengthening and securing international relations and regional stability

How does hydro-diplomacy work? How can it become an effective tool? How can hydro-diplomacy be put into practice? The answers lie in addressing three key challenges:

a) building consensus,
b) building institutions for hydro-diplomacy; and
c) identifying and catalysing the processes necessary to mobilise hydro-diplomacy.

It is important to keep in mind that consensus building in hydro-diplomacy starts with national interests, including economic development, security, and concerns and needs of the local population. Consensus building then requires trust and political will, platforms for dialogue and transparency, knowledge and information, capacity and tools for integration of competing demands and for identifying mutual benefits. Institutions for hydro-diplomacy include "truly" representative river basin

organisations (RBOs) that involve different stakeholders. RBOs need to work alongside other regional platforms across sectors and with the drivers of change in different rivers and different basins. Agreements will work on the ground only if they involve water users and have their support and take into account local politics. In order to catalyse and mobilise hydro-diplomacy, it is necessary to have in place processes in national agendas and in international dialogues, and also processes that support interaction with stakeholders. Education of stakeholders, communication and capacity development, and strengthening of national institutions is required in order to make these processes effective. Platforms and partnerships for dialogue that work across sectors and constituencies and inform and backstop governments would need to be put in place. Effective governance at the national level, sound policies and laws that align with trans-boundary issues would also need to align with hydro-diplomacy processes. There would need to be a better understanding of the issues that countries and citizens want to solve and what their concerns are. Lastly, it would be necessary to drive the application of the existing international processes related to water.

Hydrodiplomacy stems from the need to negotiate where competing and even conflicting interests towards shared water resources are present. National institutions involved in the management of water in transboundary rivers focus on their own national interests, often with consequences to the riparian needs and interests of the countries with whom they share the water resources. As pressures on water resources continue to increase with the prospect of climate change, population growth and fast developing technologies for water abstraction, water allocation and sharing between transboundary riparian states is likely to create frequent and more intense tensions. In response to this challenging reality, hydrodiplomacy could prove to be a crucial tool in ensuring that shared water resources are managed efficiently, sustainably and equitably.

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Water and Diplomacy

C M Shafi Sami

EXPERTS APPREHEND that in not too distant future almost half of world population will come under severe threat of water scarcity. Many ecosystems will be unable to cope with the rapidly growing demands of the basic needs, improvement of quality of life and economic development of an ever-increasing world population. As scarcity accentuates balancing the competing needs of societies will become a contentious issue between regions within many countries of the world. It will be an even more formidable task in case of international or trans-boundary water resources which are shared by two or more states. The enormity of the task can better be appreciated when we realize that there are 263 trans-boundary water sources in the world that straddle or cross political boundaries of one or more sovereign states, constituting over 80 percent of worlds fresh water sources – rivers and aquifers. Most of the water basins are shared by just two countries; others are shared by three or more countries – with the Danube River being shared by as many as 18 nations. As many as 145 countries of the world have territories within one or more trans-boundary water sources. More than 95 percent of the territories of as many as 33 countries lie within international river basins making them totally dependent on shared water resources. Trans-boundary water resources cover about half of the land surface of the earth and as much as forty to fifty percent of the total world population is dependent on shared water resources.

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On the other hand, there is a strong belief that rather than causing open conflict, trans-boundary water can serve as stimulus for cooperation. The need of water together with the prospect of sharing benefits from equitable use of these common water resources for sustainable socioeconomic development provides incentives for trans-boundary inter-state cooperation. According to the Food and Agricultural Organization, over the last millennium more than 3,600 treaties on international water resources have been negotiated with more than 200 such treaties being signed during the last century alone. Another significant aspect of cooperation in water sector is that once cooperation is forged the benefits of cooperation ensure that it becomes enduring and resilient.

Nations deriving benefit from water treaties find it prudent to hold on to them and continue to draw its advantage. The most remarkable resilience has been demonstrated by the Indus Water Treaty signed in 1960 between India and Pakistan; it survived more than half a century's bitter hostility between the neighbors and withstood two bitterly fought wars between them.

For long the international community has deliberated on various theoretical approaches governing the utilization, share, management and quality control of the shared water resources. These have resulted in the formulation of four major doctrines over a period of time. The main characteristics of these are presented in easily understood simple terms.

The Doctrine of Absolute Territorial Sovereignty was propounded in 1885 by US Attorney General J. Harmon and is popularly known as Harmon Doctrine. It gave all riparian states full and unlimited rights to whatever it wished to do with the water course falling within its territory without any regard for the needs and concern of other riparian countries. In reality this doctrine gave exceedingly favorable dispensation to an upper riparian state; a country having absolute sovereignty over the portion of an international watercourse within its borders would be free to use or divert all of the water from an international watercourse, leaving none for downstream states. This doctrine was invoked by the US on the flows of the Rio Grande river as an upper riparian state vis- a-vis Mexico. Interestingly, the USA itself rejected this doctrine in 1950 during its dispute over the waters of Columbia River in which Canada was the upper riparian state with USA lying down stream. On the other extreme and diametrically opposed to the Harmon Doctrine is the Doctrine of Absolute Territorial Integrity which asserts that a lower riparian country has the right to demand uninterrupted natural flow of water from the territory of any upper riparian state. This doctrine held that an upstream state could do nothing to interfere with the natural flow of the river into a downstream state. The third doctrine that deserves mention is the Doctrine of Limited (Restricted) Territorial Sovereignty which seeks to strike a reasonable balance between the earlier two doctrines. This doctrine gives recognition of a state's sovereignty over the water resources in its territory but enunciates that all states have equal sovereignty over the common water resources and hence sovereignty of one state is not unfettered and is 'limited' by the sovereignty of another state. Simply put every state has the sovereign right to use waters lying within its territory provided its use does not prejudice the sovereign rights and uses of another state sharing the common watercourse. This doctrine guarantees reasonable water to all co-riparian states under reasonable conditions; the doctrine seeks to espouse the principle of equitable utilization and no harm done to other riparian states. The fourth doctrine is known as the Doctrine of Community of Co-riparian States or Community of Interests. It is an attempt to improve upon the concepts in the doctrine of limited sovereignty. It enunciates a common legal right of all co-riparian states on international water resources. The doctrine establishes a perfect equality of all riparian states in the use of entire water course and excludes any preferential privilege for any riparian state in relation to others.

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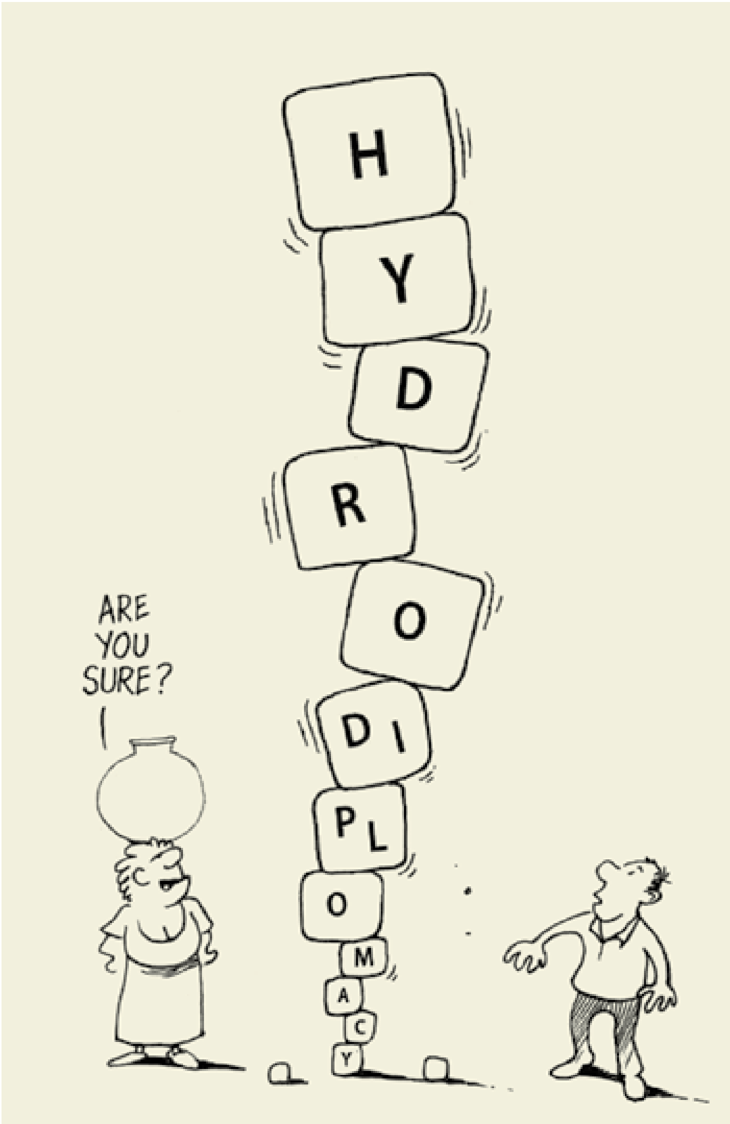
There is now an explicit recognition that all riparian states are entitled to the use of international water course in an equitable and reasonable manner. Another important principle has now achieved international recognition that riparian states have an obligation not to cause significant harm to the other riparian states and all riparian states shall exercise due diligence in the utilization of international water resources. Although these principles have generated interminable debates on how exactly to determine reasonableness, equity, significant harm and due diligence, these concepts are indeed important milestones in achieving good governance of international water courses. Some of these norms and principles are contained in the 1966 Helsinki Rules on the Uses of the Waters of International Rivers and the 1997 UN Convention on Non-navigational Uses of International Water Courses.

Diplomacy, the medium of inter-state interactions, has a pivotal role in balancing the competing interests of states

The 1997 UN Convention represents an important step towards the strengthening of the rule of law in international waters. Of particular importance is the principle embodied in this Convention requiring a state to utilize the watercourse, in its territory, in a manner that is equitable and reasonable vis-à-vis the other states sharing that water course. Another crucially important provision is the obligation imposed on a state not to cause any significant harm to other states sharing an international water course. The Convention also puts an obligation on a state undertaking any project to notify other states of planned activities to allow the other states to assess if there would be any a significant adverse effect; the intention is to obviate such adverse effects. These are very positive and important principles which will promote good governance in this increasingly critical area of international relations.

Conflict or cooperation on international waters - clearly there are two contradictory and clashing prognoses before us. Whether it is averting the threat of conflict or harnessing the prospects of cooperation the challenge before the world is formidable. The quality of governance of trans-boundary waters will play a role of paramount importance in determining which of these two courses mankind will opt for. As decisions relating to utilization, share, management and quality control of the international water fall within the jurisdictions of more than one country, the governance encompassing these elements will bring into play inter-state interactions. Diplomacy, the medium of inter-state interactions, has a pivotal role in balancing



Rustam Vania

the competing interests of states. One also has to reckon that the dynamics of water negotiations is in a state of flux as it moves from zero-sum attitudes to positive-sum integrative win-win approaches, from right based volumetric sharing to the creation and sharing of benefits derived from water resources. This development will create more economic opportunities and simultaneously bring into play additional political challenges. Synthesizing and harmonizing the complex mix of economic opportunities and political challenges will thus impose pronounced demands on diplomacy.

There is a growing feeling among experts that these principles and laws need to be more concrete and precise. Simultaneously with harmonizing inter-state interests, in clearer and unambiguous terms it will be of vital importance to concretize and crystallize principles and laws relating to the regimes of these precious resources and to create institutional mechanism that will have the capacity of enforcement as well as conflict resolution. On all these counts diplomacy will be called upon to play a role of crucial and overwhelming importance in the days ahead.

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Recollections of India – China Cooperative Exchanges on the Brahmaputra

Gautam Bambawale

INDIA IS the lower riparian on the Brahmaputra which originates in the highlands of the Tibet Plateau, flows eastwards in China and then makes what is described as a "great bend", enters India and flows westward. The mighty Brahmaputra in India is used for irrigation, transportation and power generation and has a central role in a complex ecosystem[22]. Through history, monsoon flooding of the river has caused misery and loss to several generations.

When the Government of India discovered in 2007 that China was building a series of cascading dams on the middle reaches of the Brahmaputra at Zangmu, Dagu, Jiacha and Jiexiu the first reaction from Beijing was to deny such claims. Little realizing that modern satellite cartography available commercially could clearly pick up the construction activity underway, the denials then gave way to statements that these were all run-of-the-river dams which would not lead to large scale storage of water. India and China first concluded and signed a Memorandum of Understanding (MOU) for Sharing of Hydrological Data on the Yarlung Zangpo/Brahmaputra in 2002. This MOU provides for the annual meeting of an Expert Level Mechanism (ELM) whose job it is to assess how the mechanism of data sharing has been working. Fairly regular meetings of this ELM have taken place over the years although not each and every year. However, the ELM has resulted in Indian and Chinese water experts getting into the habit of talking and cooperating with each other. I, for one, believe that this habit is much more than many other nations do with China on trans-boundary rivers. I have had the good fortune of participating in a few of these ELMs and I vouch for the fact that while at the start the two delegations would view each other with some suspicion, over time this has changed, and the two sides do have a cooperative attitude when they meet. The MOU has been extended beyond its original 5-year period and continues to be an area of cooperation for India and China.

India and China first concluded and signed a Memorandum of Understanding (MOU) for Sharing of Hydrological Data on the Yarlung Zangpo/ Brahmaputra in 2002

When I was India's Ambassador to China in 2017-18, we had one experience which depicts how cooperation can indeed play a positive role in saving lives and property when there are blockages on the Yarlung Zangpo in Tibet, China. The ELM had a meeting in China in mid-March 2018. I remember being informed by my colleagues who attended the meeting that it had been a relatively pleasant one and the two delegations had got to know each other relatively well. Later that summer, late one evening one of our Embassy officers received a call from a contact in the Chinese Ministry of Water Resources to inform us that there had been a blockage of part of the river in the middle reaches in Tibet, China. The information was being shared since the blockage was leading to the formation of a kind of lake. The pressure from the water could burst the blockage and could lead to a large mass of water flowing down the river into India. Such a flood could potentially have damaging consequences in our country. On my instructions, the Indian Embassy in Beijing immediately relayed the information shared by China to our own Ministry of External Affairs as also our Ministry of Water Resources as well as the Cabinet Secretariat. This last action was essential since there were at least two separate State Governments involved namely Assam and Arunachal Pradesh. Hence, informing the Cabinet Secretary was essential, since he and his Secretariat could convey the news to the States in India.

Surely, a few days later the water at the blockage site had sufficient pressure to blow off the blockage, which had occurred due to a landslide. That mass of water began moving down the Brahmaputra. It would reach India within two days especially the areas in India which are settled and fairly low lying.

Then began a vigil for all of us involved on the Indian and Chinese sides. We began to received almost hourly updates from the Chinese Ministry of Water Resources on where the flood had reached and what was the flow of water at places where they had measuring stations. This information was immediately relayed to India. I recollect one instance where the Cabinet Secretary of India held a video conference with me in Beijing and the Chief Secretaries of the two States of India involved. Based on the data received from the Chinese side, our own hydrologists were able to project by extrapolation how high the flood would be in different parts of India. Based on these projections, in turn, a fair number of people living in low lying areas on the banks of the Brahmaputra were evacuated by our authorities.

Such cooperation is not merely possible but also implementable when the personnel involved clearly understand the potential for saving lives, crops, habitations. Suspicion must be replaced by a desire to cooperate

Now, it was our turn to share with China what steps we had taken based on the information shared by them. When I did so and informed about the thousands of people evacuated, and how we were possibly saving lives due to this cooperation between India and China, I found my Chinese interlocutors feeling very satisfied with the scope and level of cooperation the two countries had achieved.

Within two days, as the experts had predicted, the flood had reached India and the level of the Brahmaputra swelled significantly. However, the flood peak was in line with what our hydrologists had predicted and was not of a magnitude to create too much damage. The lower lying areas, particularly in Assam, were flooded but there was no loss of life due to the evacuations of the populace which had already been effected. The flood peak passed down the river in a few hours and with it so did the crisis. All of us dealing with the issue heaved a sigh of relief, but we also had a feeling of satisfaction with what we had achieved. The next day as the Indian Ambassador to China I wrote out a letter to the Chinese Ministry of Water Resources outlining and highly appreciating the level of cooperation we had been able to reach.

What are the lessons from this particular incident that I took away with me? They are:

(a) Cooperation on trans-boundary rivers between nation states, increases welfare of people in all the cooperating countries.
(b) Such cooperation is not merely possible but also implementable when the personnel involved clearly understand the potential for saving lives, crops, habitations. Suspicion must be replaced by a desire to cooperate.
(c) Big countries need to take a large-hearted approach to trans-boundary river cooperation.
(d) Sharing of information must be a two-way street. It cannot just be the upper riparian sharing data and information with the lower riparian. Indeed, the lower riparian also needs to share with the upper riparian how such data has been utilized.
(e) We need more cooperation rather than less on major river systems across the globe.

Based on these recollections, I do hope that India and China can consider expanding their cooperation on trans-boundary rivers such as the Brahmaputra.

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China begins sharing hydrological data for Bramhaputra for monsoon season

Press Trust of India
NEW DELHI, 20 MAY

China has begun sharing hydrological data with India on the Bramhaputra river for this year's monsoon season, a senior Water Resources Ministry official said Monday.

It is also expected to start sharing data on the Sutlej river from June 1, the start of monsoon season in the country, the of-

Framework for cooperation in the GBM Basin[23]

Golam Rasul

THE EASTERN Himalayan countries of Bangladesh, Bhutan, India and Nepal, along with the Tibet Autonomous Region of China, are interconnected by the river systems of the Ganges (or Ganga), the Brahmaputra (known as Yarlung Tsangpo in China and Jamuna in Bangladesh) and the Meghna. Together these three river systems are often referred to as the Ganges-Brahmaputra-Meghna (GBM) basin, covering an area of 174.5 million hectares. At present about 700 million people live in the GBM basin, comprising more than 10 percent of the world's population. The average annual water flow in the GBM basin is estimated at around 1160 billion cubic meters. The GBM basin is geographically connected and has a high level of economic complementarity and interdependence. It is also closely linked hydrologically, and these links lead to a high degree of interdependence and call for cooperative governance of water resources.

These river systems are rich in water, land, and forest resources. They provide fertile agricultural flood plains and feed into one of the most productive estuarine ecosystems in the world, the Sundarbans, which sustains the lives and livelihoods of millions. Despite such richness in natural resources, the region is one of the poorest in the world. Rapid population growth, the fast pace of urbanisation together with economic development have increased the pressure on this finite resource. Water resources in the region are distributed very unevenly over time and space. About 84 percent of the rainfall occurs between June and September and 80 percent of the annual river flow takes place in the four months between July and October. Huge amounts of water during the monsoon period trigger floods and other hazards, whereas in the dry season the water is insufficient to meet the requirements for irrigation, navigation, and maintaining minimum environmental flow in the rivers. While the need for water has increased rapidly, water supplies have become more erratic as a result of both poor management and climatic effects.

Upstream-downstream interdependencies and geographical linkages necessitate the development of a shared and integrated river system through collaboration among the riparian countries

The Need for Better Cooperation

In the GBM basin, the abundant water during the monsoon leads to hazards such as flooding and other natural disasters. At the same time, the GBM basin is very rich in water resources, but this potential has remained largely untapped. Upstream-downstream interdependencies and geographical linkages necessitate the development of a shared and integrated river system through collaboration among the riparian countries. Such collaboration could deliver a number of benefits. The high precipitation in the summer monsoon season (June to September / October) renders the Eastern Himalayan countries vulnerable to natural hazards such as floods and landslides. The Ganges-Brahmaputra basin is one of the most flood-prone regions in the world. The loss of human life is highest in Bangladesh (on average around 6000 people per year) and the number of people affected by floods is highest in India (more than 22 million per year). While floods cannot be completely avoided, the damage can be minimized through the joint efforts of governments and those living in the major river basins. For example, the lead time for flood forecasting can be increased substantially through exchange of real time data on river flow from upstream areas of the basins.

The fundamental problem with water governance in the GBM basin lies in the seasonal concentration of rainfall and spatial variation in its distribution, as well as unreliability in water supplies. These characteristics of water availability mean that water should be stored when it is abundant and redistributed when and where required within a framework of regional understanding and cooperation. Literature on potential sites for storage reservoirs in India and Nepal, for example, reveals that there is great potential for storage of monsoon water in the GBM basin.

Potential for Transboundary Cooperation

Although there are challenges, the opportunities for collaboration are also growing as civil society and other non-state actors emerge, and new forces for cooperation.

Hydropower generation. Abundant rain-fed and snow fed water resources and topography with a favourable relief for hydropower generation provide an excellent opportunity for generating an enormous amount of hydropower in the basin. The energy requirements of the region could be met, and the surplus exported. For example, the theoretical hydropower potential of glacial rivers in Nepal is estimated to be 83,000MW, in Bhutan 21,000 MW, and in north-east India about 58,971MW.

It is estimated that the GBM river systems have about 200,000MWof hydropower potential, of which half or more is considered feasible for harnessing. Alongside this, establishment of an inter-country power grid could facilitate the integration of different power systems and the export of excess hydropower from Nepal and Bhutan to India and Bangladesh. Besides hydropower, the GBM river systems offer a huge potential for the development of water resources for irrigation, navigation, transportation, fisheries, tourism and ecosystems.

Water transportation is another area for potential improvements. The Ganges, the Brahmaputra, and the Meghna rivers flow into Bangladesh from three directions and merge into a single outlet that constitutes a vast water network. This provides an opportunity to develop an integrated water transport system. Two countries in the basin, Bhutan and Nepal, are landlocked and this is an obstacle to their industrial growth and overall economic development. It is technically feasible for Nepal and Bhutan to gain direct access to the sea. Regional cooperation for the development of waterways has gained momentum in South Asia. Recently, the government of India declared 106 additional waterways and amended the bilateral navigation protocol between India and Bangladesh to allow third countries to use their waterways. Waterways along the Brahmaputra and Ganges Rivers could provide a basis for sub-regional connectivity for South Asia, connecting Bangladesh, Bhutan, the north-eastern states of India, and Nepal to the sea via the Ganges-Brahmaputra-Meghna basin. Nepal could be directly connected to the ports of Haldia and Kolkata through India's National Waterway 1, Bhutan could be connected through the Manas River to the Brahmaputra at the Jogighopa confluence, and north-east Indian states could be connected to many ports on the Brahmaputra through National Waterway 2. In view of these opportunities, the prime ministers of India and Nepal made the decision to develop the inland waterways for the movement of cargo within the framework of trade and transit and are now working to operationalize the agreement.

Waterways along the Brahmaputra and Ganges Rivers could provide a basis for sub-regional connectivity for South Asia, connecting Bangladesh, Bhutan, the north-eastern states of India, and Nepal to the sea

There are also potential political benefits. Transboundary water resources have become a contentious issue in the GBM region, as in other parts of the world. With the right perspective, transboundary water resources can become a source of understanding of regional cooperation, and peace. Through cooperative development of water resources, current tensions between neighbouring countries can be reconciled to a great extent and this would bring political benefits to all the countries involved through building trust and increasing regional security and economic growth.

Challenges. Although the potential benefits of collaborative development of the transboundary water resources in the Eastern Himalayan region are huge, there are a number of challenges that must be met and impediments to overcome before these benefits can be realised. For optimal development, a river basin needs to be managed through an integrated basin-wide approach. Transboundary water resources in the Eastern Himalayan region are generally seen from a national perspective, with a focus on problems of sharing water rather than expanding the benefits through

joint resource development. This narrow perspective often leads to bilateralism and encourages unilateral and fragmented decisions, with transboundary water resource development seen as a 'zero sum game' in which the gains of one country must mean losses for another, and negotiations become deadlocked. Moreover, transboundary water resource management has become a purely diplomatic matter, with little space for civil society, nongovernmental organisations, private sector, and other stakeholders, who are directly and indirectly involved in water management. This is a major obstacle to cooperative development of transboundary water resources.

However, there has been a positive shift in the region towards cooperative water management. Although slow, efforts are ongoing to resolve differences over water issues. The Bangladesh-India Ganges Treaty states that both countries will work together to augment the river flows in the upstream and share such waters. This provision opens a path for regional cooperation to harness the water resources of the GBM basin. Efforts are also ongoing in the Koshi basin. Bangladesh has agreed in principle to allow transit from Bhutan, India and Nepal to use the Mongla and Chittagong ports. A waterway transit for Bhutan to Mongla port is under consideration. The cooperation between Bhutan and India on hydropower development is also a very good start. Similarly, the signing of the Mahakali treaty between India and Nepal and the treaty for sharing Ganges water between Bangladesh and India have opened up opportunities for collaboration in regional water resource development.

A Framework on Transboundary Cooperation in GBM Basin

There is a strong case for a framework for the cooperative development of transboundary water resources in the basin in order to support the realisation of such benefits. Key aspects of the framework are presented below

- Promote a multi-purpose basin-wide approach for optimum use of Himalayan water resources in an integrated manner. The starting point could be cooperation in flood control, as flooding is a common issue for all countries in the region. Greater efforts need to be made to engage policy makers and other key stakeholders, including the private sector, think tanks, research organizations and civil society on the future interactive challenges of water, energy and food security on the regional level, possible regional approaches, and the potential benefits of integrated management of transboundary water resources at the basin level.
- Shift the focus from sharing water to sharing the benefits of water. Link water sector strategies with broader national and regional development goals, including shifting the focus from hydro-diplomacy to a hydro-economic perspective.
- Build trust: a concerted effort is required to build trust and confidence so that negotiations and discussions can start. Mistrust is partly due to poor understanding of the benefits and costs of collaborative development and there is a need to promote joint research on transboundary water management issues. A concentrated effort and multi-track diplomacy are necessary to overcome the existing mistrust and build common understanding of the benefits of cooperation and the costs of non-cooperation. One of the reasons for mistrust has to do with the sharing of costs and benefits. Mechanisms for sharing the costs and benefits of co-operatively developed transboundary water resources need to be established following international standards. Dispute-resolution mechanisms and institutional arrangements also need to be developed to settle disputes among the riparian countries.
- Facilitate multi-track diplomacy, with efforts made to facilitate cross-border exchange among civil society organisations, NGOs, academic and scientific communities, and government officials.
- Undertake joint research by the Eastern Himalayan countries to produce credible information and knowledge, explore development potential and options, and assess risks, costs, and benefits of cooperative management to support sound decision making.
- Establish a mechanism and institutional arrangements to coordinate, facilitate and strengthen cooperation in water, hydropower, and flood management in the GBM basin. Water management institutions in the region are generally weak and lack the technical, financial and human capabilities needed to develop and implement comprehensive plans for transboundary water cooperation. Building the capacity of national and regional institutions and establishing a basin-level coordination committee is critical to promote better water governance.

Shift the focus from sharing water to sharing the benefits of water. A concerted effort is required to build trust and confidence so that negotiations and discussions can start

- Explore joint projects for development of transboundary water resources for short, medium and long-term measures based on mutual understanding and priorities. Joint investments in regional public goods for mutual benefit will be vital. There is a need to develop mechanisms for sharing costs and benefits in an equitable manner in the provision of regional public goods, particularly along transboundary rivers and in regional infrastructure development.
- Establish a basin-wide data bank and system for timely sharing of meteorological, hydrological, economic and environmental data and information among the countries sharing the basin.

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Interdisciplinary Governance of the Transboundary Brahmaputra River System

Jayanta Bandyopadhyay

THE YARLUNG Tsangpo- Brahmaputra trans-boundary river system is characterised by wide diversity in climate, geology, demography, administration, politics, culture, etc. which provide conditions for potential cooperation as well as disputes among the riparian countries. There have been some analytical studies on the scope of water diplomacy in the Brahmaputra river system[24]. However, the Brahmaputra is a complex river system and needs much more analytical attention. As a result, the available studies have not yet been of effective use in generating a comprehensive approach to governance of this river system.

Based on the trans-boundary status of the Brahmaputra sub-basin, this chapter outlines some of the governance challenges, potential or present or even just perceived by some analysts. n order to understand these challenges objectively, knowledge of the characteristic environmental features, like precipitation pattern, hydrological profile, geomorphological dynamics, population, land use, irrigation, hydropower potential, etc. is necessary. In addition, the human interventions like structures built, or planned by the riparian countries, will have to be considered.

Important in-situ services of the flows of the Brahmaputra sub-basin include navigation and fishery, which provide livelihood options to many people

Precipitation: Spatial and Temporal Variations

Based on the annual precipitation, the area of the Brahmaputra sub-basin can be divided in four clear climatic zones. The Yarlung Tsangpo stretch mainly passes through semi-arid areas in Southern Tibet in which the annual precipitation is about 400. As it travels round Namcha Barwa and starts the descent along the south aspect of the Himalaya, the annual precipitation gradually increases. After entering India near Tuting, Yarlung Tsangpo gets the name Siang, which reaches the plains of Assam at Pasighat (150 m), where the annual precipitation goes up to about 4000 mm. However, the most of

the extreme precipitation events have been reported in the mountainous catchments of neighbouring Lohit and Dibang rivers The tributaries from the rain rich south aspect of the Himalaya, from Subansiri to Teesta, make large additions to the flow of mainstream Brahmaputra. Thus, the river system has areas of low water availability, as in Tibet, and areas of high but seasonal water availability, as in the south aspect of the eastern Himalaya. The result is high flows or floods, erosion and sedimentation during the summer monsoon, together with shifting of the braided river flows. Important in-

situ services of the flows of the Brahmaputra sub-basin include navigation and fishery, which provide livelihood options to many people. Scarcity of flow in the lean season seriously affects irrigation for paddy in Assam and Bangladesh. Further, with summer paddy getting increasing importance in food security in Bangladesh, the pre-monsoon scarcity of water in Brahmaputra has also becme an identity of the Brahmaputra sub-basin as much the monsoon floods.

It is in the above background, that the challenges in the governance of this trans-boundary sub-basin will be analysed. It needs to be stressed that flows in the Himalayan rivers are subject to high level of uncertainty[25], which itself can often produce trans-boundary disputes. Impacts of global warming and climate change will only increase this uncertainty. Further, with the political sensitivity and ecological complexity of the sub-basin, the traditional approach to governance based on engineering structures

alone, will be inadequate. Water science has become highly interdisciplinary now. Knowledge based on extensive data is now guiding the design of governance institutions. For future interventions to be successful the role of interdisciplinary knowledge will be central. Within the available space for this chapter, all challenges in trans-boundary governance cannot be discussed.

Firstly, the China-India relations on the various structural interventions made or planned by China on Yarlung Tsangpo have got wide media coverage which need some clarity. Secondly, what is seen by this author as the primary governance agenda for the Brahmaputra sub-basin as a whole will be presented.

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China-India Relations and the Yarlung Tsangpo Projects

Dam projects on the Yarlung Tsangpo have been the subject of many journalistic writings all over the world and some analysts have even warned of a 'Water War' between China and India over the shared rivers, especially the Brahmaputra. The commissioning of a series of dams by China built around Zangmu on the Yarlung Tsangpo very much fuelled such reports. Some of these writings even predicted the drying up of the Brahmaputra in Assam as a result of dam construction by China. Indeed, in the context of two most populated countries with ambitious plans for rapid economic growth, competition for enhanced access to limited sources of water is a possibility, leading to prospects of serious conflicts, as perceived by SAWI[26]. On the other hand, depending on the high level of objectivity in diplomacy, the competition can be replaced by cooperation[27]. The rise of the 'Water War Narrative' has been the result of lack of hydrological clarity on a complex river system, since many such writings depend on very weak database and do not distinguish between the cartographic and hydrological continuity of the Yarlung Tsangpo. It needs to be stressed that at Zangmu, the flow of Yarlung Tsangpo would be a small part of the total flow of the Brahmaputra at downstream of Bahadurabad in Bangladesh (about 6-7 per cent). The situation can easily be addressed by diplomats with more openness and more willingness to gather technical information on the part of the protagonists of the Water War Narrative. Commenting on the improbability of Water Wars over dams on Yarlung Tsangpo, Ho[28] has commented that "The difficulties in managing the Brahmaputra, and the fact that both China and India suffer from water scarcity, have led to predictions that the two countries will fight over water in the future. Despite these predictions, armed conflict in the Brahmaputra is unlikely in the current context." Instead, she has raised the question "Why are China and India unable to establish robust mechanisms for cooperation on the Brahmaputra River, and how, with little institutionalized cooperation in the Brahmaputra, have both sides managed to keep their riparian relations from creating open conflicts?" Indeed, future governance of the Brahmaputra has to respond to this question urgently. However, this is a localised governance issue for the sub-basin.

Cooperative Governance for the Whole Sub-basin

The greater issue in the sub-basin is to generate an informed and comprehensive governance response to the monsoon floods, to reduce vulnerability and enhance socio-economic advantages. The governance institution should involve all sub-basin countries: China, India, Bhutan and Bangladesh.

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In a period when the scarcity of water has become a global problem, the Brahmaputra sub-basin finds annual monsoon floods as a major problem. In the context of the complexity of the climate process in the Himalaya, the meteorology of flood producing rainfall events in Brahmaputra is still at a stage of evolution[29]. All tributaries from the Himalaya have historically recorded anomalous rainfall and produced floods. The catchments of tributaries Luhit, Dibang, Siang and Subansiri face such precipitations more frequently and flood moderating structures were planned on them without being followed. The impact of monsoon floods in downstream Bangladesh is also quite heavy. The four sub-basin countries have to address the flood moderation with a sense of urgency, for which Bangladesh and India may be the prime mover. China should be a good source of knowledge especially in view of the experiences from the Yellow river[30], once devastated by floods and sedimentation. Thus, one important dimension of this sub-basin would be cooperative governance and exchange of engineering knowledge among the four countries. Managing flood producing precipitation at the location where it falls would be the role of storage structures in the uplands, thus reducing the potential damage in the downstream parts. Such a participatory process will also help much needed reduction in suspicion of NGOs, professionals and politicians in Bangladesh about upstream designs, as identified by Ahmed[31]. Thus, urgency exists in pushing forward the idea of cooperative governance of the Brahmaputra sub-basin for developing a basin wide strategy for the governance of monsoon floods.

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Fostering a Spirit of Cooperation among the Brahmaputra River Basin Riparians

Taylor W. Henshaw and Anamika Barua

THE SOUTH Asia Water Initiative (SAWI) is a multi-donor Trust Fund supported by the UK, Australia and Norway and managed by the World Bank. SAWI supports a rich portfolio of activities designed to increase regional cooperation in the management of the major Himalayan river systems in South Asia to deliver sustainable, fair and inclusive development and climate resilience. It does this through four complementary outcome areas: strengthening awareness and knowledge on regional water issues; enhancing technical and policy capacity across the region; dialogue and participatory decision processes to build trust and confidence; and scoping and informing investment designs. Its work, structured across three river basins (Indus, Ganges and Brahmaputra) and the Sundarbans Landscape, spans seven countries: Afghanistan, Bangladesh, Bhutan, China, India, Nepal and Pakistan.

Part of the South Asia Water Initiative's (SAWI) early engagement on the Brahmaputra Basin included leading study tours for high-level and technical delegations to the Yellow River Basin in China (2014) and the Mississippi River Basin in the USA (2015), where participants discussed pressing Brahmaputra governance issues and learned practical management approaches from basin organizations facing similar water resource management challenges. Notably, the delegations recommended that a "Brahmaputra Forum" be formed at the national level in each riparian country and at the basin level. While the national forums would explore local and national solutions to basin challenges; the regional forum would focus on working toward a "joint response mechanism" for issues such as navigation, hydropower investment and food management. For such a dialogue to be effective, they expressed, the process would need to increasingly extend to higher levels of stakeholders and be nimble enough to deliberate on emerging windows of opportunity for cross-border cooperation.

For such a dialogue to be effective, the process would need to increasingly extend to higher levels of stakeholders and be nimble enough to deliberate on emerging windows of opportunity for cross-border cooperation

During this period, the policy research institute South Asia Consortium for Interdisciplinary Water Resources Studies (SaciWATERs), with The Asia Foundation and supporting partners, started a dialogue process in the Brahmaputra Basin, of which SAWI was largely an early observer. The first phase of the dialogue process (2013-14) included six consultation meetings in Bangladesh and India at the Track III diplomatic level (CSOs, NGOs and academics/ researchers). An initial status report on water management practices and policies for the Brahmaputra Basin concluded that "the innumerable channels and tributaries, varied topographical and climate regimes, and multiple water uses across countries unequal in size and power dynamics have made a straightforward management strategy seemingly impossible; concerns and voices of legitimate stakeholders have largely been neglected in previous basin dialogues and forums; basin dialogue is only bilateral in nature; and negotiations are largely formed by virtue of adversarial positional bargaining." A Track III Bangladesh-India joint dialogue meeting reflected on the country-level consultations and called for movement in diplomatic participation from Track III to Track II, to include more influential non-government stakeholders, including prominent ex-bureaucrats that interact regularly with government officials, and to bring in stakeholders from all four riparian countries to enable a more holistic conversation on Brahmaputra management issues.

In phase two of the dialogue (2014-2015), SAWI was a behind-the-scenes influencer, helping to heighten riparian government awareness of and confidence in the dialogue process, and to secure participation. For the first time, Track II stakeholders from India (Arunachal, Assam and Delhi) and Bangladesh and Track III stakeholders from Bhutan and China came together in a multi-country dialogue to share ideas, knowledge and experience for good governance of the Brahmaputra Basin. The importance of a multi-country dialogue process on the basin was reinforced, with a call to action to move the process from Track III and Track II modes to Track I½ mode (where government and non-government actors deliberate together) and to create a single dialogue platform with participation from all four riparian governments.

The potential for formal collaboration between SAWI and this dialogue process was identified at a Brahmaputra regional workshop in Dhaka in 2015, where SaciWATERs presented findings from the first two phases of operation and expressed need for support to sustain the dialogue and expand its reach. For SAWI, partnering with SaciWATERs on a third phase was an opportunity to advance the recommendations coming out of the study tours with a credible partner, building on the dialogue's early achievements, and to disseminate evidence generated through SAWI's basin modeling and analytical activities. SAWI funded and helped implement the demand-driven third (2016-2017) and fourth (2018-2020) phases of the dialogue, aimed at providing the means, mandate and resources necessary to facilitate formal and informal knowledge exchange and interaction among key basin stakeholders, fostering a spirit of cooperation to develop and manage the basin optimally, holistically and sustainably.

These country meetings helped identify key people and institutions that can play an important role in advancing the dialogue and further understanding of country-specific views and opinions on potential co-management of the basin

Combined Track III, II and I½ country-level dialogue meetings took place in Bangladesh (June), China (July), India (August) and Bhutan (September) in 2016. Discussions were structured around three themes: knowledge sharing and review of water resources management legal instruments from international experience; economic opportunities that would help address issues of poverty and food and energy security; and disaster management, such as flood risk management and bank erosion control. These country meetings helped identify key people and institutions that can play an important role in advancing the dialogue and further understanding of country-specific views and opinions on potential co-management of the basin.

A regional workshop in Singapore in October 2016 aimed to lay the groundwork for political commitment to a basin-wide multi-purpose institutional framework for managing and developing the Brahmaputra Basin. The small event drew senior government participation from Bangladesh, as well as high- and mid-level stakeholders from Bhutan, China and India, marking a breakthrough in track diplomacy in the basin, and signifying the quality and importance of the dialogue process. Convening this level of participation required a sustained effort by SAWI and SaciWATERs, including several rounds of national-level consultations with high-level stakeholders (including across the multiple Indian states that share the Brahmaputra Basin).

The momentum in the third phase led to the Brahmaputra River Symposium (BRS), held in Delhi in September 2017. The BRS brought together 150 delegates, including, for the first time, prominent stakeholders from all four basin riparian countries (including senior government officials from Bangladesh, Bhutan and India and academic institutions with close ties to government agencies in China) exemplifying the strides this dialogue process has made in terms of credibility and importance. The Symposium delegates identified several recommendations to combat the challenges of developing and managing the Brahmaputra Basin. The recommendations focused on generating and sharing knowledge to close the science-policy gap and inform evidence-based decision making in the basin, strengthening institutions, and integrating investments. One of the major outcomes was consensus among the delegates that this dialogue process has the potential to navigate the geopolitical complexity hindering good governance in the basin, and that it must be sustained to rally stakeholders, from community to cabinet, in each of the four basin countries to champion the movement.

Preparing and organizing the BRS involved holding meetings in China with academics acting as advisors to government to ensure there was strong Chinese representation at the Symposium. SAWI engagements in India were instrumental in the strong Indian presence at the event, including the Commissioner, Brahmaputra and Barak Basin Wing, Ministry of Water Resources, River Development and Ganga Rejuvenation.

The call to action agenda set at the BRS sparked the fourth phase of the Brahmaputra Dialogue, which was launched in May 2018. This phase has seen the dialogue process institutionalized, with a consortium of institutions connected to government in each riparian country taking facilitation roles—IIT-Guwahati (India), Institute of Water Modeling (Bangladesh), Bhutan Water Partnership (Bhutan) and Yunnan University (China)—in collaboration with a range of partners working to advance sustainable Brahmaputra Basin water resources management.

Significantly in the fourth phase, a regional workshop on south-south cooperation and the climate-water-energy nexus was held in Shanghai, jointly organized by Shanghai Institute for International Studies and IIT-Guwahati. This workshop was the first multilateral international workshop held within China under the Brahmaputra Dialogue. Feedback from workshop participants noted that the forum continues to strengthen the built network of government officials, academicians, researchers, NGOs, CSOs and media toward co-management of the basin.

Because the international experience demonstrates that the efficiency and effectiveness of an international institutional framework largely depends on the social and political characteristics prevailing within a basin, first-of-their-kind institutional and power mapping exercises were carried out on the Brahmaputra Basin. Through literature reviews and one-on-one interviews with key institutional stakeholders, the institutional mapping is helping further understanding of the complex, multi-tiered management (roles and responsibilities) and policy landscape of the Brahmaputra Basin at the domestic and international levels. The power mapping is identifying power relationships and the influence of various institutions in devising policies and programs related to (cross-border) water resources management in each of the riparian countries. This work will enable the dialogue process to identify the most relevant institutions, key actors and other stakeholders, and their interactions and locus of control for future dialogue participation, and to improve coordination and make the dialogue more effective.

Dialogue processes on international river basins are closely linked to the geopolitics of the region, and political development in any of the riparian countries could hinder opportunities for dialogue. The Brahmaputra Dialogue has managed political sensitivity risk through the manner in which workshops and discussions are structured. Country-level workshops are held so participants can speak candidly about national and transboundary basin management issues. The regional event discussions are focused on thematic areas that are of common interest to all riparians and relatively apolitical (such as disaster risk management, inland water transport and the water-energy-food nexus).

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Outcomes

THE EARLY phases of the dialogue process comprised a small group of stakeholders at the Track III and II diplomatic levels. The dialogue has since morphed into an expanded and engaged group up to Track I½. To achieve this transformation, riparian country-level workshops and meetings—supported by informal one-on-one follow-ups with key stakeholders—established the political connection, commitment and momentum long needed for dialogue breakthroughs.

The nature of the dialogue discourse is evolving beyond technical management issues, opening up thinking toward common understanding across sectors and geographies, and on policy viewpoints. Events are starting to serve as a marketplace of ideas, bringing together the producers and consumers of knowledge, and Brahmaputra Basin knowledge partnerships are emerging.

The nature of the dialogue discourse is evolving beyond technical management issues, opening up thinking toward common understanding across sectors and geographies, and on policy viewpoints

The dialogue is working through and with a range of partners, which has expanded over time and is central to SAWI's long-term sustainability strategy. The dialogue process is now institutionalized across the basin, with a consortium of institutions connected to government in each riparian country taking facilitation roles.

While various CSOs are engaging on the Brahmaputra through multiple activities, they are working largely in isolation of one another. A CSO meeting in Guwahati, India, in November 2018 was held to bring the major CSOs together to discuss convergence of activities and identify gaps that need to be filled, potentially through future activities under the dialogue. The first-of-its-kind meeting has stemmed fruitful and ongoing discussions on identifying CSO synergies and areas for collaborative work.

This first multilateral international workshop on the Brahmaputra in Shanghai in 2018 marked the Brahmaputra Dialogue's full active engagement in all four riparian countries. It also showed China's increasing interest in regional cooperation in the basin, which will be critical to move the dialogue process forward, with legitimacy.

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8. VOICE

Perspectives

Nitin Desai

Shafi Sami

Runa Khan

Yang Yi

Ravindra Kumar Sinha

Yu Hongyuan

Ma Jun

Sanjoy Hazarika

M Panging Pao

Ainun Nishat

Yumiko Yasuda

Qazi Kholiquzzaman Ahmad

Imtiaz Ahmed

Bibhab Talukdar

Karma Chopel Gongsar

सिआंग
雅鲁藏布江

Mutual learning between different civilizations

YANG YI

THE "Yarlung-Tsangpo-Siang-Brahmaputra-Jamuna" River, which finds its origin in the northern foothills of the Himalayas, as a trans-boundary river and one of the major rivers of Asia, it nourishes the fertile land on both sides of the river, feeds hard working people and splendid cultures since ancient times.

> *"The rational and sustainable development and utilization of cross-border river water resources calls for our wisdom and cooperation."*

The upper reaches basically belong to nomadic areas, the vast grasslands on the Tibetan antelope, Yak and other wild animals' paradise. The lower reaches benefits for irrigation and transportation from the water. It's the cradle of the birth and development of many civilizations, also a witness to inter-civilizational communication and cultural exchanges among the people, which have their own characteristics and influence each other. This civilizational and cultural blend runs through the river basin. The riparian countries are linked by mountains and rivers, and have similar historical circumstances and the same pursuit of dreams. From the high altitude Tibet Autonomous Region, deep mountains area, the valley stream side, to the cross-cultural tea county Assam, and the Ganges Delta, you can hear the sound of bells from representative temples and palaces, you may meet the cultural relics created by different ethnic groups, they are the products of cultural exchanges, representing the prosperity and glory of the past and human history's quest, also the common heritage of mankind.

Civilizations have been enriched and become more colorful through exchange and mutual learning. The exchange and mutual learning serve as important drivers of human progress and global peace and development. At a crossroads in world history, all countries look forward to peace and tranquility, common prosperity, openness and integration in face of a profound unprecedented change in a century. Great hopes go hand in hand with great challenges. How can riparian countries jointly meet the challenges and move towards a better future? The Chinese President Xi Jinping proposed to consolidate the "cultural foundation" of jointly building a community with a shared future for Asia and humanity. Specifically, treating each other with respect and as equals; appreciating the beauty of all civilizations; adhering to openness, inclusiveness, mutual learning; and keeping pace with the times.

The fast-changing international and regional landscapes request all of us to follow the trend of our times, jointly enhance international cooperation in the field of cultural governance and sustainable development and build a more favorable environment and better life to all riparian people in the coming days. The rational and sustainable development and utilization of cross-border river water resources calls for our wisdom and cooperation.

Spanning thousands of miles and years, the river plays an important economic, social, cultural role for riparian countries with great potential for growth now. With the progress of the times, we need inject new impetus into river for sustainable development, to realize civilization connectivity. The river brings not only the past to the people along the river, but also a glorious future.

যমুনা
যমুনা

Bangladesh: a land of thousand rivers!

RUNA KHAN

AWE INSPIRING in its resilience, overpowering in its strength and a feeling of continuity between the river and its communities is possibly what struck me when, 20 years ago, I first came face to face with the mighty River Jamuna and the chars (river islands), along it's multiple banks, the people, the communities and life. So broad was the Jumna that one could fit the city of Paris between its two shores!

During the Summer, the river is in spate, and can flow at 10, even 12 knots. As you watch it move at a speed and with a volume incomprehensible to those who have never seen a river of 25 km in breadth, you are filled with astonishment and fear, at this sight. One is often overwhelmed with emotions and helplessness, as you witness the chars breaking and disappearing with the current. Washed away in front of your eyes as you watch from your boat, meter by meter the very land where you had seen the children play, where crops were growing and men came home to their wives, just a month ago. The river carrying away in its might, livelihoods, lives and hope of all those who live on them.

These are nomadic islands, like the nomadic people who live on them. Migrant climate refugees. Families, persons, moving up to 48 times in their lives, island to island, year after year – daring not even to hope.

This river is staggering in its wondrous might. Bangladesh is built on the silt brought down by the Rivers Brahmaputra, Ganges and the Meghna. The names of the first two rivers, are famous all over the world as two of the world's greatest rivers. Yet as they journey down from the Himalayas, down the deltaic plains, the Brahmaputra changes its name to Jamuna and the Ganges to Padma and together they meet the Meghna and as the Meghna, they flow into the sea. Ironically, neither the mighty Brahmaputra nor the mighty Ganges, enters the Bay of Bengal with their famous names.

"Nowhere else in the world do you see the variety and the technical skills which are used in these smooth skinned boats of Bangladesh."

Bangladesh is 'the land of a thousand rivers.' The rivers are as important to Bangladesh as veins are to our body and laces through as intrinsically. The Jamuna brings with it life, mobility, food, water, cultures, proximity and distance. It also encompasses our fears.

It is on these seemingly unnavigable, unpredictable waters, where foreign marine influence could not reach, that the largest fleet of inland wooden boats came into existence. Their unique crafts remained unmatched for millennia. These boats with their ochre sails are a heritage of humanity. Nowhere else in the world do you see the variety and the technical skills which are used in these smooth skinned boats of Bangladesh. Twenty years ago, the rivers were filled with the ochre sails, of the malar, panshis, baich, balar. Today these are reminiscences of the past, except for the B613 and the Fleche d'Or which we built, to preserve their technology and save some of the last carpenters from an untimely extinction.

The Jamuna teaches us much. Humility if we are ever tempted to control it and understanding and respect if we ever try to work without taking into consideration its capricious nature.

ব্রহ্মপুত্র

ব্রহ্মপুত্র

Water of despair, waters of hope

SANJOY HAZARIKA

THE RIVERS of Northeast India leap and bound over hills; they do not flow. There are not less than 33 major rivers which in turn flow into that greatest of all Indian rivers, the Brahmaputra; there are 22 which have already fallen upstream in Tibet and in Bangladesh three more join it, including the Ganga.

One is not reflecting on the power of these rivers, which is immense. Others see that power differently: mention the scale and fall from the Himalayan heights to a civil or electric engineer and his or her eyes will probably light up at the thought of dams and projects that will create a surge of energy. One is not talking about that either.

Who realizes that in the cacophony about dialogue and development and Look East policies, we seem to have forgotten the persistent and critical challenge before us: how do we enable a minimum of 3-5 million an opportunity to cope with floods. Because unless we do that none of our policies or talk is going to work.

I am always stunned at the lackadaisical way we approach this problem, showing concern only when urban conglomerates like Guwahati are affected by ingress of high water. I think places like Guwahati deserve to be flooded because its residents, contractors and politicians as well as bureaucrats, have destroyed the land below their feet – they have emptied out wetlands and built high rises. When the next earthquake hits, don't be surprised by high casualties and no amount of disaster preparedness or firefighting exercises will help.

And that is the point: the floods delineate a political process as much as an environmental and economic one. It is the story of the strong and the weak, of the poor and the underprivileged on the one hand and lawmakers and policy-makers on the other, with business in between. In some cases civil society is stepping in to fill the breach. But is anyone talking about dialogue; a dialogue which includes debate and discussion on many issues, not just one or two that come to mind. One can only see enormous gaps of communication and comprehension. A dialogue to be true must involve all principal stakeholders – the people who are most affected by the strife and consequent problems, not just those who see themselves as stakeholders: government and its agencies as well as business.

Talk about water in India and these are the last groups in the government's mind. Water policy and water flows are classified information even though with GIS any decent researcher can get the information he or she wants without going on bended knees to the government. In our case, the task force was not even prepared to look at the issue of watershed management and problems upstream until one of the region's most prominent geographers questioned and challenged its members.

"Unless the most marginalized of our people, those who are river-dependent among other groups, are represented at the dialogue table, conditions will not change."

Again, where is the dialogue? For true dialogue to take place one must have the other prerequisites in place – information and transparency, not rhetoric or 'facts' as paraded by one side or another.

So, unless the most marginalized of our people, those who are river-dependent among other groups, are represented at the dialogue table, conditions will not change except through growing pressure and violence. Come floods and overnight people lose homes and farms, livestock and life savings, forced to live without the basics of human dignity on embankments and roads for weeks and months without food security and a change of clothes. And people talk about freedom? Where is the freedom from indignity for the most vulnerable?

Let that be first addressed by those who claim to speak in our name. Let them participate in efforts to save our people and improve their economic conditions, instead of hectoring foreign countries and abusing those who disagree.

Our own group, the Centre for North East Studies and Policy Research, although small, works in some 25 research sites and has a basic interactive rural group of not less than 2,000 persons ranging across seven districts of Assam. One demand that we have been pressing for some time is the urgency of building high-rise platforms where people can take shelter in times of flood, with a separate area for livestock. We must restore dignity and basic rights. Surely that is the essence of conversation, understanding and dialogue? If we are not bothered about how people live in conditions which defy the very basic definition of human rights – including safety, the right to clean water, food and shelter – then our policies and projects and programmes.

"By bringing in people-centric, people-consulting policies which can be implemented simply and with the involvement of those they seek to benefit."

The GOI's Look East policy is extremely commendable and worthy of support. However, the policy and a lot of the thinking around it – connecting to Southeast Asia and our neighbours – overlooks one basic point. Without a water transport policy capable of moving large volumes of goods by river, the Look East policy will run into the sandbanks of the Brahmaputra. For it does not even consider the most basic of problems: when the region and its main road and rail corridor are under water or affected by water (either hit by it or recovering from it) for anything between five to eight months of the year, how can we have an economic policy that does not consider this very basic factor?

Massive interventions are being planned, proposed and implemented across the rivers of the Northeast. But has anyone studied the impact on aquatic life, on the endemic fish species of the region, on the dolphins, one of the most endangered fresh water mammals in South Asia, of which there are only some 200 left? We need to script another success story with the dolphin like that of the rhino – how can there be Bihu without the xixu?

Let me share one small experience where we are developing a physical intervention which could, we believe, make a difference to river dependent communities. I call this the boat of hope, because with limited funds and a team of boat builders, traditional builders, with new designs and a more powerful engine, we are building a boat that will take health services to people in time of need – especially during floods. Why hasn't this been thought of earlier? Because there's no money to be made, perhaps, if I am permitted to be cynical

But there are reasons for hope: they lie in addressing issues head on. They lie in thinking innovatively and out of the box but with our feet on the ground and with commitment as well as by bringing in people-centric, people-consulting policies which can be implemented simply and with the involvement of those they seek to benefit.

ཡར་ཀླུངས་གཙང་པོ།

ব্রহ্মপুত্র

Integrated approach to governance of a transboundary river

YUMIKO YASUDA

THE YARLUNG-Tsangpo-Brahmaputra river originates in the Himalayas and flows through China, India, and Bangladesh to the Bay of Bengal with some tributaries flowing from Bhutan. It supports life and livelihoods for approximately 130 million people

It also causes floods, sedimentation, riverbank erosion, and water pollution. Real time data sharing among the riparian countries in recent years supported flood risk management, which was possible due to political commitments of the riparian countries. In order to maximize benefits from the river and minimize risks, it is critical to take an integrated basin management approach at two levels. The first level of integration is to ensure multi-sectoral integration. River basin management requires engagement of various sectors: for example, industrial and household activities, which increase sedimentation and may therefore lead to increased flood levels. Industrial and household pollution and waste management impact negatively on water quality, affecting coastal and terrestrial ecosystems. The Integrated Water Resources Management (IWRM) approach aims to ensure cross-sectoral coordination. Currently, all countries are engaged in reporting on the degree of IWRM implementation (SDG 6.5.target). Sharing experiences among riparian countries can create an opportunity to bring stakeholders together to discuss this common approach and find better management approaches. GWP is working in many countries to support the process of achieving SDG targets, including its reporting process through UN custodian agencies.

The second level involves ensuring integrated management of the river from its source to sea, requiring enhanced cooperation among riparian countries and stakeholders. At this level of integration, it is important to engage multiple levels of stakeholders who play different roles in making integration happen at the basin-level. In this context, the multi-track water diplomacy approach can be effective in achieving healthy management of the Yarlung-Tsangpo-Brahmaputra

"It is important to engage multiple levels of stakeholders who play different roles in making integration happen at the basin-level."

river. The positive trend in the region is that there are already several efforts and actors contributing to multi-track water diplomacy throughout the basin. Multi-stakeholder platforms, including but certainly not limited to the Global Water Partnership, could be a vehicle for engaging a wide range of stakeholders in the governance of this important river.

Tackling both levels of integration may sound like an immense challenge for a large river. However, we are observing a trend that can potentially move riparian countries and stakeholders in this direction. At the basin-level, riparian countries in South Asia and China historically worked primarily at the bilateral level over their water cooperation, but there is a trend towards cooperation at the multilateral scale. The economic corridor approach taken in the region also pushes and supports this trend. There are also trends in exchanges of benefits across sectors and borders: for example, in the case of inter-sectoral exchanges between electricity supply and internet access between Bangladesh and India. In 2016, the Indian state of Tripura started providing 100MW of electricity to Bangladesh in exchange for 10 gigabits per second internet bandwidth. This shows that countries have already started collaboration outside of the sectoral 'box'. Such win-win exchanges among riparian countries illustrates potential to expand at the basin-level, facilitating the promotion of benefit sharing and exchanges across sectors and borders.

ব্রহ্মপুত্র

सिआंग

Ané Siang or Mother Siang

M PANGING PAO

THE MIGHTY Brahmaputra has different names in different nations and regions. In Tibet, where it has the longest stretch of about 1625 km, it is called as the Yarlung Tsangpo. The river carries out a massive U-Turn at Namcha Barwa and enters India near Gelling in Arunachal Pradesh. In Arunachal it flows for about 260 km and is called as the Siang. The Siang river enters Assam south of Pasighat, where it is joined by the Dibang river and the Lohit rivers. After flowing through Assam, the river flows into Bangladesh as the Jamuna.

The Brahmaputra's upper course was long unknown in India; its identity with the Yarlung Tsangpo was only established by British led explorations in 1884-86. Before this discovery, in the plains of Assam the Lohit river was mistaken as the Brahmaputra for ages.

The Siang river is revered in Arunachal Pradesh and local people call the river as 'Ané Siang' or Mother Siang. From about 300-700 metres width all along its flow in Arunachal, the river widens beyond Pasighat in the foothills to a width of about 10-15 km reaching the plains of Assam. The Siang and its tributaries support livelihood of lakhs of people in Arunachal Pradesh. The mighty river supports a vibrant eco-system with a wide variety of flora and fauna and a diverse, rich aquatic & animal life. In fact there are five districts in Arunachal Pradesh bearing the name Siang.

Some recent events on the river in Tibet have caused some serious downstream affects in Arunachal. There was a massive flood caused by the river in year 2000 causing massive devastation to downstream areas damaging life and property. It is alleged that water surge and flooding was caused by sudden breaching of a massive river blockade due to landslide in Tibet.

Subsequent to the China floods of 2000, India & China signed a MoU in 2002 with follow up MoUs in 2013 & 2018 on sharing flow information of the Yarlung Tsangpo. However, till date there is no water sharing treaty with China.

Recently in 2018 the Yarlung Tsangpo was again blocked due to landslides in Tibet twice causing much concern to downstream areas of Arunachal leading to evacuation of people to safer zones and deployment of emergency response teams. Another event occurred on the Siang which created much concern to downstream people. There was sudden darkening and contamination of the Siang with oily, dark patches all along the river due to mysterious reasons. Suspected reasons included series of earthquakes in Tibet, massive construction work in Tibet, increased mining activities in Tibet etc. This contamination and darkening of the Siang affected aquatic life and livelihood of many people.

During 2018-19, many areas of East Siang District in Arunachal Pradesh have been devastated by the rampaging Siang river. The rampaging Siang River is threatening many villages of Mebo and Pasighat area due to massive soil erosion by rising levels of the Siang river despite deficient rainfall. Many villagers are unable to sleep peacefully and many have shifted their houses to better locations. It is estimated that about 10,000 Hectares of forested land, plantations, irrigated fields, community burial grounds, schools etc have been washed away. In fact vital roads and bridges are on the verge of being washed away. It seems that the continuing contamination of the Siang river originating in Tibet has led to rise in the river bed leading to this dangerous and rampaging Siang river. It is estimated that the river bed of the Siang river has been raised by several feet leading to the river spreading sideways and causing massive soil erosion. The most probable reason for this increase in the river bed is the prolonged deposits of cement/oil mix caused by massive construction/mining

"The mighty river supports a vibrant eco-system with a wide variety of flora and fauna and a diverse, rich aquatic & animal life."

activities along the Tibetan side of the river.

Towards preventing further damage by the rampaging Siang, affected villagers of the area created a group called SEEANG (Siang Eco-System Environment Protection and Nurture Group) to create awareness and mobilise the affected villages. Under the aegis of SEEANG, affected villages carried out multiple crash programs on self help basis without Govt support to create flood protection measures with local resources like Bamboo/Wood Porcupines, Stone/Net/Sand Bag spurs & bandhs etc. Entire villages including men, women & youth worked in these crash programs voluntarily. Recently a plantation program was also held which was attended by Forest Man of India Jadav Payeng and Forest Man of Arunachal Indi Glow. This volunteering work and plantation is planned to continue to prevent further damage.

The mighty Siang supports, sustains lives and a diverse, vibrant ecosystem; Siang also destroys and uproots life & property. Events upstream of the river in Tibet have a cascading effect on lakhs of downstream people living along the river. Local people are carrying out traditional rituals, shamans are offering prayers for Ané Siang to show mercy and protect their villages, fields and community burial grounds! Is the local and neighbouring govts listening?

ཡར་ཀླུངས་གཙང་པོ།

यमुना

Bhutan: A land rich with water resources

KARMA CHOPEL GONGSAR

BHUTAN IS endowed with rich water resources with long term average annual flows of 73,000 million m3/year giving rise to one of the highest per capita mean annual flow availability of over 100,000 m3. However, being landlocked, its water resources are mainly in the form of rivers. There are four major river basins, viz. the Amo Chhu (Toorsa), the Wang Chhu (Raidak), the Punatsang Chhu (Sunkosh) and the Drangme Chhu (Manas), all of which empties into the Brahmaputra in the Indian plains. The "Chhu" in its local dialect refers to river and by extension also means water. All the river systems originate within the country except three rivers viz. Amo Chhu in western part of the country, Gongri and Kuri Chhu in the eastern, all of which originate in the southern part of the Tibetan Plateau.

Water plays a pivotal role in all four of Bhutan's major economic drivers, viz. agriculture, hydropower, tourism and small-scale industry. Agriculture consumes over 90% of water resources used in Bhutan where 60% its population are engaged in subsistence farming. Agriculture contributes over 15% to the country's GDP.

The energy sector in Bhutan comprises almost wholly of hydropower, accounts 25% of its domestic revenue. Bhutan's accelerated development of hydropower projects has set a target of 10,000 MW by 2020; and in actual we were able to develop only 2,335 MW till date.

Bhutan's transition from a Least Developed Country (LDC) to an upper middle-income country rests almost entirely to the revenues earned through hydropower export. Tourism is an important source of employment and an estimated 20% of non-hydropower revenues are also to a large extent dependent on the pristine natural landscapes maintained in their lush and verdant state with the natural flow of pristine river systems.

The 2,674 glacial lakes perching on the northern high-altitude alpine areas are mostly small, yet serve as important headwater sources of the riverine systems. The outburst of some of these lakes from time to time has resulted in enormous flash floods and damages downstream.

The current scenario of abundant water resource might be challenged by the new, complex and pervasive dynamics caused by population growth and socio-economic development. These challenges will have to be effectively addressed through appropriate Policies, Acts and Regulations. Further public education and awareness, stakeholder participation and well-designed developmental programs with efficient and coordinated management institutions are important. These are all envisaged and carried out under Integrated Water Resources Management (IWRM), which is a systematic process for the sustainable development, allocation and monitoring of water resource use in the context of social, economic and environmental objectives.

Bearing in mind the impacts that could be visible from rapid hydropower development, it is imperative to ensure the sanctity of the riverine ecosystems through enforcement of minimum ecological flow reserve and the mandatory provisions on the migratory pathways for aquatic fauna such as fish ladders.

The Water Act, its Regulation and the standards are strictly enforced within the country through regular monitoring of the ambient and industrial samples. Any likely hazards such as flash floods in the basin adjoining the downstream Indian territories are intimated through the hydro met stations. A regular biannual meeting is held between the experts of Bhutan and India on issues of trans-boundary flooding and hydro-meteorological data exchanges.

"Water plays a pivotal role in all four of Bhutan's major economic drivers, viz. agriculture, hydropower, tourism and small-scale industry."

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雅鲁藏布江

Where is the river born?

IMTIAZ AHMED

THERE IS a general perception that a river is born from its sources, the place of its origin. But the Yarlung Tsangpo-Siang-Brahmaputra-Jamuna gets re-born at every stage of its long, tumultuous journey. Throughout its journey to destination, it grows to maturity and at one point dies out of aging. The 'birth' of the Tsangpo-Brahmaputra-Jamuna-Meghna is seen in every point of the river, indeed, not only with respect to its geo-territorial naming, that is, within China, India and Bangladesh, but also with respect to its transformation, for instance, from a male deity called the Brahmaputra to a female deity called the Jamuna. And in this region, the rivers are Gods and Goddesses.

> *"The Yarlung Tsangpo-Siang-Brahmaputra-Jamuna gets re-born at every stage of its long, tumultuous journey."*

In Sanskrit, river is nadi, nadi denotes shakti (power), prana (life) and atman (soul). The river is both life-giver and life-eliminator. The flow of water could create both pain and pleasures in the life and living of the people. If the river causes normal floods, as it is the case with the river almost every year, then it enriches the soil and helps to produce bumper crops in the surrounding region. But then the same river could be the cause of 'big floods' and could end up creating havoc in the life of the people in the same region. But the course of the river is not dictated by nature alone. Human intervention in the name of development has transformed the course of the river in a significant way. In fact, the craze for development has allowed for a precise 'mentality' to emerge, which cannot help thinking and eventually building bridges, canals and dams when confronted by a river. Development mentality otherwise has not only concretized, indeed, with cement and iron rods, the respective segments of the river and tributaries in China, India, Bhutan and Bangladesh but also distorted the natural flow of the river often to the detriment of the river itself. Rivers also have their rights, including the right to be relatively pollution free, to be a safe habitat for riverine forms of life and, within limits, to flow freely. It is precisely this 'right' and the sanctity that we need to ensure with respect to this formidable river and there lies the challenge!

Need for co-operation

YU HONGYUAN

TO ACHIEVE the SDGs in Yarlung Tsangpo-Brahmaputra-Jamuna River Basin, we need to reorganize the regional cooperation model, consolidate the cohesion between energy-food-water development, strengthen urban-rural water infrastructure, restore public health-clean water co-developemnt system, alleviate poverty and inequalities, upgrade sustainable development governance capacity, as well as enhance capacity of addressing climate change and various disasters.

China can also reinforce the cooperation with developing countries, help with each other and enhance mutual understanding and trust. In the developing world, water, energy and food formed a security nexus with great sensitivity and vulnerability. Security nexus provides a new explanation for resources competition, cooperation and conflicts, and promotes water – food – energy research shift from the technical aspects to foreign policy level, and finally provides new international political ideas for resource and environmental solutions. In the security nexus perspective, as through international cooperation to solve ecological problems is not a simple technical issue, but an international political and economic issue. Based on the special political and economic advantages that China owns, China and developing countries should jointly cope with the challenges of security nexus is an important opportunity for deepening of friendly and cooperative relation.

> *"We need to reorganize the regional cooperation model, consolidate the cohesion between energy-food-water development."*

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The River: A precious Heritage

MA JUN

THE YARLUNG TSANGPO River is a magnificent river, although so few of us really know about it. Originating from the glaciers at the northern foot of the Himalayas, the Yarlung Tsangpo runs through the south of Tibet from west to East, with an average elevation of more than 3000 meters above the sea level. It is one of the highest rivers in the world. What's more, the silver ribbon on the plateau also has an amazing amount of water. The annual runoff is three times that of the Yellow River.

At the source of the Yarlung

Tsangpo River and its many tributaries, alpine glaciers bring stable water supply. But the more important reason is that the Grand Canyon cut by the Yarlung Tsangpo River, which suddenly turns to the south, enables the warm and humid air flow from the Indian Ocean to penetrate into the hinterland of Qinghai Tibet, so that the input water vapor is equal to the total water vapor flowing to the north of the Yangtze River in China. The unique topography and landforms endow the Yarlung Tsangpo River with extremely high ecological value. In the upper reaches, there is a unique plateau ecosystem; at the big turning point, the Indian Ocean water vapor channel pushes the tropical boundary northward for six latitudes (550 kilometers), and within a vertical height of 5000 meters, it contains all the natural landscapes from alpine ice and snow to tropical seasonal rain forest, forming a rich biodiversity, and also conserving the largest forest area in Tibet.

"Most of the political, economic and cultural centers in Tibet are located in the Yarlung Tsangpo valley."

The river, more than 2000 kilometers long, moistens the land on both sides and breeds ancient and splendid culture. Most of the political, economic and cultural centers in Tibet are located in the Yarlung Tsangpo valley.

The huge elevation drop concentrated in the middle and lower reaches of the River, coupled with the substantial discharge, makes the Yarlung Tsangpo River rich in hydropower potentials. As a geosyncline between Indian Ocean plate and Eurasian plate, the Yarlung Tsangpo River Basin is also rich in mineral resources.

At the same time, the ecological environment of the Yarlung Tsangpo River Basin is very fragile. The interference of human activities, coupled with global climate change, may cause ecological degradation that is difficult to restore and aggravate geological disasters.

In recent years, in order to construct an ecological civilization, China has vigorously strengthened environmental protection. Up to now, the Yarlung Tsangpo River is still one of the cleanest rivers in China. The water quality of the main rivers in the basin is above class III, including the main stream of the Yarlung Tsangpo River and many main tributaries such as the Palong Tsangpo River and the Niyang River, which maintain class II water quality all the year round.

The Yarlung Tsangpo River, together with the Brahmaputra River and Jamuna river at its lower reaches, and even the flat and wide Ganges River delta formed by the confluence of the Ganges River, jointly supports the ecological environment and social and economic development in the basin.

I hope the publication of this book can enhance the common and mutual understandings of the whole river basin, promote more exchanges and cooperation among relevant parties in the river basin, jointly care for this pure and precious water resources, protect this rich and diverse home, and pass it on to future generations forever.

सिआंग

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Brahmaputra flood plains without Rhino seems an incomplete proposition

BIBHAB KUMAR TALUKDAR

TO ME, the rhino is the symbol of Assam, it reflects the conservation commitment of Assam and its people and as such rhino has to be conserved for our future generations with support from all section of the society. While rhino poaching is visibly being seen as the major threat to future of the rhinos, but change in grassland and wetland habitats in rhino bearing areas, emergence of invasive plant species, occupying key grassland patches in rhino bearing areas and diseases like Anthrax could also pose serious threats to future of rhinos in Assam. As such we need to keep our ears and eyes open to periodically assess the threats rhino are facing and initiate timely intervention to reverse the threats to secure the future of greater one horned rhino – the pride of Assam. I am sure, we can save the species in years to come to showcase our rhino as living legend of flood plains Brahmaputra ecosystems.

"Rhino is a living legend of the flood plains of Brahmaputra."

Ganges River dolphin from a trans-boundary perspective

RAVINDRA KUMAR SINHA

THE GANGES River dolphin, Platanista gangetica gangetica, commonly known as susu, is an obligatory freshwater dolphin which never enters sea; and is probably the most ancient living cetacean as it has many ancient and vestigial organs not found in any other cetaceans of today. It is known as blind dolphin as its pin-hole eyes without crystalline lens and with meagre vestigial retina cannot form image. It is distributed in Ganga-Brahmaputra-

Meghna (GBM) river systems from tidal zone to as far up as rivers are navigable in India, Nepal and Bangladesh; and Karnaphuli-Sangu river system in South-East Bangladesh. It is solitary in nature unlike other cetaceans. Combining current knowledge on abundance from the entire distribution range an educated guess is that the entire species numbers is about 3700 individuals of all ages. A total of 197 individuals were counted in River Brahmaputra in India

"The Ganges River dolphin is a flagship species in all its range countries. It can be used as a tool for trans-boundary river cooperation."

The species has been classified by IUCN as endangered in 1996. The main threats are: directed and incidental killings as fishery by-catches, habitat degradation/loss due to indiscriminate water abstraction/diversion by construction of dams and barrages leading to declining and regulated flows in rivers, besides creating physical barriers for dispersal of dolphins, intense river pollution, loss of forests in catchment areas resulting in heavy siltation, river traffic using mechanized boats/ vessels, heavy sand mining, lack of awareness among common mass, etc. There has been an age-old practice of using the dolphin oil as fish attractant for some commercially important fishes.

There was a great passion in me to learn and save this species since my school days in 1960s. I have devoted almost four decades learning, studying and conducting surveys in the entire length of the Ganges and parts of most of its tributaries in India and Nepal since early 1980s using oar driven small boats to assess its status and distribution range, and threats the species was facing. At the behest of Cetacean Specialist Group of IUCN, I discovered an alternative to dolphin oil as fish attractant from fish scraps freely available at the door steps of fishers (Sinha 2002). Later on, I undertook extension program to popularize this alternative among the fishers of Bihar and Assam where oil fishing was rampant. On my initiatives, the Prime Minister of India declared the dolphin as National Aquatic Animal on 5th October, 2009 which was formally notified on May10, 2010. Thus India became first country in the world to have a dolphin as its National Aquatic Animal.

The Ganges River dolphin as a flagship species for trans-boundary river cooperation. Water scarcity has resulted in geopolitical tension and stunted development throughout the world. There is a need for 'hydro-diplomacy' – making scarce water a reason for cooperation, rather than a reason for conflict. There is a serious need for greater international cooperation based on the growing communal urgency and need for water around the world in general and in Indian subcontinent in particular. Hydro-diplomacy is a critical tool to ensure that shared water resources are managed efficiently, sustainably and equitably.

The Ganges River dolphin is a flagship species in all its range countries. It can be used as a tool for trans-boundary river cooperation.

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The complexity of managing a trans-boundary river

AINUN NISHAT

IT IS very important to remember that the Brahmaputra-Jamuna not only carry a huge discharge, it also carries a large volume of sediment load. The flow of water and sediment load influence the landscape through which it flows; protects and nourishes the ecosystem of the surrounding landscape. People's livelihoods are built around the river. To manage a river, does not mean only managing the flow. We have to take into account the sediments, the aquatic biodiversity, the surrounding ecosystem and communities living along the river. Now we have modern tools like numerical models, GIS and remote sensing technologies to better understand the river and how it will behave, more importantly we have instruments like environmental flows to ensure that the needs of the river and surrounding ecosystems are taken care of. Armed with this knowledge and understanding, it should be easier to manage a river, even as mighty as the Brahmaputra.

When a river and its catchment is confined within the borders of one country, the task is simpler. Complications arise when a river flows through two or more countries. Like we see in the case of the Jamuna. To this end, the Convention on the Law of Non-Navigational Uses of International Watercourses, adopted by the United Nations in 1997, states that there are three parties to trans-boundary river management—the riparian countries and the river itself. In case of any need to control the flow of water, we have to consider the needs of the river and we need to ensure that ambient environment is not disrupted; it is not harmed. For supporting development, if the flow regime has to be altered, then how much water can be withdrawn from river should be determined by reserving ecological flow. As population is increasing, it will not be prudent to demand that nature must not be left untouched.

"In case of any need to control the flow of water, we have to consider the needs of the river and we need to ensure that ambient environment is not disrupted."

Management of trans-boundary rivers is made complex from political consideration of the riparian countries. But the approach has to be scientific but political decisions must guide the process and, as may be necessary, be able to over-ride technical as well so called legal arguments.

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Managing a shared resource

NITIN DESAI

FRESH WATER, on which all life depends, is a shared resource, whether it is a village pond, a large lake, an underground aquifer or a river. The central issue for water management at all geographical levels from the village or town, to the regional, national or global level is the adequacy of the governance arrangements to allow all who share the resource a say in the decisions about its development and use.

A river poses a truly complex challenge for governance because of the multiple uses it serves. It provides water for household, agricultural and industrial use. It can be a major source of hydroelectric power when it descends from the hills to the plains. It may be used for water transport in barges and boats. It can be a source of fish for consumption. It has to be managed to contain flood risks, control pollution and protect biodiversity. All this requires a shared understanding of the hydrology of the river and relevant data exchange between the multiple political jurisdictions through which river passes, within or between countries. A further source of complexity that is becoming more important now is the potential impact of climate change on the hydrology of the river.

These multiple uses of a river interact with each other. When waste from human settlements and industrial plants pollutes the river, its potential as a source of household water may be compromised. When a river is used extensively for navigation or hydro power, it may interfere so much with fish spawning grounds that fishery prospects may be adversely affected. When the quantity of water withdrawn from the river goes beyond a limit it may reduce flows to a point at which river species are threatened with extinction. Population pressures and changing patterns of land use, particularly those that encroach on flood plains, can increase the threat of floods. Hence separating the different uses of the river under different governance arrangements may not be appropriate.

All of these threats are becoming more acute and may become unmanageable if climate change leads to radical shifts in the quantum and timing of water flows. Hence the need for cooperation between the political jurisdictions is now even more necessary than in the past when demands for water and other services that a river provides were lower and less threatened by demographic, economic and ecological changes. When these jurisdictions are within a country the political framework for strengthening cooperation is available, though, the experience of countries like India shows that the entrenched views about rights make this quite difficult. At the international level the framework for cooperation is even weaker and is often locked in a stalemate because of sharp differences between upstream and downstream countries on their respective rights.

The way ahead requires a dilution of the distinction between the rights of upstream and downstream states. A shared resource is not owned by any one party, not even the flows that traverse through its territory. The river bed may lie in one jurisdiction; but the water travels from one jurisdiction to another. This emphasis on shared ownership and shared responsibility is reflected in the available international guidelines like the Berlin Rules on Water Resources, adopted by the International Law Association in 2004, which are more comprehensive than the earlier Helsinki Rules on the Uses of Waters of International Rivers. These guidelines may not have the force of law but are valuable as a starting point for organised cooperation as they reflect a consensus between legal specialists from upstream and downstream states.

The challenge of international cooperation in the management of international rivers is particularly acute in Asia where a large number of rivers, many originating in the Tibetan plateau, like the Yarlung-Tsangpo-Siang-Brahmaputra-Jamune River. Today, what we need are more complete agreements that deal with all possible uses of the river and that bring together all the jurisdictions through which the river passes. This book about one such shared river, written by many specialists from the region is a valuable first step in this direction.

"Today, what we need are more complete agreements that deal with all possible uses of the river and that bring together all the jurisdictions through which the river passes."

ব্রহ্মপুত্র सिआंग

The urgent need for regional river-based cooperation

QAZI KHOLIQUZZAMAN AHMAD

WHEN, thousands of years ago, humans moved out of caves and took up agricultural activities, they had to organize their lives in conducive locations. One consideration was surely proximity to sources of water needed for farming, in addition to water for life. Up to the beginning of the first Industrial Revolution (circa 1870), human

"Given the fast worsening climate change impacts in the basin, a regional river-based cooperation becomes even more urgent."

settlements, by and large, grew alongside rivers.

Currently, road, rail and air transportation along with ground water extraction, water diversion methods, water purification and transporting of water long distances are so developed that proximity to rivers is not as important as it used to be - generally speaking that is.

But in certain parts of the world, rivers still define the way of life. The catchment area of the Yarlung Tsangpo-Brahmaputra-Jamuna Rivers, running across China, India and Bangladesh, is one such region. Millions of people of the countries through which these rivers and their tributaries flow through remain crucially dependent on them for water for life and water for livelihood including irrigation, transportation, hydroelectricity, water for industrial and other economic systems and natural systems. Employment and income earning opportunities, particularly of the rural people, of the basin still largely evolve around these rivers.

While these rivers are a boon for the people, they also bring sorrow due to frequent floods and river erosion. Moreover, downstream countries often suffer from very low flows due to excessive upstream extraction of water during the dry season. There is therefore this double jeopardy for the people living in the downstream regions of this basin.

But, international rules, Helsinki Rules for example, provide for equitable share of transboundary rivers to be available to all co-riparians. Indeed, it is now generally accepted that a transboundary river is best managed by co-riparians together under an agreed cooperative framework for larger benefits. But politics, diplomacy and, not infrequently, bureaucratic tangles often prevent cooperation among the co-riparians.

In the wake of global climate change, which is fast worsening, major floods are occurring more frequently and devastatingly. The changing and shifting pattern of rainfall also introduces variations in the water flow levels and patterns, thereby disturbing crop cycle and other economic activities.

Given the fast worsening climate change impacts in the basin, a regional river-based cooperation becomes even more urgent also to address climate change impacts together, while at the same time tackling basin-wide river development issues. That is, the cooperation framework has to cover the basin all the way from the origins of the three rivers, their joining one another at places and eventually flowing down to the sea. The purpose is to benefit all the peoples of all co-riparians in terms of access to water for various purposes including irrigation, timely information sharing with lower riparian countries as flood water rises upstream, cooperative generation and equitable sharing of hydro-electricity, excavation and river training, addressing climate change adaptation, and cleaning up the water of the rivers as required all along the course across the countries the river runs through.

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References

2. FLOW-*The River's Journey*

1. Based on recent remote sensing studies on the origin of the river the length and area have been revised.
2. Jain, S. K., Agarwal, P. K. and V. P. Singh. (2007) Hydrology and Water Resources of India. Springer. Pp 419-472.
3. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. (2014) Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh.
4. Sharma, J. N. (2004) An Overview of the Brahmaputra river system. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Springer Science & Business Media. Pp 17-23.
5. Immerzeel, W. (2008) Historical trends and future predictions of climate variability in the Brahmaputra basin, International Journal of Climatology, 28, 243–254. DOI: 10.1002/joc.1528
6. An antecedent river is one whose path of flow was established before the mountainous structure was uplifted.
7. A geological epoch (subdivision of the geologic timescale) that lasted from about 56 to 33.9 million years ago.
8. USGS. (2015) The Himalayas: Two continents collide. [online] United States Geological Survey. URL: https://pubs.usgs.gov/publications/text/himalaya.html
9. Manish, K. and M. K. Pandit. (2018) Geophysical upheavals and evolutionary diversification of plant species in the Himalaya. PeerJ. 2018; 6: e5919. doi: 10.7717/peerj.5919
10. Lang, K. and K. Huntington. (2014) Antecedence of the Yarlung–Siang–Brahmaputra River, eastern Himalaya. Earth and Planetary Science Letters. 397. 145–158. 10.1016/j.epsl.2014.04.026.
11. Rudra, K. (2018) Rivers of the Ganga-Brahmaputra-Meghna Delta: A Fluvial Account of Bengal. Springer. p. 27
12. Goswami, D.C. and Das, P.J. (2003) The Brahmaputra river, India: the eco-hydrological context of water use in one of world's most unique river systems, Ecologist Asia 11 (1): 9-11 URL: http://nealliance.net/wp-content/uploads/2010/10/NE-Dams.-Ecologist-Vol-11-No1.pdf
13. Purkait, B. (2004) Hydrogeology. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 113-138.
14. Sharma, J. N. (2004) An Overview of the Brahmaputra river system. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 72-87
15. Ibid
16. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. (2014) Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh
17. Sharma, J. N. (2004) An Overview of the Brahmaputra river system. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 72-87
18. Ibid
19. Goyal, M. K., Gupta, S., Sarma, A. and D. Singh. (2018). Subansiri: Largest Tributary of Brahmaputra River, Northeast India. In The Indian Rivers. Springer Hydrogeology. pp.523-535. DOI: 10.1007/978-981-10-2984-4_36
20. NEC (2016), National Integrated Water Resources Management Plan, National Environment Commission, Royal Government of Bhutan
21. Ibid
22. ADB/NEC (2016), Water: Securing Bhutan's Future, Asian Development Bank/National Environment Commission Royal Government of Bhutan, Thimphu, Bhutan, ISBN: 978-99936-865-3-8

23. The Dooars or Duars are the alluvial floodplains that lie south of the outer foothills of the Himalayas and north of the Brahmaputra Valley. This region stretches from the Teesta River in West Bengal to the Dhansiri River in Assam.
24. ADB/NEC (2016), Water: Securing Bhutan's Future, Asian Development Bank/National Environment Commission Royal Government of Bhutan, Thimphu, Bhutan, ISBN: 978-99936-865-3-8
25. Nishat, B., Chakraborty, S. K., Hasan, E. and A. J. M. Z. Rahman. (2014) Rivers Beyond Borders. India-Bangladesh Transboundary River Atlas. Ecosystems for Life: A Bangladesh-India Initiative. International Union for Conservation of Nature (IUCN). Dhaka, Bangladesh
26. Ibid
27. Ibid
28. Ibid
29. Ibid
30. Pervez M. S. and M. H. Geoffrey. (2015) Assessing the impacts of climate and land use and land cover change on the freshwater availability in the Brahmaputra River basin. Journal of Hydrology: Regional Studies 3:285-311.
31. Immerzeel, W. (2008) Historical trends and future predictions of climate variability in the Brahmaputra basin, Int. J. Climatol., 28, 243–254, 2008.
32. Hasson S., Lucarini V. and P. Salvatore. (2013) Hydrological cycle over South and Southeast Asian river basins as simulated by PCMDI/CMIP3 experiments. *Earth System Dynamics* 4(2): 199-217.
33. Kumar, G. A., Immerzeel, W. W., Sperna W. F. C., and M. F. P. Bierkens. (2011) Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling. Hydrology and Earth System Sciences 15(5): 1537-1545.
34. Immerzeel, W. (2008) Historical trends and future predictions of climate variability in the Brahmaputra basin, International Journal of Climatology, 28, 243–254. DOI: 10.1002/joc.1528
35. Lupker M., Lavé J., France-Lanord C., Christl M., Bourlès D., Carcaillet J., Maden C., Wieler R., Rahman M., and D. Bezbaruah (2017) Be systematics in the Tsangpo-Brahmaputra catchment: the cosmogenic nuclide legacy of the eastern Himalayan syntaxis. Earth Surface Dynamics 5(3): 429-449.
36. Fu C. and J. O. Fletcher Joseph. (1985) The relationship between Tibet-tropical ocean thermal contrast and interannual variability of Indian monsoon rainfall. Journal of climate and applied meteorology. 24(8): 841-847.
37. Sharma, J. N. (2004) An Overview of the Brahmaputra river system. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 72-87
38. BWDB. (2015) Environmental Impact Assessment (EIA) (Draft Final) Volume I (Main Text) River Bank Improvement Program (RBIP). Bangladesh Water Development Board. Ministry of Water Resources.
39. Brun F., Berthier E., Wagnon P., Kääb A., and D. Treichler. (2017) A spatially resolved estimate of High Mountain Asia glacier mass balances from 2000 to 2016. *Nature geoscience* 10(9): 668.
40. Shrestha A. B., Agrawal N. K., Alfthan B., Bajracharya S. R., Maréchal J. and B. van Oort. (2015) *The Himalayan Climate and Water Atlas: impact of climate change on water resources in five of Asia's major river basins*. Available online: https://www.cabdirect.org/cabdirect/FullTextPDF/2016/20163337389.pdf
41. Shrestha A. B., Agrawal N. K., Alfthan B., Bajracharya S. R., Maréchal J. and Oort B van. (2015) *The Himalayan Climate and Water Atlas: impact of climate change on water resources in five of Asia's major river basins*. Available online: https://www.cabdirect.org/cabdirect/FullTextPDF/2016/20163337389.pdf.
42. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. (2014) Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh, Pp xii + 74
43. Ibid
44. Based on data between 1977 and 2006. Data source: National Water Resources Database, Bangladesh. Analysis by Centre for Environmental and Geographic Information Services (*CEGIS*)
45. Liu, X.C. and Xiao, C.D. Preliminary study of the Jiemayangzong Glacier and lake variations in the source regions of the Yarlung Zangbo River in 1974-2010. (2011) Journal of Glaciology and Geocryology. 2011, *33(3)*, 488-496.
46. Ibid
47. B. Datta and V. P. Singh. (2004) Hydrology. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 72-87
48. B. Nishat and S M Rahman. (2009) Water Resources Modeling of the Ganges-Brahmaputra-Meghna River Basins using Satellite Remote Sensing Data" In Journal of American Water Resources Association in 'Satellites and Transboundary Water' Volume 45, Issue 6 December, 2009
49. Model developed by Centre for Environmental and Geographic Information Services (CEGIS)
50. Map has been developed from model calculations by Centre for Environmental and Geographic Information Services (CEGIS)
51. Based on observed data and model calculations by Centre for Environmental and Geographic Information Services (CEGIS).
52. Sharma, J. N. (2004) An Overview of the Brahmaputra river system. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 72-87
53. Cumec = cubic meters per second (m3/second)
54. Tian F. , Xu R. , Nan Y. , Li K. , He Z. . (2020) Quantification of runoff components in the Yarlung Tsangpo River using a distributed hydrological model. Advances in Water Science, 31(3): 324-336.
55. Barthakur, M. (2004) Weather and Climate. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 17-23.
56. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. 2014. Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh.
57. Ibid
58. Barthakur, M. (2004) Weather and Climate. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 17-23.
59. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. 2014. Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh, Pp xii + 74
60. Jain, S. K., Agarwal, P. K. and V. P. Singh. 2007. Hydrology and Water Resources of India. Springer. Pp 419-472.
61. Mahanta, C., Zaman, A. M., Newaz, S. M. S., Rahman, S. M., Mazumdar, T. K., Choudhury, R., Borah, P. J. and L. Saikia. 2014. Physical Assessment of the Brahmaputra River. IUCN, International Union for Conservation of Nature, Dhaka, Bangladesh
62. Ibid
63. Purkait, B. (2004) Hydrogeology. In The Brahmaputra Basin Water Resources. Eds Singh, V. P., Sharma, N. and C. S. P. Ojha. Kluwer Acedemic Publishers. pp 113-138.
64. NCHM. (2020) Hydrological Extreme Events of Bhutan. National Center for Hydrology and Meteorology (NCHM), Royal Government of Bhutan Accessed from https://www.nchm.gov.bt/ on 15 June 2020.
65. Joint River Commission, Bangladesh
66. Ibid
67. NEC (2016), National Integrated Water Resources Management Plan, National Environment Commission, Royal Government of Bhutan.
68. Bhutan Water Fact 2018, Ugyen Wangchuck Institute for Conservation and Environmental Research (UWICER), Department of Forests and Park Services, Ministry of Agriculture and Forests, Royal Government of Bhutan, Bumthang and WWF Bhutan Programme Office, Thimphu
69. Chhopel GK, Dulal IR, Chhophel K, Wangchuk C, Rinzin U, Dupchu K, Kunzang, Tse-ring K, Tshethar K, Dorji U, Wangchuk T, Lhamo T, Nidup J (2011) Securing the Natural Freshwater Systems of the Bhutan Himalayas: climate Change and Adaptation measures on Water Resources in Bhutan. A climate summit for a living Himalaya. Available from http://sa.indiaenvironmentportal.org.in/files/file/Water_Paper_Bhutan.pdf
70. Datta B., Singh V.P. (2004) Hydrology. In: Singh V.P., Sharma N., Ojha C.S.P. (eds) The Brahmaputra Basin Water Resources. Water Science and Technology Library, vol 47. Springer, Dordrecht
71. Yasuda, Y., Aich, D., Hill, D., Huntjens, P., Swain, A. (2017), Transboundary Water Cooperation over the Brahmaputra River: Legal Political Economy Analysis of Current and Future Potential Cooperation. The Hague Institute for Global Justice.
72. Datta B., Singh V.P. (2004) Hydrology. In: Singh V.P., Sharma N., Ojha C.S.P. (eds) The Brahmaputra Basin Water Resources. Water Science and Technology Library, vol 47. Springer, Dordrecht
73. BWDB. (2014). Environmental Impact Assessment (EIA) of River Bank Improvement Program (RBIP). Bangladesh Water Development Board. Ministry of Water Resources
74. Ibid

75. Ibid
76. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
77. Ibid
78. Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. *International Journal of Climatology, 28*, 243–254. doi:10.1002/joc.1528.
79. Flu¨gel, W.-A., Pechstedt, J., Bongartz, K., Bartosch, A., Eriksson, M., & Clark, M. (2008). *Analysis of climate change trend and possible impacts in the Upper Brahmaputra River Basin – the BRAHMATWINN Project*. 13th IWRA World Water Congress 2008, Montpelier, France.
80. Apurv, T., Mehrotra, R., Sharma, A., Goyal, M.K., Dutta, S. (2015). Impact of climate change on floods in the Brahmaputra basin using CMIP5 decadal predictions. *Journal of Hydrology, 527*, 281-291. http://dx.doi.org/10.1016/j.jhydrol.2015.04.056
81. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
82. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC). The RCPs are consistent with a wide range of possible changes in future anthropogenic (i.e., human) GHG emissions, and aim to represent their atmospheric concentrations.
83. A Representative Concentration Pathway (RCP) is a greenhouse gas concentration (not emissions) trajectory adopted by the Intergovernmental Panel on Climate Change (IPCC)..
84. Pervez, M. S., & Henebry, G. M. (2014). Projections of the Ganges–Brahmaputra precipitation— Downscaled from GCM predictors. *Journal of Hydrology, 517*, 120–134. doi:10.1016/j.jhydrol. 2014.05.016
85. Wijngaard, R, R., Lutz, A.F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A.B., Immerzeel, W.W. (2017). Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. *PLoS ONE 12*(12): e0190224. https://doi. org/10.1371/journal.pone.0190224
86. Lutz, A.F., Maat, H. W.ter., Wijngaard, R.R., Biemans, H., Syed, A., Shrestha, A.B., Wester, P., Immerzeel, W. (2019). South Asian river basins in a 1.50C warmer world. *Regional Environmental Change, 19*, 833-847. https://doi.org/10.1007/s10113-018-1433-4
87. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237
88. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
89. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
90. Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. *International Journal of Climatology, 28*, 243–254. doi:10.1002/joc.1528.
91. Flu¨gel, W.-A., Pechstedt, J., Bongartz, K., Bartosch, A., Eriksson, M., & Clark, M. (2008). *Analysis of climate change trend and possible impacts in the Upper Brahmaputra River Basin – the BRAHMATWINN Project*. 13th IWRA World Water Congress 2008, Montpelier, France.
92. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
93. Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. *International Journal of Climatology, 28*, 243–254. doi:10.1002/joc.1528.
94. In previous IPCC assessments, the most widely used and referred-to family of emissions scenarios were the SRES scenarios (Special Report on Emissions Scenarios). These scenarios were based on future global population growth, technological development, globalization, and societal values. RCP scenarios supersedes SRES scenarios from 2014).
95. The SRES scenarios (Special Report on Emissions Scenarios) are based on future global population growth, technological development, globalization, and societal values.
96. Dobler, A., Yaoming, M., Sharma, N., Kienberger, S., & Ahrens, B. (2011). Regional climate projections in two alpine river basins: Upper Danube and Upper Brahmaputra. *Advances in Science and Research, 7*, 11-20. doi:10.5194/asr-7-11-2011
97. Wijngaard, R, R., Lutz, A.F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A.B., Immerzeel, W.W. (2017). Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. *PLoS ONE 12*(12):
98. Lutz, A.F., Maat, H. W.ter., Wijngaard, R.R., Biemans, H., Syed, A., Shrestha, A.B., Wester, P., Immerzeel, W. (2019). South Asian river basins in a 1.50C warmer world. *Regional Environmental Change, 19*, 833-847. https://doi.org/10.1007/s10113-018-1433-4
99. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
100. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237
101. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
102. Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. *International Journal of Climatology, 28*, 243–254. doi:10.1002/joc.1528.; Immerzeel, W. W., van Beek, L. P. H., & Bierkens, M. F. P. (2010). Climate change will affect the Asian water towers. *Science, 328*, 1382–1385. doi:10.1126/science.1183188
103. Apurv, T., Mehrotra, R., Sharma, A., Goyal, M.K., Dutta, S. (2015). Impact of climate change on floods in the Brahmaputra basin using CMIP5 decadal predictions. *Journal of Hydrology, 527*, 281-291. http://dx.doi.org/10.1016/j.jhydrol.2015.04.056
104. Shrestha, AB; Agrawal, NK; Alfthan, B; Bajracharya, SR; Maréchal, J; van Oort, B (eds). (2015). *The Himalayan Climate and Water Atlas: Impact of climate change on water resources in five of Asia's major river basins*. ICIMOD, GRID-Arendal and CICERO
105. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237
106. Gain, A. K., Immerzeel, W. W., Sperna Weiland, F. C., & Bierkens, M. F. P. (2011). Impact of climate change on the stream flow of the lower Brahmaputra: trends in high and low flows based on discharge-weighted ensemble modelling. *Hydrology and Earth System Sciences, 15*, 1537–1545. doi:10.5194/hess-15-1537-2011.
107. Immerzeel, W. (2008). Historical trends and future predictions of climate variability in the Brahmaputra basin. *International Journal of Climatology, 28*, 243–254. doi:10.1002/joc.1528.
108. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237
109. Lutz, A.F., Maat, H. W.ter., Wijngaard, R.R., Biemans, H., Syed, A., Shrestha, A.B., Wester, P., Immerzeel, W. (2019). South Asian river basins in a 1.50C warmer world. *Regional Environmental Change, 19*, 833-847. https://doi.org/10.1007/s10113-018-1433-4
110. Ghosh, S., & Dutta, S. (2012). Impact of climate change on flood characteristics in Brahmaputra basin using a macro-scale distributed hydrological model. *Journal of Earth System Science, 121*, 637–657. doi:10.1007/s12040-012-0181-y.
111. Wijngaard, R, R., Lutz, A.F., Nepal, S., Khanal, S., Pradhananga, S., Shrestha, A.B., Immerzeel, W.W. (2017). Future changes in hydro-climatic extremes in the Upper Indus, Ganges, and Brahmaputra River basins. *PLoS ONE 12*(12): e0190224. https://doi. org/10.1371/journal.pone.0190224
112. Immerzeel, W. W., van Beek, L. P. H., & Bierkens, M. F. P. (2010). Climate change will affect the Asian water towers. *Science, 328*, 1382–1385. doi:10.1126/science.1183188
113. Prasch, M., Marke, T., Strasser, U., & Mauser, W. (2011). Large scale integrated hydrological modelling of the impact of climate change on the water balance with DANUBIA. *Advances in Science and Research, 7*, 61–70. doi:10.5194/asr-7-61-2011
114. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237.; Lutz, A.F., Maat, H. W.ter., Wijngaard, R.R., Biemans, H., Syed, A., Shrestha, A.B., Wester, P., Immerzeel, W. (2019). South Asian river basins in a 1.50C warmer world. *Regional Environmental Change, 19*, 833-847. https://doi.org/10.1007/s10113-018-1433-4

115. Nepal, S., & Shrestha, A. B. (2015). Impact of climate change on the hydrological regime of the Indus, Ganges and Brahmaputra river basins: a review of the literature. International Journal of Water Resources Development, 31(2), 201-218. Lutz, A.F., Immerzeel, W.W., Shrestha, A.B., Bierkends, M.F.P. (2014). Consistent increase in High Asia's runoff due to increasing glacier melt and precipitation. *Nature climate change*. DOI: 10.1038/nclimate2237
116. Nandargi, S.S., (2020) An invited article on 'Floods in Indian Rivers and their Meteorological Aspects', Volume IV of the 'Environmental History of India' of Indian Council of Historical Research (*ICH)*
117. http://asdma.gov.in/pdf/asdmp.pdf
118. http://asdma.gov.in/pdf/asdmp.pdf
119. https://www.villagesquare.in/2017/09/06/riverbank-erosion-no-less-disaster-assam-floods/
120. https://www.villagesquare.in/2017/09/06/riverbank-erosion-no-less-disaster-assam-floods/
121. Mukherjee, N., and Khan, M. F. (2009) Factoring Climate Change Considerations in the Design of Padma Multipurpose Bridge. Consultancy Report Prepared by the Centre for Environmental and Geographic Information Services (CEGIS). Bangladesh Bridge Authority, Dhaka.
122. Ibid
123. Analysis by Centre for Environmental and Geographic Information Services (CEGIS) based on satellite images
124. Hossain, A.N.H.A. (2006) The Impact of Floods on Bangladesh and Options for Mitigation an Overview, In Siddiqui, K. and Hossain, A.N.H. ed. Options for Flood Risk and Damage Reduction in Bangladesh, The University Press Limited, Dhaka, p.60
125. ReliefWeb. (2017) Monsoon Floods in Bangladesh - Situation Report 02 (16 August 2017)
126. *Char* is the local name in Bangladesh and India for river island or shoal; a tract of land created by sediment accretion surrounded by the sea, estuary, or river.
127. Nishat, A., Nishat B. and M. F. A. Khan. (2011) A Strategic View of Land Management Planning in Bangladesh. In Flood Risk Science and Management. Eds Pender G. and H. Faulkner. Blackwell Publishers Ltd.
128. Concern Worldwide. 2019. Floods in Bangladesh cause devastation. Available at https://www.concernusa.org/story/floods-bangladesh/
129. Saha, M.K. (2013) Environmental and social impact of flood control, drainage and irrigation projects: is it a development disaster for Bangladesh??? In *Planned decentralization: aspired development*, pp. 78–85. World Town Planning Day 2013. (available at http://www.bip.org.bd/SharingFiles/journal_book/20140128163854.pdf.)
130. Neil Noble and Dipok Chandra Roy. (2011) Flood-resistant Housing, Technical Brief. Practical Action. Available at http://practicalaction.org/flood-resistant_housing
131. Wahra, G. N. (2011) Bangladesh Disaster Report 2011. Disaster Forum and Disaster Management Bureau, pp.12-32
132. Islam, M. S., Sultana, S, Saifunnar and M. A. Miah. (2014) Adaptation of Char Livelihood in Flood and River Erosion Areas through Indigenous Practice: A Study on Bhuapur Riverine Area in Tangail. Journal of *Environ. Sci. & Natural Resources,* 7(1): 13-19. DOI: https://doi.org/10.3329/jesnr.v7i1.22138
133. Maminul Haque Sarker, M. H., Huque, I. and M. Alam. (2003) Rivers, *chars* and *char* dwellers of Bangladesh. International Journal of River Basin Management Vol. 1, No. 1 (2003), pp. 61–80.
134. The channel planform is the view or outline of a river seen from directly above. Different types of river channel planform include meandering, straight, braided and braided meanders.
135. Avulsion refers to a change in channel alignment was achieved by an abandonment of one course and adoption of a new one some distance away rather than by progressive shifting
136. Major James Rennell, (b. 3 December 1742; d. 29 March 1830) was an English geographer, historian and a pioneer in oceanography. He is also known as the father of Indian geography. Rennell's survey of Bengal, which was commenced in 1764, was the first ever prepared and still used as reference for many studies.
137. Rudra, K. (2018) Rivers of the Ganga-Brahmaputra-Meghna Delta: A Fluvial Account of Bengal. Springer. p. 27
138. Alam, J. B., Uddin, M., Ahmed, J. U., Cacovean, H., Rahman, H., Banik, B. K. and N. Yesmin.(2007) Study of morphological change of river old Brahmaputra and its social impacts by remote sensing. Geographia Technica, no.2, 2007. URL: https://pdfs.semanticscholar.org/637c/14b977ae407f0593976b5cc936a2c9f52511.pdf
139. Borgohain, S., Das, J., Saraf, A. K., Singh, G. and S. S. Baral. (2007) Morphodynamic changes of Lohit River, NE India: GIS-based study. Geographia Technical, no.2, 2007. URL: https://www.currentscience.ac.in/Volumes/110/09/1810.pdf

140. Ibid
141. Sarkar, A., Garg, R. and N. Sharma. (2012) RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India. *Journal of Water Resource and Protection*, Vol. 4 No. 2, 2012, pp. 63-72. doi: 10.4236/jwarp.2012.42008.
142. Bristow, C.S. (1987) Brahmaputra River: Channel migration and deposition. In: Recent Developments in Fluvial Sedimentology. Ed. by F.G. Ethridge, R.M. Flores and M.D. Harvey. Spec. Publ. Soc. Econ. Paleont. Miner.,39, 63±74.
143. Lahiri, S. K. and R. Sinha. (2012) Tectonic controls on the morph dynamics of the Brahmaputra River system in the upper Assam valley, India. Geomorphology, Volume 169, p. 74-85. DOI: 10.1016/j.geomorph.2012.04.012
144. Sarma, J. N. and S. Acharjee. (2018) A Study on Variation in Channel Width and Braiding Intensity of the Brahmaputra River in Assam, India. *Geosciences* 2018, *8*(9), 343; https://doi.org/10.3390/geosciences8090343
145. Chatterjee, S., Scotese, C. R. and S. Bajpai. (2017) Indian Plate and Its Epic Voyage from Gondwana to Asia: Its Tectonic, Paleoclimatic, and Paleobiogeographic Evolution. Geological Society of America. p. 120.
146. Sarkar, A., Garg, R. and N. Sharma. (2012) RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India. *Journal of Water Resource and Protection*, Vol. 4 No. 2, 2012, pp. 63-72. doi: 10.4236/jwarp.2012.42008.
147. Gilfellon, G, Sarma, J and K Gohain. (2003). Channel and Bed Morphology of a Part of the Brahmaputra River in Assam. Journal of the Geological Society of India. 62.
148. RTI and Expert Committee. 2018. Framework for Proper Planning & Management of Water Resources in North East India. Report of the Expert Committee for Suggesting Immediate Measures for Proper Management of Water Resources in North Eastern India
149. Richardson, W. R. and C. R. Thorne. (2000) Multiple Thread Flow and Flow Channel Bifurcation in a Braided River: Brahmaputra -Jamuna River, Bangladesh. Geomorphology 38 (2000): 185- 96.
150. Sarkar, A., Garg, R. and N. Sharma. (2012) RS-GIS Based Assessment of River Dynamics of Brahmaputra River in India, *Journal of Water Resource and Protection*, Vol. 4 No. 2, 2012, pp. 63-72. doi: 10.4236/jwarp.2012.42008.
151. Fischer, S., Pietroń, J., Bring, A. Thorslund, J. and J Jarsjo. (2017) Present to future sediment transport of the Brahmaputra River: reducing uncertainty in predictions and management. *Reg Environ Change* 17, 515–526 (2017). https://doi.org/10.1007/s10113-016-1039-7.
152. Stewart, R. J., Hallet, B., Zeitler, P.K., Malloy, M.A., Allen, C.M. and D. Trippett. (2008) Brahmaputra sediment flux dominated by highly localized rapid erosion from the easternmost Himalaya. Geology, September 2008; v. 36; no. 9; p. 711–714; doi: 10.1130/G24890A
153. Sarker, M. and C. Thorne. (2006) Morphological Response of the Brahmaputra–Padma–Lower Meghna River System to the Assam Earthquake of 1950. Braided Rivers: Process, Deposits, Ecology and Management. 289-310. 10.1002/9781444304374.ch14.
154. BWDB. (2015) Environmental Impact Assessment (EIA) (Draft Final) Volume I (Main Text) River Bank Improvement Program (RBIP). Bangladesh Water Development Board. Ministry of Water Resources.
155. Sarker, M. H., Huque, I. and M. Alam. (2003) Rivers, chars and *char* dwellers of Bangladesh. International Journal of River Basin Management Vol. 1, No. 1 (2003), pp. 61–80
156. BWDB. (2014) Environmental Impact Assessment (EIA) of River Bank Improvement Program (RBIP). Bangladesh Water Development Board. Ministry of Water Resources
157. Chakrapani, G. J. (2005) Factors controlling variations in river sediment loads. Current Science, Vol. 88, No. 4, 25 February 2005
158. Rahman, M., Dustegir, M., Karim, R., and Haque, A., Nicholls, R. J., Darby, S. E., Nakagawa, H., Hossain, M., Dunn, F. E. and M. Akter (2018) "Recent sediment flux to the Ganges-Brahmaputra-Meghna delta system," Science of the Total Environment, 643 (2018) 1054–1064 https://doi.org/10.1016/j.scitotenv.2018.06.147.
159. Sarker, M. H., Huque, I. and M. Alam. (2003) Rivers, chars and *char* dwellers of Bangladesh. International Journal of River Basin Management Vol. 1, No. 1 (2003), pp. 61–80.
160. Sarker, M. H., Akter, J., and Rahman, M. M.,(2013). "Century-Scale Dynamics of the Bengal Delta and Future Development." 4th International Conference on Water & Flood Management (ICWFM), 2013.
161. Ibid
162. Coleman, J. M. (1969) Brahmaputra river: Channel processes and sedimentation. Sedimentary Geology Volume 3, Issues 2–3, August 1969, Pages 129-239

❄

3. LIFE-*Biodiversity of the Region*

1. Wang, L., Wang, Z., & Liu, X. (2018). Water Resources Carrying Capacity Analysis of YarLung Tsangpo River Basin (I). Water 10(9), 1131.
2. ibid
3. Smith Andrew T., Foggin Marc J. 1999. The plateau pika (*Ochotona curzoniae*) is a keystone species for biodiversity on the Tibetan plateau. *Animal Conservation*. ZSL publications.: 235-240.
4. Paltridge, N., Jin, T., Unkovich, M., Bonamano, A., Gason, A., Grover, S., Wilkins, J. Tashi, N., & Coventry, D. (2009). Agriculture in central Tibet: an assessment of climate, farming systems, and strategies to boost production. *Crop and Pasture Science* 60(7): 627-639 https://doi.org/10.1071/CP08372
5. Duan, C., Shi, P., Zong, N., Wang, J., Song, M., & Zhang, X. (2019). Feeding solution: Crop-livestock integration via crop-forage rotation in the southern Tibetan Plateau. *Agriculture, Ecosystems & Environment* 284, 106589. https://doi.org/10.1016/j.agee.2019.106589
6. Li, X., Bleisch, W., Liu, X., & Jiang, X. (2020). Camera-trap surveys reveal high diversity of mammals and pheasants in Medog, Tibet. *Oryx*, 1-4. https://doi.org/10.1017/S0030605319001467
7. Shen Weishou. 1997. Classification and sorting of the psammophytic vegetation in the middle Yarlung Zangbo river basin, Tibet. Journal of Desert Research, 17, 269-273. (in Chinese); Huai Huyin. 1997. Characteristics of Alpine Shrubs on Qinghai-Xizang Plateau. Journal of Gansu Sciences, 9(4): 23-25.
8. Li Hui. 2000. Biological resources and their characteristics in the Yarlung Zangbo river canyon. Tibet science and technology, (3): 77-78. (in Chinese)
9. He Ping, Guo Ke, Gao Jixi, et al. 2005. Vegetation Types and Their Geographic Distribution in the Source Area of the Yarlung Zangbo. Journal of Mountain Science, 23(3): 267-273. (In Chinese); Chen Bin, Li Haidong, Cao Xuezhang, et al. 2015. Vegetation pattern and spatial distribution of NDVI in the Yarlung Zangbo River Basin of China. Journal of desert research, 35(1):120-128. (in Chinese)
10. Zhang Jian, Tan Jiali, Deng Lilan. et al. 2008. Investigation and Assessment of the Terrestrial Vegetation in the Middle Reaches of the Yarlung Zangbo River in Tibet. Forest Resources Management (4):118-123. (In Chinese)
11. Qiong La, Zhaxi Ciren, Zhu Weidong, et al. 2014. Plant species-richness and association with environmental factors in the riparian zone of the Yarlung Zangbo River of Tibet, China. Biodiversity Science, 22(3): 337-347.
12. Yang, L., Li, J. and Tsamchu Drolma. 2016. Number and distribution of wintering black-necked crane (*Grus nigricollis*) in drainage area of Yarlung-Zangbo River and its two branches from Tibet, China. Journal of Northeast Forestry University 44(5), 70-72, 83.
13. Yan, R., Shen, W., Zhao, W. and Ouyang, Y. 2018. Dynamics of suitability and conservation of the black-necked crane habitats in the midstream of the Yarlung-Zangbo River. Journal of Ecology and Rural Environment. 34(2), 146-152.
14. Hu, G., Du, X., Cheng, L., Ji, F., Mou, Z., Ma, B., Li, L. and Jin, X. 2019. Current situation, major problems and countermeasures of fishery resources in Xizang Autonomous Region. Chinese Journal of Fisheries. 32(3): 58-64 (in Chinese).
15. Boruah, S. Biswas, S.P. 2002. Ecohydrology and fisheries of the Upper Brahmaputra basin. *The Environmentalist*, 22(2):119-131
16. Poff, N.L. & J.V. Ward. 1989. Implications of stream flow variability and predictability for lotic community structure: a regional analysis of stream flow patterns. *Canadian Journal of Fisheries and Aquatic Sciences*, 46:1805–1818
17. Tripathi, S.D. 1984. Integrated fish-crop-livestock production in India. Working paper of the 6th-session of the IPFC Working Party of Experts on Aquaculture. FAO, Rome.
18. Saikia, A.K., S. K. Abujam, D.N. Das & S.P. Biswas. 2015. Economics of paddy cum fish culture: A case study in Sivsagar, Assam. *International Journal of Fisheries and Aquatic Studies*, 2(5): 198-203
19. Ferdous, M.J, Karim, M.R., Hossain, M. A., Rahman, M. A. & M.M. Iqbal. 2015. Fin fish assemblage and biodiversity status of carps on Halda river, Bangladesh. *Annals of Veterinary and Animal Science*, 2(6):151-161
20. Grimmett, R., C. Inskipp and T. Inskipp. 1999. Pocket Guide to the Birds of the Indian Subcontinent. Oxford University Press, New Delhi. 384pp.
21. Stattersfield, A & J., Crosby, M. J., Long, A & Wege, D. C. 1998. Endemic bird areas of the world: priorities for biodiversity conservation. Cambridge, UK: BirdLife International.
22. Choudhury, A.U. 2000. *The Birds of Assam*. Gibbon Books and World Wide Fund for Nature-India, Guwahati.
23. Rahmani, A.R. and A. Choudhury. 2012. Threatened Birds of India: Their Conservation Requirements. Indian Bird Conservation Network: Bombay Natural History Society, Royal Society for the Protection of Birds and BirdLife International. Oxford University Press. Pp xvi + 864.
24. Ibid; Rahmani, A. R. 2017. Conservation of threatened grassland birds of the Brahmaputra Floodplains. Final Report submitted to Bombay Natural History Society. Pp 1-66.
25. Choudhury AU. 2015. Conservation of Status of threatened waterbirds in north–east India. In: Gopi GV. & Hussain SA. (Eds.), Waterbirds of India, ENVIS Bulletin: Wildlife and Protected Areas. Vol. 16; Wildlife Institute of India, Dehradun–248001, India.
26. Rahmani AR. Islam MZ. & Kasambe RM. 2016. Important Bird and Biodiversity Areas in India: Priority Sites for Conservation (Revised and updated). Bombay Natural History Society, Indian Bird Conservation Network, Royal Society for the Protection of Birds and BirdLife International (U.K.): pp. 1992+xii.
27. Choudhury AU. 2015. Conservation of Status of threatened waterbirds in north–east India. In: Gopi GV. & Hussain SA. (Eds.), Waterbirds of India, ENVIS Bulletin: Wildlife and Protected Areas. Vol. 16; Wildlife Institute of India, Dehradun–248001, India.
28. Alam, F., Alam, Q., Rezac, S., Khurshid-ul-Alamc, S.M., Salequeb, K. and Chowdhury, H. 2017. Sourcing green power in Bhutan: A review. *Energy Procedia*, 110:586 – 591.
29. Bajrachary, S.R., Maharjan, S.B. and Shrestha, F. 2014. The status and decadal change of glaciers in Bhutan from the 1980s to 2010 based on satellite data. *Annals of Glaciology*, 55(66):159-166.
30. UWICER. 2018. Relationship between land-use management and hydropower development in Bhutan. Ugyen Wangchuck Institute for Conservation and Environmental Research, Department of Forests and Park Services - Royal Government of Bhutan. UWICER Press.
31. NRCR&LF. 2017. *Field Guide to Fishes of western Bhutan*. National Research Centre for Riverine and Lake Fisheries of the Department of Livestock of the Ministry of Agriculture and Forests
32. DoFPS. 2015. Protected areas of Bhutan. National Parks, Wildlife Sanctuaries, Strict Nature Reserve, and Biological Corridors. Department of Forest and Park Services, Thimphu Bhutan.
33. Tashi, T. 2013. The Brown Trout. Kuensel, January 12, 2013.
34. Everard, M., Pinder, A.C., Raghavan, R. and Kataria, G. 2019. Are well-intended Buddhist practices an under-appreciated threat to global aquatic biodiversity? *Aquatic Conserv: Mar Freshw Ecosyst*, 1–6. https://doi.org/10.1002/aqc.2997
35. Gurung, D.B., Dorji, S., Tshering, U. and Wangyal, J.T. 2013. An annotated checklist of fishes from Bhutan. *Journal of Threatened Taxa*, 5(14): 4880–4886
36. Ibid
37. Waiba, T.N. 2018. Environment Friendly and Better Farm Roads: An Urgent Necessity in Bhutan. UWICER, Lamaigonpa, Bhutan.
38. Galay, K. 2008. Socio-economic and Environmental Impact Analysis of Khothagpa Gypsum Mine. *Journal of Bhutan Studies*, 18:51-81.
39. Gurung, D.B. and Thoni, R.J. 2015. Fishes of Bhutan, A preliminary checklist. Centre for Rural Development, College of Natural Resources, Lobesa, Bhutan.
40. Marchese, C. 2015. Biodiversity hotspots: A shortcut for a more complicated concept. *Global Ecology and Conservation*, *3*.: 297-309.; Mittermeier, R. A., Turner, W. R., Larsen, F. W., Brooks, T. M., & Gascon, C. 2011. Global biodiversity conservation: the critical role of hotspots. In *Biodiversity hotspots*. Springer, Berlin, Heidelberg: 3-22.
41. Acharya, B. K., & Vijayan, L. 2011. The birds of Sikkim: an analysis of elevational distribution, endemism and threats. In *Biodiversity of Sikkim Exploring and Conserving a Global Hotspot*. IPR Department, Government of Sikkim, Gangtok.: 255-282.
42. Praveen, J., Jayapal, R., & Pittie, A. 2019. Updates to the checklists of birds of India, and the South Asian region—2019. *Indian BIRDS*, *15*(1).: 1-9.
43. Ali, S. 1962. The Birds of Sikkim. Oxford University Press, New Delhi.
44. IUCN 2020. The IUCN Red List of Threatened Species. Version 2020-1. https://www.iucnredlist.org. Downloaded on 23 June 2020.
45. Sharma, P. 2004. Wetlands and their Role in the Geo-Ecological Environment. In N. S. Vijay P. Singh, *The Brahmaputra Basin Water Resources* (pp. 366-375). Springer-Science and Business Media, B.V. and Kluwer Academic Publishers.
46. Biswas, D. A. 2011. Bangladesher Nodikosh. Dhaka: Bengal Publications.

47. Wikipedia. Retrieved from www.wikipedia.org: https://en.wikipedia.org/wiki/Chalan_Beel. Accessed June 20,2020.
48. Mostafa A. R. Hossain, M. N. 2009. The Chalan beel in Bangladesh: Habitat and biodiversity degradation, and implications for future management. *Lakes & Reservoirs: Research and Management 2009*, 14: 3–19.
49. ibid
50. S.M. Galib, M. S. June 2009. Present Status of Fishes in the Chalan Beel- the Largest Beel (Wetland) of Bangladesh. *nternational Journal of Animal and Fisheries Science 2(3)*, 214-218.
51. Mostafa A. R. Hossain, M. N. 2009. The Chalan beel in Bangladesh: Habitat and biodiversity degradation, and implications for future management. *Lakes & Reservoirs: Research and Management 2009*, 14: 3–19.
52. Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89,; IUCN Bangladesh. 2015. *Red List of Bangladesh Volume 3: Birds*. IUCN, International Union for Conservation of Nature, Bangladesh Country Office, Dhaka, Bangladesh.
53. Smith, Brian D., AKM Aminul Haque, M. Shakhawat Hossain, and Anisuzzaman Khan. 1998. River dolphins in Bangladesh: conservation and the effects of water development. *Environmental management* 22: 323-335.; Ashworth, Philip J., James L. Best, Julie E. Roden, Charles S. Bristow, and Gerrit J. Klaassen. 2000. Morphological evolution and dynamics of a large, sand braid-bar, Jamuna River, Bangladesh. *Sedimentology* 47: 533-555.
54. Wegge, Per, Anil K. Shrestha, and Stein R. Moe. 2006. Dry season diets of sympatric ungulates in lowland Nepal: competition and facilitation in alluvial tall grasslands. *Ecological Research* 21: 698-706.
55. Personal observation by the author
56. BirdLife International. 2019. IUCN Red List for birds. Available online: http:/www.birdlife.org (accessed on 14 November 2019); Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89
57. Kabir, Tarik., Sayam U. Chowdhury, Tareq Onu, A. B. M. Sarwar Alam., Sakib Ahmed, Omar Shahadat, and Md. Foysal. 2016. New breeding record of riverine birds in Bangladesh. *BirdingAsia* 26: 39-42.; Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89; Ahmed, Sakib, Sayam U. Chowdhury, and Robert Sheldon. 2018. Surveys of River Lapwings Vanellus duvaucelii in Bangladesh and observations on their nesting ecology." *Wader Study* 125(2). doi:10.18194/ws.00117.
58. BirdLife International. 2019. IUCN Red List for birds. Available online: http:/www.birdlife.org (accessed on 14 November 2019); Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89
59. Kabir, S. M. H., M. Ahmad, A. T. A. Ahmed, A. K. A. Rahman, Z. U. Ahmed, Z. N. T. Begum, M. A. Hassan, and M. Khandker. 2009. *Encyclopedia of flora and fauna of Bangladesh Volume 25*: *Amphibians and Reptiles.* Asiatic Society of Bangladesh, Dhaka.
60. Dudgeon, D. 2002. An inventory of riverine biodiversity in monsoonal Asia: present status and conservation challenges. *Water Science and Technology* 45: 11-19.
61. BirdLife International. 2019. IUCN Red List for birds. Available online: http:/www.birdlife.org (accessed on 14 November 2019); Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89; Kabir, Tarik., Sayam U. Chowdhury, Tareq Onu, A. B. M. Sarwar Alam., Sakib Ahmed, Omar Shahadat, and Md. Foysal. 2016. New breeding record of riverine birds in Bangladesh. *BirdingAsia* 26: 39-42; Ahmed, Sakib, Sayam U. Chowdhury, and Robert Sheldon. 2018. Surveys of River Lapwings Vanellus duvaucelii in Bangladesh and observations on their nesting ecology." *Wader Study* 125(2). doi:10.18194/ws.00117.
62. Dudgeon, D. 2002. An inventory of riverine biodiversity in monsoonal Asia: present status and conservation challenges. *Water Science and Technology* 45: 11-19.; Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89
63. Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89; Kabir, Tarik., Sayam U. Chowdhury, Tareq Onu, A. B. M. Sarwar Alam., Sakib Ahmed, Omar Shahadat and Md. Foysal. 2016. New breeding record of riverine birds in Bangladesh. *BirdingAsia* 26: 39-42.
64. Chowdhury, Sayam U., Mohammad Foysal, John Sharpe, and Omar Shahadat. 2014. A survey for Black-bellied Tern Sterna acuticauda and other riverine birds on the Jamuna and Padma rivers in Bangladesh. *Forktail* 30, 84-89.
65. Banglapedia. 2020. "Madhupur National Park". <www.en.banglapedia.org>. Accessed in June 2020.; Gain, P. 1998. The Last Forests of Bangladesh. Society for Environment and Human Development (SEHD), Dhaka, Bangladesh.;Green, M.J.B. 1990. IUCN directory: South Asian Protected Areas. Cambridge, UK.; Khan, M.M.H. 2008. Protected Areas of Bangladesh: A Guide to Wildlife. Nishorgo Program, Bangladesh Forest Department, Dhaka, Bangladesh.;Nishat, A., Huq, S.M.I., Barua, S.P., Reza, A.H.M.A., Khan, A.S.M. 2002. Bio-ecological Zones of Bangladesh. IUCN-Bangladesh, Dhaka, Bangladesh.

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4. GROW-*Living off the land*

1. Ray, Patrick A., Yi-Chen E Yang, Sungwook Wi, Abedalrazq Khalil, Vansa Chatikavanij and Casey Brown. 2015. "Room for improvement: Hydroclimatic challenges to poverty-reducing development of the Brahmaputra River basin". *Environmental Science & Policy* 54: 64–80.
The study uses FAO CROPWAT for analysis. FAO CROPWAT is a tool for estimating monthly water use for each crop in each demand sector. CROPWAT takes as input the crop type, latitude and longitude, and planting date, and outputs an estimate for irrigation water need (total crop water consumption minus effective rainfall).
2. FAO. Pastoralism in the new millennium. Accessed June 23, 2020; May 3, 2021 http://www.fao.org/3/y2647e/y2647e02.htm#P8_3480
3. ibid
4. Nyima Tashi. Pastoral systems, change and the future of the grazing lands in Tibet. FAO. Accessed June 23, 2020; May 3, 2021. http://www.fao.org/3/y4856e/y4856e0d.htm
5. For more information, refer section on shifting cultivation
6. FarmingIndia.in. Paddy cultivation guide: Different methods of rice cultivation in India. Accessed June 23, 2020; May 3, 2021. https://www.farmingindia.in/paddy-cultivation/
7. Pangare Ganesh, Vasudha Pangare and Binayak Das. 2006. Springs of Life. New Delhi. Academic Foundation, World Water Institute, Bharathi Integrated Rural Development Society (BIRDS):
8. ibid
9. Nyima Tashi. Pastoral systems, change and the future of the grazing lands in Tibet. FAO. Accessed June 23, 2020; May 3, 2021. http://www.fao.org/3/y4856e/y4856e0d.htm
10. Brown, Colin, Lava Prakash Yadav, Jing Zhang and Deqing Zhouma. 2019. Sustainability of Agricultural Diversity in the Farm Households of Southern Tibet. *Sustainability* 2019, 11, 5756.
11. Planning Commission. Government of India. 2017. Final Report of the Working Group on Agro-climatic Zonal Planning including Agriculture Development in North-Eastern India for XI Five Year Plan (2007-12). Accessed June 23, 2020; May 3, 2021. https://niti.gov.in/planningcommission.gov.in/docs/aboutus/committee/wrkgrp11/wg11_agrclim.pdf
12. ibid
13. Department of Agriculture. Government of Assam. Rashtriya Krishi Vikash Yojana (RKVY). Accessed June 23, 2020; May 3, 2021. http://www.rkvyassam.in/?rain
14. Renewable Natural Resources Statistics Division, Directorate Services, Ministry of Agriculture and Forests Bhutan. RNR Statistics 2017. Royal Government of Bhutan: 49. Accessed June 23, 2020; May 3, 2021. http://www.moaf.gov.bt/bhutan-rnr-statistics-2017-2/
15. Sharma, Ghanashyam and Lalit Kumar Rai. Climate Change and Sustainability of Agrodiversity in Traditional Farming of the Sikkim Himalaya. n.d. Accessed June 23, 2020; May 3, 2021. http://www.sikenvis.nic.in/writereaddata/12-Chapter_Climate_Change_and_Sustainability_of_Agrodiversity_in_Traditional_farming.pdf

16. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning. 2019. Yearbook of Agricultural Statistics-2018. 30th Series. Government of the People's Republic of Bangladesh. Dhaka. Accessed June 23, 2020; May 3, 2021. www.bbs.gov.bd
17. A species of Daphne plant used in Tibetan and Chinese and medicine.
18. Statistical and crop data in this section is accessed from Tibet Statistic Bureau (2018) Tibet Statistic Yearbook. China Statistic Press. Beijing, China.
19. Zhang, Geli, Jinwei Dong, Caiping Zhou, Xingliang Xu, Min Wang, Hua Ouyang and Xiangming Xiao. 2013. Increasing cropping intensity in response to climate warming in Tibetan Plateau, China. *Field Crops Research 142*: 36–46
20. Li, Y. 2019. Linzhou County in Tibet to grow over 2.91 km^2 organic barley. People.cn. Accessed June 23, 2020. http://xz.people.com.cn/n2/2019/0429/c138901-32892660.html
21. Yang, S. and Y. Tang. 2016. Price increase of the Gangba Sheep in Tibet. Xinhua Net. Beijing. China. Accessed June 23, 2020. http://xz.people.com.cn/n2/2016/0613/c138901-28498078.html
22. Wang, L. 2017. Prevention and control measures of agricultural pests in Tibet. *South China Agriculture* 11(23): 24-25 (in Chinese).
23. Department of Agriculture and Husbandry. 2017. Grassland resources and ecologic statistics. China Agricultural Statistic Press. Beijing, China.
24. Tibet Statistic Bureau. 2018. Tibet Statistic Yearbook. China Statistic Press. Beijing, China
25. Tibet promotes greenhouse technology. 2011. Accessed June 23, 2020. http://www.agronet.com.cn/Tech/709038.html
26. Greenhouse technology contributes to poverty reduction. 2019. Accessed on June 23, 2020. http://xz.people.com.cn/n2/2019/1014/c138901-33432209.html
27. Badr, A. et al. 2000. On the origin and domestication history of barley (Hordeum vulgare). Mol. Biol. Evol. 17, 499–510.
28. Zeng, X., Y. Guo, and Q. Xu. et al. 2018. Origin and evolution of qingke barley in Tibet. *Nature Communications 9: 5433*.
29. Badr, A. et al. 2000. On the origin and domestication history of barley (Hordeum vulgare). *Mol. Biol. Evol. 17*, 499–510.
30. Tibet Statistic Bureau. 2018. Tibet Statistic Yearbook. China Statistic Press. Beijing, China.
31. Zang, J., Kan, J., Chen, Z. and Zhao, G. 2004. Applications of barley and study on its components. China Food Additives. 4: 43-46.
32. Hou, D. and Shen, Q. 2020. Analysis of nutrition and functional components of 29 kinds of highland barley in China. *Journal of Chinese Institute of Food Science and Technology 20(2)*: 289-298. (in Chinese)
33. Jiang, C., Yan, D., Tan, J., Feng, Z. and Yu, N. 2010. Research and application status of barley. Tibetan Technology. 2: 14-16 (in Chinese).
34. Tibet Statistic Bureau. 2018. Tibet Statistic Yearbook. China Statistic Press. Beijing, China.
35. Department of Agriculture. Government of Arunachal Pradesh. Accessed June 23, 2020; May 3, 2021. http://www.agri.arunachal.gov.in/aboutus.php
36. ibid
37. TERI School of Advanced Studies. 2018. State Specific Action Plan for water Sector- Arunachal Pradesh New Delhi: TERI School of Advanced Studies, [Project Report No. 2017QP01] Accessed June 23, 2020; May 3, 2021. http://nwm.gov.in/sites/default/files/Report_Draft-SSAP_Arunachal_Pradesh.pdf
38. Department of Agriculture. Government of Arunachal Pradesh. Accessed June 23, 2020; May 3, 2021. http://www.agri.arunachal.gov.in/aboutus.php
39. TERI School of Advanced Studies. 2018. State Specific Action Plan for water Sector- Arunachal Pradesh New Delhi: TERI School of Advanced Studies, [Project Report No. 2017QP01] Accessed June 23, 2020; May 3, 2021. http://nwm.gov.in/sites/default/files/Report_Draft-SSAP_Arunachal_Pradesh.pdf
40. Pangare Ganesh, Vasudha Pangare and Binayak Das. 2006. Springs of Life. New Delhi. Academic Foundation, World Water Institute, Bharathi Integrated Rural Development Society (BIRDS): 152-155
41. Shifting Cultivation, Livelihood and Food Security: New and Old Challenges for Indigenous People in Asia. 2014. Asia Indigenous Peoples' Pact (AIPP) and the International Work Group for Indigenous Affairs (IWGIA), Chiang Mai.
42. Government of Assam. AGRI VISION 2025. Accessed June 23, 2020; May 3, 2021. https://diragri.assam.gov.in/information-services/agri-vision-2025

43. Government of Assam, Department of Agriculture and Horticulture, Directorate of Agriculture. Accessed June 23,2020; May 3, 2021. https://diragri.assam.gov.in
44. Ibid.
45. Government of Assam, Department of Agriculture and Horticulture, Directorate of Agriculture. Accessed June 23, 2020; May 3, 2021. https://diragri.assam.gov.in/portlets/irrigation
46. ibid
47. Government of Assam, Department of Agriculture and Horticulture, Directorate of Agriculture. Accessed June 23, 2020; May 3, 2021. https://diragri.assam.gov.in
48. Mandal, R. 2017. "Assam's Sorrow – Is there a Way Out?", *Economic and Political Weekly*, Vol. LII, No. 36, pp. 20-22.
49. Government of Assam. 2017. "Flood and Erosion Problem," Water Resource Department, Government of Assam. Accessed on 21 August 2017.
50. Goyari, P. 2005. "Flood Damages and Sustainability of Agriculture in Assam", *Economic & Political Weekly*, 40(26), pp 2723-29.
51. Mandal, R. 2010. "Cropping Patterns and Risk Management in the Flood Plains of Assam", *Economic and Political Weekly*, Vol. XLV, No. 33, pp. 78-81.
52. Mandal, R. 2014. "Flood, cropping pattern choice and returns in agriculture: A study of Assam plains, India", *Economic Analysis and Policy*, Vol. 44, pp. 333-344.
53. Mandal, R. 2014. "Flood, cropping pattern choice and returns in agriculture: A study of Assam plains, India", *Economic Analysis and Policy*, Vol. 44, pp. 333-344.
54. Refer to Flow chapter
55. ibid
56. Information for this section has been extracted from Department of Agriculture, Ministry of Agriculture and Forests, Twelfth Five Year Plan, 2018-2023. Royal Government of Bhutan, Thimpu, March 2019. Accessed June 23, 2020; May 3, 2021. https://www.gnhc.gov.bt/en/wp-content/uploads/2019/05/12FYP-Volume-II-Central-Plans.pdf
57. ibid.
58. Labour Market Information and Research Division, Department of Employment and Human Resources. Labour Force Survey Report 2016. Ministry of Labour and Human Resources. Royal Government of Bhutan. Accessed June 23, 2020; May 3, 2021. https://www.molhr.gov.bt/molhr/wp-content/uploads/2017/12/Labour-Force-Survey-Report-2016.pdf
59. Forest Resources Development Division, Department of Forests and Park Services. 2017. Land Use and Land Cover 2016. Ministry of Agriculture and Forests, Thimpu. Bhutan. Accessed June 23, 2020; May 3, 2021. https://www.researchgate.net/publication/335715768_LAND_USE_AND_LAND_COVER_OF_BHUTAN_2016_MAPS_AND_STATISTICS
60. 2017 Population and Housing Census of Bhutan, Monggar Dzongkhag, 2018. National Statistics Bureau, Royal Government of Bhutan. Accessed June 23, 2020; May 3, 2021. https://www.nsb.gov.bt/?s=population+and+housing+census+2017
61. RGOB (Royal Government of Bhutan). 2009. RNR sector tenth five year plan (2008- 2013): Enabling farming communities to overcome poverty (Vol. I: Main document). Thimphu: Ministry of Agriculture, Royal Government of Bhutan. Accessed June 23, 2020; May 3, 2021 https://www.gnhc.gov.bt/en/wp-content/uploads/2017/05/TenthPlan_Vol1_Web.pdf
62. Twelfth Five Year Plan, 2018-2023, Department of Agriculture, Ministry of Agriculture and Forests, Royal Government of Bhutan, Thimpu, March 2019. Accessed June 23, 2020; May 3, 2021. https://www.gnhc.gov.bt/en/wp-content/uploads/2019/05/12FYP-Volume-II-Central-Plans.pdf
63. Sustainable Socio-economic Development through the Commercialisation of Organic Framing, National Organic Programme ARDC-Yusipang Department of Agriculture Ministry of Agriculture and Forests National Organic Programme ARDC-Yusipang Department of Agriculture Ministry of Agriculture and Forests. Accessed June 23,2020; May 3, 2021. http://flagship.gnhc.gov.bt/wp-content/uploads/2020/05/Organic-Flagship-_March-2019.pdf
64. Food Security and Agriculture Development Department, Government of Sikkim. Accessed June 23, 2020; May 3, 2021. https://sikkim.gov.in/departments/food-security-and-agriculture-development-department http://www.sikkimorganicmission.gov.in/wp-content/uploads/2015/01/Comprehensive-report.pdf
65. ibid

66. Ibid.
67. Status of Environment and Related Issues. Forest and Environment Department. Government of Sikkim. Accessed June 23, 2020; May 3, 2021. http://www.sikenvis.nic.in/Database/Agriculture_777.aspx
68. Food Security & Agriculture Development Department. Annual Progress Report 2013-14. Government of Sikkim. Accessed June 23, 2020; May 3, 2021. http://www.sikkimagrisnet.org/General/UploadedFiles/Downloads/30024.pdf
69. ibid.
70. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
71. Quddus, M. A. 2009. Crop Production Growth in Different Agro-Ecological Zones of Bangladesh. *Journal of Bangladesh Agricultural University* 7(2): 351–360.
72. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
73. Social forestry is the afforestation of barren land, forest management and protection of forest with the purpose of helping environment, social and rural development. It involves the growing of trees at the farm level to provide firewood, cash crops and the processing of forest products at the household and local artisan levels to generate income of the forest dwelling communities.
74. Rahman, M. A., M. M. Rahman, and S. Hossain, 2019. Climate-Resilient Agricultural Practices in Different Agro-ecological Zones of Bangladesh. In book: W. Leal Filho (ed.), Handbook of Climate Change Resilience (pp.1-27); Publisher: Springer, Cham. Accessed June 23, 2020; May 3, 2021. https://doi.org/10.1007/978-3-319-71025-9_42-1
75. Embankment cropping is cultivation or growing of crops on the embankment of canal or *haor* (ditch). Generally, farmers grow vegetables and fruits on embankments for their own consumption and selling.
76. Shelley Israt, Misuzu Takahashi-Nosaka, Mana Kano-Nakata, Md. Shahidul Haque,,and Yoshiaki Inukai. 2016. Rice Cultivation in Bangladesh: Present Scenario, Problems, and Prospects. *Journal of International Cooperation for Agricultural Development* 14. 20-29
77. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
78. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
79. Islam, A.B.J.; Shahidullah, S.M.; Mostafizur, A. B. M. and Saha, A. 2017. Diversity of Cropping Pattern in Bogra. Bangladesh Rice Journal 21 (2): 73-90.
80. Rashid, Mamun-ur. 2016. Maize Growers Eye Bumper Yield in Jamuna Basin Areas. The Daily Star. February 17, 2016.
81. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
82. Qureshi, Asad S. Zia Uddin Ahmad, and Timothy J. Krupnik. 2015. Moving from Resource Development to Resource Management: Problems. *Water Resources Management* 29(11): DOI: 10.1007/s11269-015-1059-y.
83. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
84. Shah T. 2007. The Groundwater Economy of South-Asia: An Assessment of Size, Significance and Socioecological Impacts. In: Giordano M, Villholth KG (eds) The Agricultural Groundwater Revolution: Opportunities and Threat to Development. CABI, Wallingford, pp 7–36.
85. Dey, N. C., S. K. Bala, Saiful Islam A. K. M., Rashid, M. A. 2013. Sustainability of Groundwater Use for Irrigation in Northwest Bangladesh. Policy Report prepared under the National Food Policy Capacity Strengthening Programme (NFPCSP): Dhaka, Bangladesh. 89 pp.
86. Hossain Md. Ayub. 2019. Solar Pump Irrigation for Sustainable Crop Production in Bangladesh. The Asian Age, 9 January 2020, Dhaka, Bangladesh.

87. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
88. Shamsuzzaman, M. M., Mohammad Mahmudul Islam, Nusrat Jahan Tania, Md. Abdullah Al-Mamun, Partho Protim Barman, and Xiangmin Xu. 2017. Fisheries Resources of Bangladesh: Present Status and Future Direction. *Aquaculture and Fisheries*. Accessed June 23, 2020; May 3, 2021. http://dx.doi.org/10.1016/j.aaf.2017.03.006
89. Hossain, Mostafa Ali Reza. 2014. An Overview of Fisheries Sector of Bangladesh. *Research in Agriculture, Livestock and Fisheries* 1(1): 109-126
90. Banglapedia. 2015. *National Encyclopedia of Bangladesh*. Asiatic Society of Bangladesh: Dhaka, Bangladesh.
91. Hossain, M. Ayub, Ashoke Kumar Sarker, M. Nurul Amin, M. Mokarrom Hossain, and M. Sumon Miah. 2016. Development and Performance Evaluation of Sludge Remover for Intensive Aquaculture. *Aquacultural Engineering* 74: 62-69.
92. Hossain, Mostafa Ali Reza. 2014. An Overview of Fisheries Sector of Bangladesh. *Research in Agriculture, Livestock and Fisheries* 1(1): 109-126
93. Rahman, S., I. A. Begum, and M. J.Alam. 2014. Livestock in Bangladesh: Distribution, Growth, Performance and Potential. *Livestock Research for Rural Development* 26(10): No. 173.
94. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
95. DLS. 2019. *Annual Report on Livestock*. Division of Livestock Statistics, Ministry of Fisheries and Livestock, Farmgate, Dhaka, Bangladesh.
96. Hamid, M. A., A. Rahman, M.A. Zaman, and K.M. Hossain. 2017. Cattle Genetic Resources and Their Conservation in Bangladesh. *Asian Journal of Animal Sciences* 11: 54-64. DOI: 10.3923/ajas.2017.54.64
97. Sarker, N. R., M. A. Habib, M. R., Amin, S. Yeasmin, F. Tabassum, and D. Yeasmin, 2018. *Bangladesh Journal of Animal Science* 46(3): 206-214.
98. BBS. 2018. *Yearbook of Agricultural Statistics-2018*. Bangladesh Bureau of Statistics, Statistics and Informatics Division, Ministry of Planning, Government of the People's Republic of Bangladesh, 30thSeries, May 2019, www.bbs.gov.bd
99. MOA-GOB. *National Agriculture Policy 2018*. Ministry of Agriculture, Government of Bangladesh (MOA-GOB), 2018
100. Peña-Arancibia, Jorge L., Mohammed Mainuddin, Mobin D. Ahmad, Geoff. Hodgson, Khandakar F. Ibn Murad, Catherine Ticehurst, M. Maniruzzaman, M. Golam Mahboob, and John M. Kirby. 2020. "Groundwater Use And Rapid Irrigation Expansion In A Changing Climate: Hydrological Drivers In One Of The World'S Food Bowls". Journal Of Hydrology 581: 124300. doi:10.1016/j.jhydrol.2019.124300.
101. Purdy, Adam J., Cédric H. David, Md. Safat Sikder, John T. Reager, Hrishikesh A. Chandanpurkar, Norman L. Jones, and Mir A. Matin. 2019. "An Open-Source Tool To Facilitate The Processing Of GRACE Observations And GLDAS Outputs: An Evaluation In Bangladesh". Frontiers In Environmental Science 7. doi:10.3389/fenvs.2019.00155.
102. Mainuddin, Mohammed, Mac Kirby, Glen Walker, and Jeff Connor. 2014. Sustaining Water Resources For Food Security In Bangladesh. Canberra: CSIRO.
103. Twice yearly phenomenon of poverty and hunger in Bangladesh. It happened during September–November (after the aman crop is planted) and from March–April (after the boro crop is planted)
104. Dey, Nepal C., Ratnajit Saha, Mahmood Parvez, Sujit K. Bala, AKM Saiful Islam, Joyanta K. Paul, and Mahabub Hossain. 2017. "Sustainability Of Groundwater Use For Irrigation Of Dry-Season Crops In Northwest Bangladesh". Groundwater For Sustainable Development 4: 66-77. doi:10.1016/j.gsd.2017.02.001.
105. Mojid, Mohammad A., Mohammad F. Parvez, Mohammed Mainuddin, and Geoff Hodgson. 2019. "Water Table Trend—A Sustainability Status Of Groundwater Development In North-West Bangladesh". Water 11 (6): 1182. doi:10.3390/w11061182.
106. Peña-Arancibia, Jorge L., Mohammed Mainuddin, Mobin D. Ahmad, Geoff. Hodgson, Khandakar F. Ibn Murad, Catherine Ticehurst, M. Maniruzzaman, M. Golam Mahboob, and John M. Kirby. 2020. "Groundwater Use And Rapid Irrigation Expansion In A Changing Climate: Hydrological Drivers In One Of The World'S Food Bowls". Journal Of Hydrology 581: 124300. doi:10.1016/j.jhydrol.2019.124300.
107. Rahman, A.T.M. Sakiur, Takahiro Hosono, Quamrul H. Mazumder, and Chowdhury S. Jahan. 2020. "Sustainable Groundwater Management In Context Of Climate Change In Northwest Bangladesh."

108. Mojid, Mohammad A., Mohammad F. Parvez, Mohammed Mainuddin, and Geoff Hodgson. 2019. "Water Table Trend—A Sustainability Status Of Groundwater Development In North-West Bangladesh". Water 11 (6): 1182. doi:10.3390/w11061182.
109. Mojid, Mohammad A., Mohammad F. Parvez, Mohammed Mainuddin, and Geoff Hodgson. 2019. "Water Table Trend—A Sustainability Status Of Groundwater Development In North-West Bangladesh". Water 11 (6): 1182. doi:10.3390/w11061182.
110. Peña-Arancibia, Jorge L., Mohammed Mainuddin, Mobin D. Ahmad, Geoff. Hodgson, Khandakar F. Ibn Murad, Catherine Ticehurst, M. Maniruzzaman, M. Golam Mahboob, and John M. Kirby. 2020. "Groundwater Use And Rapid Irrigation Expansion In A Changing Climate: Hydrological Drivers In One Of The World'S Food Bowls". Journal Of Hydrology 581: 124300. doi:10.1016/j.jhydrol.2019.124300.
111. Purdy, Adam J., Cédric H. David, Md. Safat Sikder, John T. Reager, Hrishikesh A. Chandanpurkar, Norman L. Jones, and Mir A. Matin. 2019. "An Open-Source Tool To Facilitate The Processing Of GRACE Observations And GLDAS Outputs: An Evaluation In Bangladesh". Frontiers In Environmental Science 7. doi:10.3389/fenvs.2019.00155.
112. IWM. *Bangladesh Integrated Water Resources Assessment Supplementary report: Surface Water and Groundwater Interaction*. Institute of Water Modelling, Bangladesh (IWM), 2014.
113. Dey, Nepal C., Ratnajit Saha, Mahmood Parvez, Sujit K. Bala, AKM Saiful Islam, Joyanta K. Paul, and Mahabub Hossain. 2017. "Sustainability Of Groundwater Use For Irrigation Of Dry-Season Crops In Northwest Bangladesh". Groundwater For Sustainable Development 4: 66-77. doi:10.1016/j.gsd.2017.02.001.
114. Purdy, Adam J., Cédric H. David, Md. Safat Sikder, John T. Reager, Hrishikesh A. Chandanpurkar, Norman L. Jones, and Mir A. Matin. 2019. "An Open-Source Tool To Facilitate The Processing Of GRACE Observations And GLDAS Outputs: An Evaluation In Bangladesh". Frontiers In Environmental Science 7. doi:10.3389/fenvs.2019.00155.
115. Kirby, Mac, Mobin Ahmad, Mohammed Mainuddin, Wahid Palash, Mohammed Quadir, Sardar Shah-Newaz, and Monowar Hossain. 2015. "The Impact of Irrigation Development On Regional Groundwater Resources In Bangladesh". Agricultural Water Management 159: 264-276
116. "National Agriculture Policy". 2020. Badc.Portal.Gov.Bd. http://badc.portal.gov.bd/sites/default/files/files/badc.portal.gov.bd/page/c23bdffd_22fd_4f15_8fc4_b1fc7a91a36a/d5a84d165253f9e02–d6190b5d28b1340.pdf.
117. Zhao, H. and Wang, C. (1990) Tea's introduction to and cultivation in Tibet. China Tibetology. 3: 006.
118. Wang, Z. (2016) Current status of tea productions in Tibet. Chinatea. 7.
119. Tibet Statistic Bureau (2018) Tibet Statistic Yearbook. China Statistic Press. Beijing, China.
120. Tea Board, India. Ministry of Commerce & Industry. Government of India. Accessed June 23, 2020; May 3, 2021 http://www.teaboard.gov.in/TEABOARDCSM/Ng==
121. Government of Assam. Industries and Commerce. Small tea growers. Accessed June 23, 2020; May 3, 2021. https://industries.assam.gov.in/portlet-innerpage/about-tea-industries
122. ibid
123. http://www.teaboard.gov.in/TEABOARDCSM/Ng==
124. Government of Assam. Transformation and Development. Directorate of Economics and Statistics. State Profile of Assam. Accessed June 23, 2020; May 3, 2021. https://des.assam.gov.in/information-services/state-profile-of-assam
125. Government of Assam. Industries and Commerce. Small tea growers. Accessed June 23, 2020; May 3, 2021. https://industries.assam.gov.in/portlet-innerpage/about-tea-industries
126. Nabajyoti Deka & Kishor Goswami. 2020. Organic cultivation and farm entrepreneurship: a case of small tea growers in rural Assam, India, Agroecology and Sustainable Food Systems, 44:4, 446-466, DOI: 10.1080/21683565.2019.1646373
127. Prashnani Meghavi, Qadir Abdul, Goswani J, Raju P L N, 2019, Spatio-Temporal Study of Brahmaputra River Islands (Chars) for Agricultural Expansion in Assam, India, The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XLII-3/W6, 2019 ISPRS-GEOGLAM-ISRS Joint Int. Workshop on "Earth Observations for Agricultural Monitoring", 18–20 February 2019, New Delhi, India.

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5. PEOPLE-*One river, many cultures*

1. Meyer, M.C., M.S. Aldenderfer, Z. Wang, D. Hofman, J. Dahl, D. Degering, et al. 2017. Permanent human occupation of the central Tibetan Plateau in the Early Holocene. *Science* 355: 64-67.
2. Miehe, G., S. Miehe, K. Kaiser, C. Reudenbach, L. Behrendes, L. Duo and F. Schultz. 2009. How old is pastoralism in Tibet? An ecological approach to the making of a Tibetan landscape. *Palaeogeography, Palaeoclimatology, Palaeoecology* 276: 130-147.
3. Meyer, M.C., C. Hofman, A.M.D. Gemmel, E. Haslinger, H. Hausler and D. Wangda. 2009. Holocene glacier fluctuations and migration of Neolithic yak pastoralists into the high valleys of northwest Bhutan. *Quaternary Science Review* 28: 1217-1237.; Meyer, M.C., M.S. Aldenderfer, Z. Wang, D. Hofman, J. Dahl, D. Degering, et al. 2017. Permanent human occupation of the central Tibetan Plateau in the Early Holocene. *Science* 355: 64-67.
4. Guo, S., P. Savolainen, J. Su, Q. Zhang, D. Qi, J. Zhou, et al. 2006. Origin of mitochondrial DNA diversity of domestic yaks. *BMC Evolutionary Biology* 6(1): 73-87.
5. Bailey J.F., B. Healy, J. Han, L. Sherchang, S.L. Pradhan, T. Tsendsuren, J.M. Foggin, C. Gaillard, D. Steane, I. Zakharov and D.G. Bradley. 2002. Genetic variation of mitochondrial DNA within domestic yak populations. In J. Han, C. Richard, O. Hannotte, C. McVeigh & J.E.O. Rege (Eds.), *Yak productions in central Asian highlands. Proceedings of the third international congress on yak*. Nairobi, Kenya: International Livestock Research Institute (ILRI).
6. d'Alpoim Guedes, J. and M. Aldenderfer. 2019. The archaeology of the early Tibetan plateau: New research on the initial peopling through the Early Bronze Age. *Journal of Archaeological Research*. https://doi.org/10.1007/s10814-019-09137-6
7. Zeng, X., Guo, Y., Xu, Q. et al. 2018. Origin and evolution of qingke barley in Tibet. *Nature Communications* 9, 5433. https://doi.org/10.1038/s41467-018-07920-5
8. Shakya, T. (1993) Whither the Tsampa Eaters? Himal Southasian, https://www.himalmag.com/whither-the-tsampa/
9. Ekvall, Robert B. 1968. Fields on the hoof: nexus of Tibetan nomadic pastoralism. Holt, Rinehart and Winston. New York.
10. Miller, D. 2008. Nomads of the Tibetan Plateau and Himalaya. Maptia Stories, https://maptia.com/danielmiller/stories/nomads-of-the-tibetan-plateau-and-himalaya
11. Sheehy, D, D. Miller and D.a. Johnson. 2006. Transformation of traditional pastoral livestock systems on the Tibetan steppe. *Sécheresse* 17(1-2): 142-51.
12 Nyima, T. 2003. China case study 3: Pastoral systems, change and the future of the grazing lands in Tibet. In J.M. Suttie & S.G. Reynolds (Eds.), *Transhumant Grazing Systems in Temperate Asia*. Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/3/y4856e/y4856e0d.htm
13. Foggin, J.M. 1998. Recent accounts from the source area of the Yangtze River. Xining, China: Plateau Perspectives. https://stories.plateauperspectives.org/ancient-ways
14. Gruschke, A. 2008. Nomads without Pastures? Globalization, Regionalization, and Livelihood Security of Nomads and Former Nomads in Northern Khams. *Journal of the International Association of Tibetan Studies* 4: 1-40.; Du, Fachun. 2012. Ecological resettlement of Tibetan herders in the Sanjiangyuan: A case study in Madoi county of Qinghai. *Nomadic Peoples* 16(1): 116-133
15. Foggin, J.M. 2011. Rethinking 'Ecological Migration' and the value of cultural continuity: A response to Wang, Song & Hu. *Ambio* 40: 100-101. https://doi.org/10.1007/s13280-010-0105-5 ; Foggin, J.M. and M.E. Torrance-Foggin. 2017. Pastoralism, Development, and the Future of Tibetan Rangelands: Experiences in the Development and Provision of Social Services and Environmental Management. In A. Gruschke & I. Breuer (Eds.), *Tibetan Pastoralists and Development: Negotiating the Future of Grassland Livelihoods*. Wiesbaden, Germany: Ludwig Reichert Verlag.
16. Chandler, M.J. and C.E. Lalonde. 1998. Cultural continuity as a hedge against suicide in Canada's First Nations. *Transcultural Psychiatry* 35(2): 193-211.
Chandler, M.J. and C.E. Lalonde. 2008. Continuity as a moderator of suicide risk among Canada's First Nations. In Kirmayer, L. & G. Valaskakis (Eds.), *Healing traditions: The mental health of Aboriginal peoples in Canada*. Vancouver, Canada: University of British Columbia Press.

17. Wang, G., J.L. Innes, S.W. Wu, et al. 2012. National Park Development in China: Conservation or Commercialization? *AMBIO* 41: 247-261. https://doi.org/10.1007/s13280-011-0194-9 ; IUCN (2019) Developing China's national park system (IUCN News, dated 26 June 2019). https://www.iucn.org/news/asia/201906/developing-chinas-national-park-system-0 ;
Katz, B. 2019. China is developing a new national parks system, inspired by Yellowstone and Yosemite. Smithsonian Magazine, 14 Nov 2019. https://www.smithsonianmag.com/smart-news/china-developing-new-national-parks-system-180973549/ ; Yan, W. 2018. China's first national park, an experiment in living with snow leopards. Mongabay News, https://news.mongabay.com/2017/05/chinas-first-national-park-an-experiment-in-living-with-snow-leopards/
18. Foggin, J.M. 2012. Pastoralists and wildlife conservation in western China: collaborative management within protected areas on the Tibetan Plateau. *Pastoralism* 2, 17. https://doi.org/10.1186/2041-7136-2-17 ; Foggin, J.M. 2018. Environmental Conservation in the Tibetan Plateau region: Lessons for China's Belt and Road Initiative in the Mountains of Central Asia. *Land* 7, 52. https://doi.org/10.3390/land7020052 ; Foggin, J.M. 2018. Snow Leopards at Large: One herding community's hope for the future in the grasslands of Tibet. In J. Xu (Ed.), *Mountain Futures: Innovation and Inspiration from the World's Highlands*. Nairobi, Kenya: World Agroforestry Centre.; Foggin, J.M. 2020. Inclusive Development, An Imperative for the Future: Building broader partnerships for better informed development decisions. Bishkek, Kyrgyz Republic: Plateau Perspectives. https://stories.plateauperspectives.org/inclusive-development ;Foggin, J.M. and L. Cabrera. 2020. Achieving sustainable development with equity in an era of globalisation; Recognizing and respecting local communities and indigenous peoples for creating the future we want. Development Issues, No. 3 (June 2020). Bishkek, Kyrgyz Republic: Plateau Perspectives.
19. Hodges, J., J.M. Foggin, R.J. Long and G. Zhaxi. 2014. Globalisation and the sustainability of farmers, livestock-keepers, pastoralists and fragile habitats. *Biodiversity* 15(2-3):109-118. https://doi.org/10.1080/14888386.2014.931247 ; Farvar, M.T., G. Borrini-Feyerabend, J. Campese, T. Jaeger, H. Jonas and S. Stevens. 2018. Whose 'Inclusive Conservation'? Policy Brief of the ICCA Consortium, No. 5. Tehran, Iran: ICCA Consortium and Cenesta.
20. Suttie, J.M. and S.G. Reynolds. 2003. *Transhumant Grazing Systems in Temperate Asia*. Plant Production and Protection Series No. 31 (Rev. 1). Rome, Italy: Food and Agriculture Organization of the United Nations (FAO). http://www.fao.org/3/y4856e/y4856e00.htm
21. Roche, Gerald and Hiroyuki Suzuki. 2018. Tibet's Minority Languages: Diversity and Endangerment. Modern Asian Studies. 52(4): 1227-1278.; Nyima, Tashi, and Hiroyuki Suzuki. 2019. Newly Recognised Languages in Chamdo: Geography, Culture, History, and Language. Linguistics of the Tibeto-Burman Area 42(1): 38-81.
22. Roche, Gerald and Hiroyuki Suzuki. 2018. Tibet's Minority Languages: Diversity and Endangerment. Modern Asian Studies. 52(4): 1227-1278
23. Nyima, Tashi, and Hiroyuki Suzuki. 2019. Newly Recognised Languages in Chamdo: Geography, Culture, History, and Language. Linguistics of the Tibeto-Burman Area 42(1): 38-81
24. Institute of Qinghai-Tibetan Plateau. 2013. Introduction of Yaks. http://qzyjy.swun.edu.cn/info/1024/1111.htm
25. Miller 1998, cited in Foggin, J.M. 2020. Inclusive Development, An Imperative for the Future: Building broader partnerships for better informed development decisions. Bishkek, Kyrgyz Republic: Plateau Perspectives. https://stories.plateauperspectives.org/inclusive-development
26. Majumdar, D. 1980. North East India - A Profile. In T. S. Majumdar (Ed.), *Eastern Himalayas*. New Delhi: Cosmo Publications.
Dutta, P. 1987. A Sociological Study of Rongker- An Annual Karbi village Festival. (B.N.Bordoloi, Ed.) *Bulletin of the Tribal Research Institute, I* (V) Ethno profile of Karbi In Plain Districts of Assam, (n.d.), Pdf file, Assam.
27. Deori. S. 2002, Bina Library, Guwahati
28. Kotoky, P., D. Bezbaruah, J. Baruah, and J. N. Sarma. 2003. "Erosion activity on Majuli-the largest river island of the world." *Current science* 84, no. 7 (2003): 929-932.
Sarma, J. N., and M. K. Phukan. 2004. "Origin and some geomorphological changes of Majuli Island of the Brahmaputra River in Assam, India." *Geomorphology* 60, no. 1-2 (2004): 1-19
29 ibid
30. Roy, Nikhil, Bindhy Wasini Pandey, and Usha Rani. 2020. "Protecting the vanishing geo-cultural heritage of India: Case study of Majuli Island in Assam." *International Journal of Geoheritage and Parks*.
31. Roy, Nikhil, Bindhy Wasini Pandey, and Usha Rani. 2020. "Protecting the vanishing geo-cultural heritage of India: Case study of Majuli Island in Assam." *International Journal of Geoheritage and Parks*.
32. https://www.deccanherald.com/national/indo-uk-team-preserve-cultural-684869.html
33. Origin, discovery of tea, wild tea and early development of tea in Assam, indigenous tea and tea drinking habit among the tribes in Assam, India.
34. http://www.pajhra.org/adivasi-peoples-history/
35. Sharma, Jayeeta. 2011. Empire's Garden. Duke University Press.
36. Antrobus, H.A. 1957. A History of the Assam Company 1839-1953. T and A Constable Lts.
37. Baran Barua, K. 2016. Buddhism and Living Atish Dipankar Srijnan-Unsurpassable Luminaries of Asia. Journal of Religious Studies, Buddhism and Living, North Carolina, USA, Cresco Online Publishing, Article Number: JRBL-1002. 1.
38. ibid
39. Ahmad, S. 2013. An imagination of Bikrampur Buddhist Vihara from the foot-print of Atish Dipankar's travel. American Journal of Engineering Research (AJER)e-ISSN:2320-0847 p-ISSN:2320-0936Volume-02, Issue-12, pp-276-295. Available at http://www.ajer.org/papers/v2(12)/ZF212276295.pdf. Accessed 1 June 2020
40. Banglapedia. 2015. Dipankar Srijnan, Atish. Available at http://en.banglapedia.org/index.php?title=Dipankar_Srijnan,_Atish Accessed 1 June 2020

❄

6. HARNESS-*Tapping the river*

1. Research Triangle Institute and
2. Water Resource Bulletin of the Yangtze River and rivers in the Southwestern region.
3. IDSA Task Force. 2010. Water security for India: The external dynamics. *Institute for Defence Studi*es and Analyses.
4. FAO. 2011. Ganges-Brahmaputra-Meghna River basin, Food and Agriculture Organization of the United Nations, Rome. http://www.fao.org/nr/water/aquastat/basins/gbm/gbm-CP_eng.pdf
5. Qu, B., Zhang, Y., Kang, S., Sillanpää, M. 2019. Water quality in the Tibetan Plateau: Major ions and trace elements in rivers of the "Water Tower of Asia". Science of the Total Environment 649, 571.
6. Colin, C., Turpin, L., Bertaux, J., Desprairies, A., Kissel, C. 1999. Erosional history of the Himalayan and Burman ranges during the last two glacial–interglacial cycles. Earth and Planetary Science Letters 171, 647-660.
7. Singh, S.K., Sarin, M., France-Lanord, C. 2005. Chemical erosion in the eastern Himalaya: major ion composition of the Brahmaputra and δ 13 C of dissolved inorganic carbon. Geochimica et Cosmochimica Acta 69, 3573-3588.
8. Zheng, M. 1989. Saline lakes on the Qinghai-Xizang (Tibet) plateau. Beijing Scientific and Technical Publishing House; Colin, C., Turpin, L., Bertaux, J., Desprairies, A., Kissel, C. 1999. Erosional history of the Himalayan and Burman ranges during the last two glacial–interglacial cycles. Earth and Planetary Science Letters 171, 647-660.
9. ECLCT. 2005. Editorial Committee of Local Chronicle, Tibet Autonomous Region. Local Chronicles of Tibet Autonomous Region: Climography: 1st edn. Tibetology Publisher: Beijing; 12–29 (in Chinese).
10. Chaudhuri, S., Clauer, N., Semhi, K. 2007. Plant decay as a major control of river dissolved potassium: a first estimate. Chemical Geology 243, 178-190.
11. Stallard, R., Edmond, J. 1981. Geochemistry of the Amazon: 1. Precipitation chemistry and the marine contribution to the dissolved load at the time of peak discharge. Journal of Geophysical Research: Oceans 86, 9844-9858.
12. Liu, T. 1999. Hydrological Characteristics of Yarlung Zangbo River. Acta Geographica Sinica 54, 157-164.
13. Shi, Y., Yang, Z. 1985. Water resources of glaciers in China. GeoJournal 10, 163-166.
14. Qu, B., Zhang, Y., Kang, S., Sillanpää, M. 2019. Water quality in the Tibetan Plateau: Major ions and trace elements in rivers of the "Water Tower of Asia". Science of the Total Environment 649, 571.
15. Qu, B., Zhang, Y., Kang, S., Sillanpää, M. 2017. Water chemistry of the southern Tibetan Plateau: an assessment of the Yarlung Tsangpo river basin. Environmental earth sciences 76, 74.; Qu, B., Zhang, Y., Kang, S., Sillanpää, M. 2019. Water quality in the Tibetan Plateau: Major ions and trace elements in rivers of the "Water Tower of Asia". Science of the Total Environment 649, 571.

16. WHO Drinking-water Quality 4th edition. 2011.
17. e. (MOH&SAC, 2006)
18. c. Huang et al. (2019)
19. Qu, B., Zhang, Y., Kang, S., Sillanpää, M. 2019. Water quality in the Tibetan Plateau: Major ions and trace elements in rivers of the "Water Tower of Asia". Science of the Total Environment 649, 571.
20. Huang, X., Sillanpää, M., Gjessing, E., Peräniemi, S., Vogt, R. (2011) Water quality in the southern Tibetan Plateau: chemical evaluation of the Yarlung Tsangpo (Brahmaputra). River Research and Applications 27, 113-121.
21. Qu, B., Zhang, Y., Kang, S., Sillanpää, M. (2017) Water chemistry of the southern Tibetan Plateau: an assessment of the Yarlung Tsangpo river basin. Environmental earth sciences 76, 74.
22. Li, C., Kang, S., Chen, P., Zhang, Q., Mi, J., Gao, S., Sillanpää, M. (2014) Geothermal spring causes arsenic contamination in river waters of the southern Tibetan Plateau, China. Environmental earth sciences 71, 4143-4148.
23. Goswami, D. C. (1985) Brahmaputra River, Assam, India: Physiography, basin denudation and channel aggradation. *Water Resources Research*. 21(7), 959-978.
24. Trivedy, R. K., & Goel, P. K. (1986) Chemical and biological methods for water pollution studies. India: Environmental Publication.
25. APHA (2005) Standard methods for examination of water and wastewater, 21stedn. American Public Health Association, Washington.
26. Sivasankar, T., Borah, S. B., Das, R., & Raju, P. L. N. (2020). An Investigation on Sudden Change in Water Quality of Brahmaputra River Using Remote Sensing and GIS. *National Academy Science Letters*, 1-5.
27. Bora, M., & Goswami, D. C. (2017) Water quality assessment in terms of water quality index (WQI): case study of the Kolong River, Assam, India. *Applied Water Science*. 7(6), 3125-3135.
28. Abbasi, S.A. (2002) Water quality indices. Elsevier, Amsterdam.
29. Brown R. M., McClelland N. I., Deininger R. A., & O'Connor M. F. (1972) A Water Quality Index-Crashing the Physiological Barrier. *Indicators of Environmental Quality*. 1, 173-182.
30. Jamwal, N. (2020), "Neither sewage, nor sewage treatment plant, the Bharalu river is a sewage channel", *Gaon Connection*, at <https://en.gaonconnection.com/neither-sewerage-nor-sewage-treatment-plant-smart-city-guwahatis-bharalu-river-is-a-sewage-channel/>.
31. Handique, B. (2012), "Waste floats on 'clean' rivulet", *The Telegraph*, at <https://www.telegraphindia.com/north-east/waste-floats-on-clean-rivulet/cid/392030>
32. Goswami, P. (2012), *The History of Assam: From Yandabo to Partition, 1826-1947*, Orient Blackswan.
33. Saikia, A. (2011), *Forests and Ecological History of Assam: 1826-2000*, New Delhi: OUP.
34. Borthakur, A., and Singh, P. (2016), "India's lost rivers and rivulets", *Energy, Ecology and Environment*, 1, 310–314, at < https://link.springer.com/article/10.1007/s40974-016-0039-2#citeas>.
35. Pollution Control Board, Assam (2013), "Conservation of River Bharalu, Guwahati", *Detailed Project Report Draft*, at <https://pcbassam.org/rlcc/Bharalu%20DPR_DRAFT_30DEC2013.pdf>.
36. Guwahati Development Department, Government of Assam (undated), "Bharalu River", *Guwahati Smart City Limited*, at < https://gscl.assam.gov.in/projects/detail/bharalu-river>.
37. Liu, D. (1986) Urgent needs to develop inland navigation in the middle reach of the Yarlung Tsangpo River. Port & Waterway Engineering. 2, 3-7.
38. Bhattacharya (2004) The Brahmaputra in Assam's economy. Singh, V.P., Sharma, N. and Ojha, C.S.P. [ed] The Brahmaputra Basin Water Resources.
39. The 20-foot container, referred to as a Twenty-foot Equivalent Unit (TEU) became the industry standard reference so now cargo volume and vessel capacity are commonly measured in TEU. www.worldshipping.org
40. World Bank. (2007). Revival of Inland Water Transport: Options and Strategies, Bangladesh Development Series, Paper No. 20. The World Bank Office, Dhaka.
41. Consultancy services for development of IWT system in Bangladesh, by Parvez Ali Anwar Khan
42. Mishra D. K. & Hussain S. M. (2012). Situation Analysis on Inland Navigation, Ecosystems for Life: A Bangladesh-India Initiative, International Union for Conservation of Nature and Natural Resources.
43. Mishra D. K. & Hussain S. M. (2012). Situation Analysis on Inland Navigation, Ecosystems for Life: A Bangladesh-India Initiative, International Union for Conservation of Nature and Natural Resources.
44. Bangabandhu Jamuna Multipurpose Bridge http://en.banglapedia.org/index.php?title=Bangabandhu_Jamuna_Multipurpose_Bridge

45. Rahaman, M. M., & Varis, O. (2009). *Integrated water management of the Brahmaputra basin: Perspectives and hope for regional development.* Paper presented at the Natural Resources Forum.
46. Chellaney, B., & Tellis, A. J. (2011). A Crisis to Come? China, India and Water Rivalry. *Carnegie Endowment Report, September13*.
47. Brammer, H. (1990). Floods in Bangladesh: II. Flood mitigation and environmental aspects. *Geographical Journal*, 158-165.
48. Jiang and He (2011) A new era for Tibet's rivers. https://www.chinadialogue.net/article/show/single/en/4055
49. Handique, K. and Dutta, A. (2012) Power and North East: The Hydro Power Scenario of North East. International Journal of Science and Research 602-609.
50. Ministry of Power, Government of India
51. https://www.mfa.gov.bt/rbedelhi/?page_id=28

7. GOVERN-*Framework for co-operation*

1. DISCLAIMER: The transboundary agreements discussed pertain to the South Asia Water Initiative basins only. Ministry and agency names often change with new governments and institutional restructuring—best efforts were made to ensure names are current.
2. Xie, L., Zhang, Y. and Panda, J.P. (2018) Mismatched Diplomacy: China-India water relations over the Ganges-Brahmaputra-Meghna River Basin. Journal of Contemporary China 27(109): 32-46.
3. Feng, Y. & He, D.M. (2009) Transboundary water vulnerability and its drivers in China. Journal of Geographical Sciences, 19, 189–199.
4. Feng, Y., Wang, W. and Liu, J. (2019) Dilemmas in and pathways to transboundary water cooperation between China and India on the Yaluzangbu-Brahmaputra River. Water 11, 2096.
5. ibid
6. Feng, Y., Wang, W. and Liu, J. (2019) Dilemmas in and pathways to transboundary water cooperation between China and India on the Yaluzangbu-Brahmaputra River. Water 11, 2096.
7. National Environment Commission. 2007. Bhutan Water Policy. Royal Government of Bhutan. Available at http://extwprlegs1.fao.org/docs/pdf/bhu167545.pdf. Accessed on 12 June 2020.
8. Ministry of Water Resources. 1999. National Water Policy 1999. Available at https://mowr.gov.bd/sites/default/files/files/mowr.portal.gov.bd/files/32e67290_f24e_4407_9381_166357695653/National%20Water%20Policy%20(English).pdf Accessed on 12 June 2020.
9. Joint Rivers Commission. 2019. History. Available at http://www.jrcb.gov.bd/site/page/1032c710-feb2-48cc-979e-1d7d47590cad/- Accessed on 28 June 2020.
10. Ministry of Shipping. First ever movement of container cargo on Brahmaputra (National Waterway -2). Press Release. Ministry of Shipping, Government of India.
11. Saran, S. 2016. South Asia's Mounting Ecological Challenge. In Thirty Years of SAARC: Society, Culture and Development. Eds, R. Kumar and O. Goyal. SAGE Publications India.
12. Baru, S., Rais, R., & Baral, L. (2010). Role of SAARC Observers: Members' Perspectives. In S. Muni (Ed.), *The Emerging Dimensions of SAARC* (pp. 229-276). Foundation Books. doi:10.1017/UPO9788175968615.011
13. Dash, K. C. 2008. Regionalism in South Asia. Negotiating Cooperation, Institutional Structures. Rutledge. London Pp 96.
14. Chatterjee, B and A. Ganguly. 2020. Time to Implement the BBIN Motor Vehicles Agreement. The Economic Times. Available at https://economictimes.indiatimes.com/blogs/et-commentary/time-to-implement-the-bbin-motor-vehicles-agreement/ Accessed on 28 June 2020
15. Ibid
16. BIMSTEC. 2020. About BIMSTEC. Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC). Available at https://bimstec.org/?page_id=189
17. Bhattacharjee, J. 2018. SAARC vs BIMSTEC: The Search for the Ideal Platform for Regional Cooperation. Observer Research Foundation. ORF Issue Brief, Issue No. 226.

18. Roy Chaudhury, D. (2019), "Kunming Meet Revives BCIM Link Plan", Accessed 25 June, 2020 URL: https://economictimes.indiatimes.com/news/politics-and-nation/kunming-meet-revives-bcim-link-plan/articleshow/69921135.cms.
19. Thakur, Ambuj (2014), *Sub-Regional Initiatives of China in South and Southeast Asia, 1999-2012*, Ph.D Thesis, New Delhi: Jawaharlal Nehru University.
20. Pangare Ganesh, Editor. 2014. Hydro-Diplomacy: Sharing Water Across Borders. IUCN. Academic Foundation, New Delhi.
21. ibid.
22. Arupjyoti Saikia, The Unquiet River: A Biography of the Brahmaputra, Oxford University Press, New Delhi (2019).
23. For further details of the issues and proposals set out in this article, see 'Why Eastern Himalayan countries should cooperate in transboundary water resource management', Golam Rasul, Water Policy 16 (2014) 19-38, IWA Publishing.
24. Bandyopadhyay, Jayanta, Nilanjan Ghosh and Chandan Mahanta. 2016. IRBM for Brahmaputra Sub-basin: Water Governance, Environmental Security, and Human Well-Being. New Delhi. Observer Research Foundation. (https://www.orfonline.org/research/irbm-for-brahmaputra-sub-basin/); Barua, Anamika. 2018. Water diplomacy as an approach to regional cooperation in South Asia: A case from the Brahmaputra basin. *Journal of Hydrology* 567:60-70.
25. Kattelmann Richard. 1987. Uncertainty in Assessing Himalayan Water Resources. *Mountain Research and Development* 7(3):289-286.
26. SAWI. 2018. China and India's Animosity About Tibetan Rivers' Fate. South Asia Water Initiative 08 August.
27. Hazarika, Obja Borah. 2015. Riparian Relations between India and China: Exploring Interactions in Trans-boundary Rivers. *International Journal of China Studies* 6(1) April:63-83.
28. Ho, Selina. 2017. Power Asymmetry in the China-India Brahmaputra River Dispute. *Asia Pacific Bulletin* 371 February 16.
29. Vellore, Ramesh K et al. 2014. On the anomalous precipitation enhancement over the Himalayan foothills during monsoon breaks. *Climate Dynamics* 43 January 04:2009-31.
30. Guoying, Li. 2005. Maintaining the healthy life of the Yellow River. Yellow River Conservancy Press. Zhengzhou.
31. Ahmed, Imtiaz. 2012. Teesta, Tipaimukh and River Linking Danger to Bangladesh India Relation. *Economic and Political Weekly* XLVII (16) April 21:51-53.

THE RESTLESS RIVER

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