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# Connecting flow and ecology in Nepal: current state of knowledge for the Koshi Basin

Editors – Tanya M Doody[1], Susan M Cuddy[1], Laxmi Dutt Bhatta[2]

[1] CSIRO Land and Water, Australia; [2] ICIMOD, Nepal

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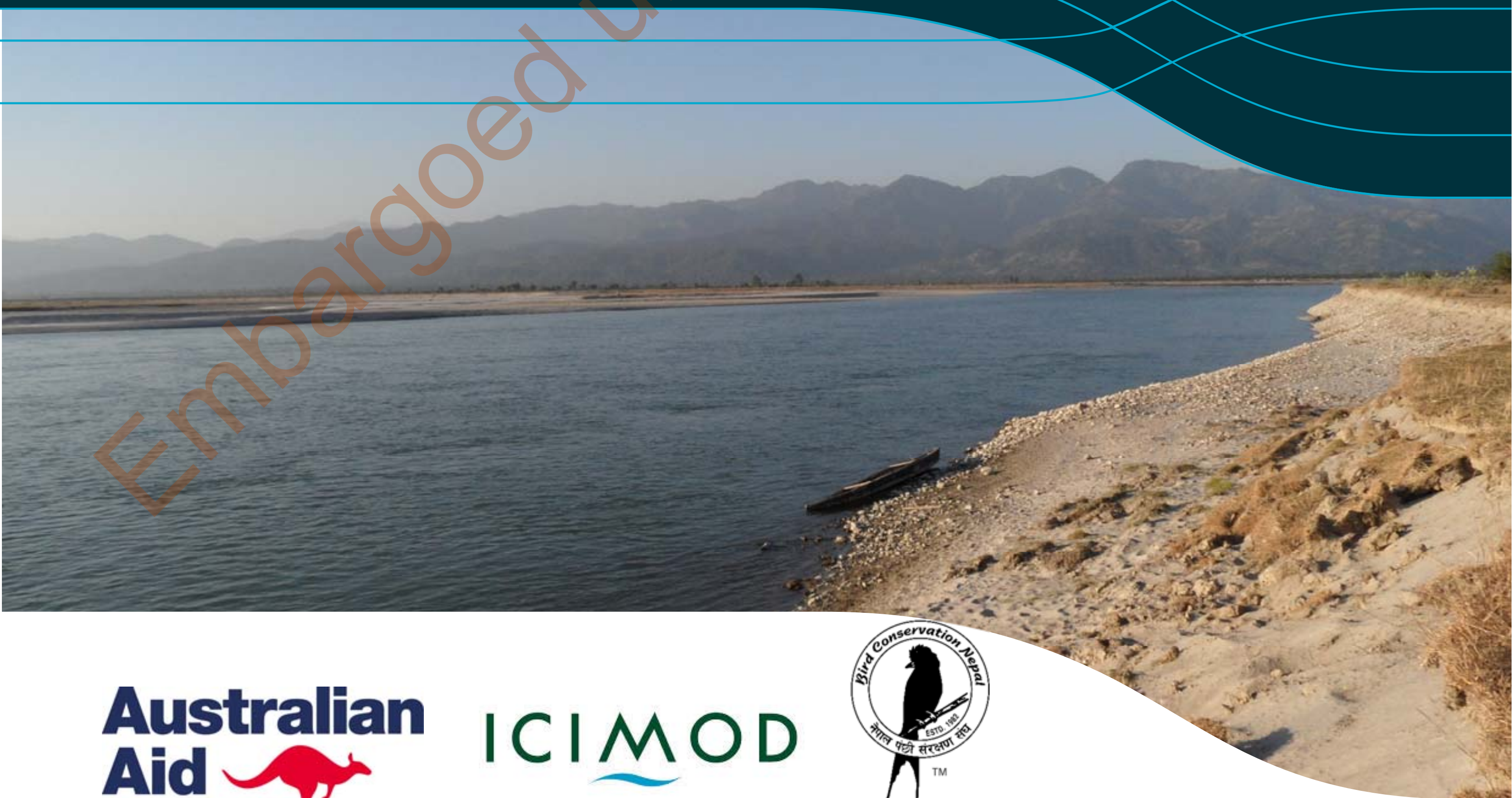

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# Foreword

The Sustainable Development Investment Portfolio (SDIP) is an Australia government initiative with the goal of increasing water, food and energy security in South Asia, targeting the poorest and most vulnerable, particularly women and girls. CSIRO is one of several partners that are delivering to this initiative. The SDIP focuses on three major river basins; the Indus, Ganges and Brahmaputra. The Ganges sub-region has an estimated 400 million people living in extreme poverty – the single largest in the world. A key target area where CSIRO expertise can help is water resources management. Within the SDIP, preliminary research and development by CSIRO has focussed on building relationships and understanding the biophysical, socio-economic, environmental, water management and policy environments of basins and sub-basins within this region. The work has focused on building capacity within key agencies and educational institutions in Pakistan, India, Nepal and Bangladesh. CSIRO is assisting these countries in building the capacity and tools needed to support their respective water reform journeys. Through this work CSIRO aims to support the SDIP goals and improve the livelihoods of the people dependent on the water resources of the region.

As part of the SDIP, CSIRO has been working with SDIP partner the International Centre for Integrated Mountain Development (ICIMOD) and other organisations in Nepal since 2013. In February 2015, ICIMOD and CSIRO hosted a workshop in Kathmandu to capture the current state of knowledge on relationships between flow and ecology, with a view to being able to comment on the likely impacts of future flow changes on ecology. The knowledge gained at the workshop was subsequently transformed into conceptual models that captured the linkages between aspects of flow and ecological condition. This report captures this journey with contributions from a team of Nepali ecologists as well as other international experts.

In producing this report CSIRO has drawn on the services of Bird Conservation Nepal and ICIMOD and we thank them for their significant contributions and input. We value the contributions of all authors, reviewers, and their organisations, as well as the relationships that have been built as part of this work.

This report provides valuable insights into the relationships between river flow, wetlands and floodplains, climate and water-dependent ecosystems in Nepal. It considers the relationships between the physical aspects of water and how this relates to livelihoods of the population, particularly women and the poor and landless people in the regions. Understanding the strong relationship between water, ecology and livelihoods is a significant step towards more sustainable management of the water resources of Nepal.

This is a valuable piece of research that clearly supports the SDIP objectives and hopefully supports Nepal on its water resource management journey.

Geoff Podger

Project Director South Asia Sustainable Development Investment Portfolio

CSIRO

## Contributors

*Listed in last name alphabetical order with chapter first author identified by *. Bracketed number [] indicates the chapter number*

| | |
|---|---|
| Dr Hem Sagar Baral, Zoological Society of London, Nepal Office | [8] Water-dependent birds*, [2] |
| Dr Khadga Basnet, Tribhuvan University, Nepal | [9] Water buffalo*, [2] |
| Mr Laxmi Dutt Bhatta, ICIMOD, Nepal | [2] Introduction*; Editor |
| Prof Ram P Chaudhary, Tribhuvan University, Nepal | [6] Flora diversity*, [2] |
| Ms Sunita Chaudhary, ICIMOD & Macquarie University, Australia | [7] |
| Dr Nakul Chettri, ICIMOD, Nepal | [7] Biodiversity*, [2] |
| Ms Susan Cuddy, CSIRO, Australia | Editor, report production |
| Mr Sagar Dahal, Tribhuvan University, Nepal | [9] |
| Dr Maheshwar Dhakal, Ministry of Forests & Soil Conservation, Nepal | [7] |
| Ms Michaela Dolk, CSIRO, Australia | [3] Climate and hydrology* |
| Dr Tanya Doody, CSIRO, Australia | [10], [2], Editor** |
| Dr Nicky Grigg, CSIRO, Australia | [3] |
| Ms Anandeeta Gurung, PhD scholar, Tohoku University, Japan | [10] |
| Dr Tek Bahadur Gurung, National Animal Science Research Institute, Nepal | [10] Fish diversity*, [2] |
| Ms Pratikshya Kandel, ICIMOD, Nepal | [7] |
| Mr Top Bahadur Khatri, Dept Hydrology & Meteorology, Nepal | [7] |
| Mr Ugan Manandhar, WWF Nepal Office | [4] Water requirements*, [2] |
| Dr Luis Neumann, CSIRO, Australia | [3] |
| Prof Wu Ning, ICIMOD, Nepal | [7] |
| Mr Shambhu Paudel, The Himalaya, Nepal | [11] Dolphin*, [2] |
| Mr Dave Penton, CSIRO, Australia | [3] |
| Ms Sunita Ranabhat, ICIMOD, Nepal | [2], [7] |
| Dr Jay Sah, Florida international University, USA | [6], [2] |
| Dr Deep Narayan Shah, IUCN, Nepal | [12] |
| Prof Karan Bahadur Shah, Tribhuvan University, Nepal | [11] Crocodiles*, [2] |
| Dr Bikash Sharma, ICIMOD, Nepal | [7] |
| Dr Eklabya Sharma, ICIMOD, Nepal | [7] |
| Prof Subodh Sharma, Kathmandu University, Nepal | [12] Macroinvertebrates*, [2] |
| Dr Ram Devi Tachamo Shah, Tribhuvan University, Nepal | [12] |
| Dr Danial Stratford, CSIRO, Australia | [3] |
| Ms Ishana Thapa, Bird Conservation Nepal, Nepal | [5] Livelihoods*, [8], [2] |
| Mr Kabir Uddin, ICIMOD, Nepal | [7] |

** Key role in shaping all chapters; lead on [13] Summary and Key Findings

## Reviewers

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| 8 | Baral HS, Thapa I (2016) *Water-dependent birds of the Koshi Basin*. Chapter 8 in: Doody TM, Cuddy SM, Bhatta LD (eds) Connecting flows and ecology in Nepal: current state of knowledge for the Koshi Basin. Sustainable Development Investment Portfolio (SDIP) project. CSIRO, Australia. pp 79–96 |
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| 11 | Shah KB, Paudel S (2016) *Ecology of crocodile and dolphin in the Koshi Basin*. Chapter 11 in: Doody TM, Cuddy SM, Bhatta LD (eds) Connecting flows and ecology in Nepal: current state of knowledge for the Koshi Basin. Sustainable Development Investment Portfolio (SDIP) project. CSIRO, Australia. pp 123–138 |
| 12 | Sharma S, Shah DN, Tachamo Shah RD (2016) *Macroinvertebrates as indicators of river health*. Chapter 12 in: Doody TM, Cuddy SM, Bhatta LD (eds) Connecting flows and ecology in Nepal: current state of knowledge for the Koshi Basin. Sustainable Development Investment Portfolio (SDIP) project. CSIRO, Australia. pp 123–138 |

# Key findings

Nepal's plentiful water resources, like other countries across the globe, require careful management to ensure equitable use across the many competing facets of water consumers. These include agricultural production, hydropower generation and human consumption. As Nepal progresses on a water reform journey, it is an opportune time to investigate the current understanding of the links between river flow and the freshwater ecosystems supported by these water resources. This report had dual purposes: to establish a baseline understanding of the current knowledge, in relation to ecological water requirements of aquatic ecosystems under natural flow variability conditions within the Koshi Basin of Nepal; and to stimulate research to address knowledge gaps and investigate species which might be good indicators of the ecological impacts of flow change in the future (indicator species). The overarching aim was to provide information to assist with Nepal's water reform journey with an emphasis on protecting freshwater ecosystems.

Through a process of expert elicitation, workshops and literature reviews, a number of conceptual models were created to highlight the known links between river flow and specific ecological components such as birds, fish, buffalo, crocodiles/gharials, invertebrates, flora and the freshwater Ganges River Dolphin. Additional information was collated to provide context around the current understanding of threats to aquatic ecosystems in relation to flow change; water regimes and environmental water requirements; and the importance of biodiversity to support livelihoods in the Basin. It appears that overall, there is a paucity of published studies which investigate the water requirements of the selected ecological components in the Koshi Basin and Nepal in general. This is understandable given the agreement at the workshops, that much of the knowledge related to flora and fauna was generally locked away in the minds of experts or in unobtainable grey literature.

For the first time in Nepal and the Koshi Basin, both qualitative and quantitative flow-ecology relationships were collated, where quantitative data express specific thresholds to flow change, which once exceeded cause a change (generally a decline) in native species populations. Qualitative data refers to knowledge which comes from observation but which hasn't been scientifically tested to determine a specific threshold to flow change.

### *Wild Water Buffalo*

In the international literature, there is a lack of published studies that relate flow regimes to the Wild Water Buffalo, specifically in Nepal and the Koshi Basin. While Water Buffalo are a species on the brink of extinction in Nepal, there is little known in relation to its key habitat and water requirements. It is known from observation that Water Buffalo require mixed riverine forest in order to have shade and to exfoliate after wallowing. Key quantitative relationships identified for the Water Buffalo include:

- a requirement for alluvial tall grassland composed of 80% *Saccharum* spp for grazing
- a requirement to wallow 6-8 hours a day to cool themselves.

However, there are many more knowledge gaps. Little is known about how big wallows need to be, what depth of water is required in the wallows and what temperature and water quality are required, to name a few.

## *Fish*

The hydrological variables that might impact fish and in particular fishery viability have been studied in more detail. A first time review undertaken within, identifies 141 reported fish species of which 134 are indigenous and seven are exotic. Factors such as high longitudinal river connectivity, oxygenated, unpolluted freshwater and minimal macrophyte area, enhance fish and fishery viability. Key quantitative relationships identified for fishes include:

- Snow Trout (*Schizothorax* spp) require the ability to migrate upstream to spawn in March to June at water temperatures between 14–21$^{o}$C. They also require clear water of depths 30–60 cm to lay eggs in gravel along stream bank
- a requirement (in general) of a dissolved oxygen threshold of between 5–7 mg $L^{-1}$
- a maximum water temperature of 28.16 (±0.19) $^{o}$C and minimum water depth of 3.0–3.6 m are unfavourable for most fishes
- Common and Grass carp *(Cyprinus carpio, Ctenopharyngodon idella)* require a water temperature between 10–25$^{o}$C for reproduction.

However, more research is required across a broader number of fish species in order to understand the water requirements that maintain viable fish populations and stimulate and support recruitment and fish development. Identification of key indicator species across the many rivers is also required.

## *Ganges River Dolphin*

Like the Buffalo, the future of the Ganges River Dolphin is highly threatened and their national population is low. The population in the Koshi Basin is the only one in eastern Nepal. Several literature resources and expert opinion describe the water requirements and flow thresholds required for the Dolphin. These include:

- a water depth requirement for adult/calf pairs of less than 2.2–2.4 m depth, sub-adults require >3.8 m depth and adults require >5 m
- gillnets that go to 4.5 m depth are a threat to dolphin life as dolphins swim primarily in that depth range and cannot get under nets
- a requirement for channels with a cross-sectional area of >700 m2 to ensure forging opportunities.

They also require high lateral and longitudinal connectivity and flow to be maintained where streams converge to create eddy counter currents. They also need to be able to move both ways through barrages. Deviations from these requirements lead to decline in population numbers.

## *Crocodile*

Crocodiles are also threatened in Nepal and the Koshi Basin and in fact the Gharial is extinct in the Basin, with only Mugger crocodiles present. Efforts to reintroduce Gharials in the past, have so far failed. Observations suggest that Muggers require basking substrate which is close to deep water and good habitat for camouflage. This includes good riparian vegetation, suitable water depth and river banks which are suitable for burrowing. Key quantitative relationships identified for Muggers include;

- a requirement for substrate for basking which is composed of 62% sand/sand bar and 37% rocky substrate
- requires shade by 14:00 in winter to manage thermoregulation
- different water depth requirements depending on size. Juveniles require 1–3 m depth, if 120–180 cm long, require 2–3 m but will use >4 m water depth if available, adults require water depth >4 m.

Studies are required to determine why reintroduction of Gharials has failed in the past, though it is likely related to flow and habitat availability. Mugger crocodiles are threatened by dam construction as their nests get flooded during monsoons and the Koshi Barrage which only allows them to travel downstream and not back upstream. More research is required to understand their breeding water requirements.

### *Birds*

A majority of the ecological research undertaken to date is related to birds in the Koshi Basin, however few studies report the water requirements of different species. Birds are incredibly important and diverse in the region and it is noted, that many of the bird species that are listed as threatened, are found in the Koshi Basin. Within the report, the focus is on water-dependent birds, however this broad range of birds has been divided further into river, water, grassland and forest birds. Observation demonstrates that many species access water-dependent food sources such as fish, snails, reptiles, insects and tubers, while other species nest along river banks or in water dependent grassland. Key quantitative relationships identified for birds include:

*Water birds*

- Lesser Adjutant Stork (*Leptoptilos javanicus*) nests in trees greater than 30m

*Grassland birds*

- Swamp francolin (*Francolinus gularis*) prefers high density grass 2–3 m tall
- Bengal florican (*Houbaropsis bengalensis*) males prefer moist, short, pure grassland 15–35 cm tall
- Bengal florican (*Houbaropsis bengalensis*) females prefer moist grassland >110 cm tall.

Significant knowledge gaps exist as indicated by the lack of quantitative relationships for river birds which will be the group of species most and rapidly impacted if and when river flow regimes change. Given the number of threatened species in the Koshi Basin, it is critical that further quantitative and qualitative water specific research is undertaken.

### *Macroinvertebrates*

Macroinvertebrates are little studied in Nepal, as indicated by only one international expert working in this field in Nepal (and the Koshi Basin). Macroinvertebrates are known key indicators of flow in other regions of the world, so it will be important in the future to train and provide opportunities for experts in Nepal. There were no key quantitative relationships identified in the Koshi Basin but from observation it is known that taxon richness is maintained in areas with little or no flow alteration. Many challenges exist to increase macroinvertebrate studies in Nepal to identify their ecological flow requirements.

### *Biodiversity*

The flow-ecology relationships for flora were difficult to identify, however a comprehensive understanding of the biodiversity values of both flora and fauna are presented across two chapters. Nepal and the Koshi Basin contain some of the most diverse regions throughout the world, however, there is an evident lack of floristic and faunal inventory at the Basin scale. There is also a lack of knowledge relating to connectivity between terrestrial, riparian and aquatic systems, as well as the importance of hydrological connectivity upstream and downstream, particularly in transboundary situations.

Wetlands and aquatic ecosystems are well recognized for their significant role in supporting high biodiversity and providing food, water and livelihoods security. The National water plan of Nepal, released in 2005, encourages integrated water resource management to promote sustainable water use with an emphasis on meeting the needs of the current generation, without compromising the needs of future generations, while at the same time maintaining the freshwater ecosystems of Nepal. However, we demonstrate within, that significant investment is required for research to not only better understand the water requirements of ecological components but to also understand the flow characteristics and connectivity of rivers, streams and wetlands under conditions of natural flow variability (where possible) to protect aquatic ecosystems into the future. Providing such critical ecological baseline data for selected species then provides a way to monitor water resources, especially under predicted increasing abstraction, particularly from hydropower development, to ensure detrimental ecosystem decline is not occurring. Baseline data also means the current environmental flow 'rule of thumb' (10% of the rivers mean monthly flow should be maintained within the river throughout the year in the dewatered sections) for dammed or diverted river systems in Nepal can be tested and amended for each potentially impacted river system. There is currently little understanding as to whether the environmental flow 'rule of thumb' is sufficient to protect all aquatic ecosystems across Nepal, yet it is the main determinant of environmental flow allocations.

We anticipate that the information provided within, has an ability to influence the revision of Nepal's environmental impact assessment process which is currently underway, by highlighting the importance of both baseline monitoring and a continued program of monitoring to ensure protection of freshwater ecosystems for the next generations. Additionally, a better understanding of aquatic ecology and the flow regimes that support these ecosystems under natural conditions (where possible), can inform the development of Nepali water policy to ensure appropriate future governance of aquatic ecosystems. Rivers, lakes, swamps and marshes are known to be the most productive ecosystems for provision of products on which the local people are highly dependent. Suitable water governance ensures that livelihoods dependent on aquatic resources are therefore also protected.

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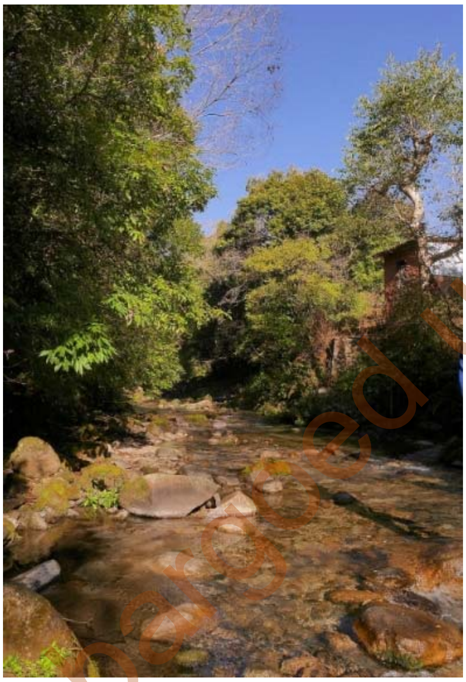
# 1 Statement of purpose

*Authors: Tanya M Doody[1], Susan M Cuddy[1], Laxmi Dutt Bhatta[2]*

Ecologists and other experts in Nepal hold an extensive body of knowledge that is relevant to the progress of environmental governance and water resources management in Nepal. The Koshi River Basin was chosen as a study region as river basin management planning is currently very active there. This report is an attempt to assemble this wealth of information in a form that can be shared with a wider audience, including researchers, practitioners and to some extent policy makers and people interested in water resources management issues in Nepal, and especially in the Koshi Basin.

## 1.1 Motivation for this report

Nepal is a country undergoing transformation in an effort to harness plentiful water resources which can deliver energy and irrigation through river generated hydropower production. Population growth is a major driver behind a need to increase agricultural production which is only possible via upgraded irrigation systems that pump water from streams and groundwater. Hydrological resources and the energy generated from them, thus provide the potential for improved economies and livelihoods in Nepal. However, quantifying their effect on river flow and the consequent impacts on aquatic ecosystems requires a sound knowledge base to mitigate environmental repercussions where possible as this transformative journey progresses. It is especially important to understand the potential impacts to livelihoods of the poorest and most vulnerable societies in Nepal, especially women and children.



Over the last several decades, through water reform, Australia (and other countries) have learnt many water management lessons that are universally applicable. These include a requirement for agreement on how much water is available, what the dominant demands on the water are and how the water can best be shared to ensure the sustainability of livelihoods and ecosystems supported by it. Now is an opportune time to work with Nepali organisations who are responsible for managing the Nepal water reform journey, to assist with building the scientific evidence base necessary to inform processes which can help protect ecosystems.

River basin management planning is currently being undertaken within the Koshi Basin. Through a series of workshops, collation of the current understanding of the relationships between the flow in rivers and the ecosystems they support was identified as a key need that would provide valuable insights into what is known and where knowledge gaps exist. The aim of this narrative is therefore to

[1] CSIRO Land and Water, Australia
[2] International Centre for Integrated Mountain Development, Kathmandu, Nepal

capture the current understanding of links between river flow and aquatic ecology in the Koshi Basin. The importance of understanding these relationships lies in understanding the ecological flow requirements that are required to maintain the integrity of ecosystems. Often, once certain flow thresholds are breached, aquatic or water dependent ecological components and ecosystems experience decline. For example, it has been identified within, that adult Ganga Dolphin require connected, deep pools in excess of 5 m to survive. A reduction in flow magnitude therefore becomes a serious threat as pools become disconnected and pool depth becomes too shallow for survival. Hence, this report also aims to promote the issue of upstream and downstream linkages in river basins.

We focus on identifying known flow-ecology relationships by engaging and collaborating with Nepali experts whose key knowledge relates to ecological components including birds, fish, dolphin, crocodiles, buffalo, flora and macroinvertebrates. It was considered that while the ecological components identified are not exhaustive, they might be useful indicators of flow change in the future where presence, absence or relative wellbeing provides a sign of overall ecosystem health in the Koshi Basin. We also consider in each chapter, how important river flow is to support livelihoods in the region, whether that is to provide clean, safe drinking water or to maintain fish stock viability.

Our collaboration also provided an opportunity to encourage Nepali scientists and other experts to consider the thresholds of flow change which lead to negative changes within the communities of relevant ecological components. A logical way to do this was to identify and conceptually map the quantitative and qualitative links between flow and ecological components from existing knowledge and literature (Figure 1-1). These conceptual models then set the scene for future research programs to set hypotheses which can address the identified knowledge gaps, in what are generally data poor regions.

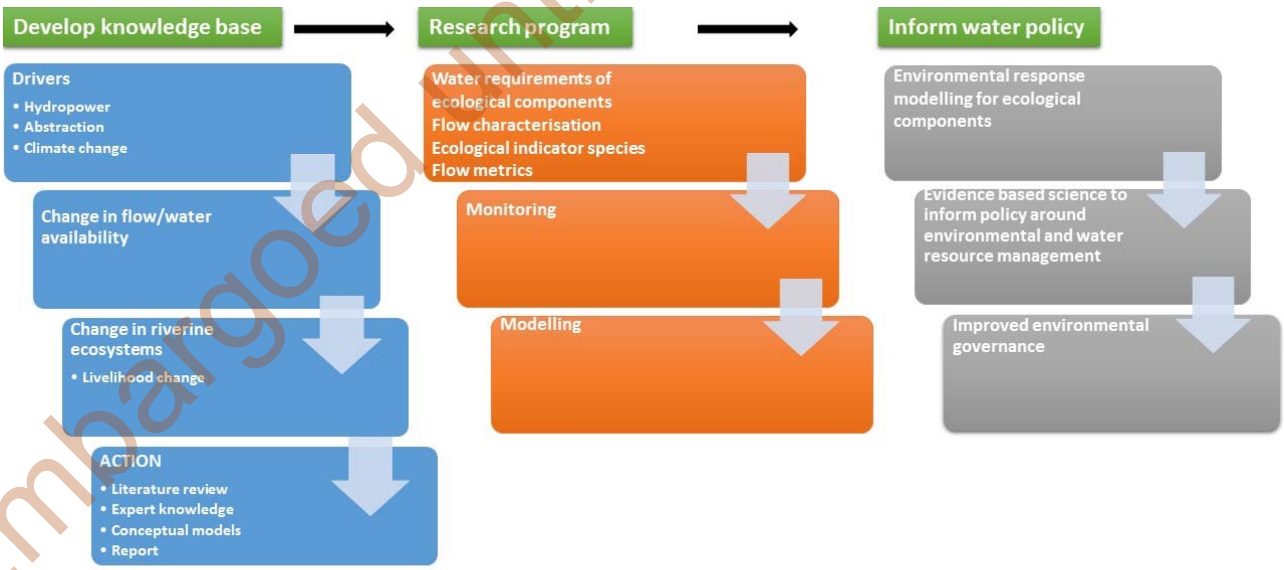



Figure 1-1 Framework to guide a research program to improve our understanding of the links between river flow and ecology in order to inform future water policy

This report is then a first step in building a knowledge base and setting a framework for extending that knowledge base and developing independent, targeted research programs. Within the research programs, an understanding of the water requirements of ecological components (for example; depth of a water hole for wallowing, water quality to maintain fish populations) and their sensitivities to how these key water requirements change is required (Figure 1-1). Additionally, an understanding of river flow characteristics (for example; seasonality, zero flow days, peak monthly flow) is required, to help identify flow thresholds, which once exceeded cause ecological components to decline in some way (decrease in population size, failure to breed).

The outcome of this collaboration is a clearer understanding of what knowledge exists in the region and the importance of building an ecological baseline understanding of the Koshi Basin, ahead of environmental damage that might be incurred by increased water abstraction or river regime changes away from a baseline state. The information presented for the Koshi Basin is very likely to be scalable across other Nepali and adjacent international river basins.

We believe that in the future, after much research investment, an opportunity exists to transfer such evidence based science to inform progressive water policy development through hydrological and environmental response modelling (Figure 1-1). This can be achieved by developing informed hydrological scenarios from which we can predict possible environmental impacts of future changes to flow regimes. Within an integrated water resource management framework, a better understanding of aquatic ecosystems will aid with the development of water policy to provide equitable allocation of water resources to ultimately improve livelihoods of the most vulnerable.

## 1.2 Structure of this report

While a chapter outline was prepared, authors were encouraged to modify it to suit the style of story they wanted to tell. Thus, each chapter exhibits the style and disciplinary practice of the authors. As we envisage that chapters may be read separately, each chapter contains some description of the physical and often the political context. Where possible we have sought to make this information consistent but this was not always possible.

The report structure presents several chapters which provide context to the Koshi Basin. This includes an overarching Context chapter and chapters which present general information related to climate, hydrology, environmental flows and biodiversity values. Several chapters then follow, which are dedicated to understanding the links between flow and ecology. We provide a summary of the knowledge gaps and for the first time, present the known quantitative and qualitative links between flow and ecology in the Koshi Basin, for each ecological component selected for the study.

Koshi River scene (photo courtesy of Jyotendra Jyu Thakuri, Bird Conservation Nepal)

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# 2 Introduction

*Authors: Laxmi Dutt Bhatta[1], Sunita Ranabhat[1], Ram Prasad Chaudhary[2], Jah P Sah[3], Tanya Marree Doody[4], Nakul Chettri[1], Khadga Basnet[5], Ugan Madandhar[6], Hem Baral[7], Ishana Thapa[8], Tek Bahadur Gurung[9], Karan Bahadur Shah[10], Shambhu Paudel[11], Subodh Sharma[12]*

## 2.1 The Koshi Basin

The Koshi River Basin (Koshi Basin herein) is one of the most important transboundary river systems between China, Nepal and India, originating from the Tibetan Plateau in China, and ending at the Ganga (Figure 2-1). The Basin covers six geological and climatic belts varying in altitude from 21 m (low alluvial plains) to above 8800 m (high mountain), including the Tibetan plateau, the Himalayas, the Himalayan mid-hill belt, the Mahabharata Range, the Siwalik Hills and the Terai.


Figure 2-1 The Koshi Basin lies between the basins of the Ganges (which it joins downstream of Nepal) and the Brahmaputra. Approximately 46% of the Basin lies within Nepal

The Basin contributes one of the largest tributaries of the Ganga River and consists of seven major sub-basins: the Indrawati, SunKoshi, TamaKoshi, Likhu, DudhKoshi, Arun, and Tamor (Figure 2-2). This is the reason that it is commonly referred to as 'Sapta Koshi' in Nepal. These rivers drain a catchment area of over 87,000 km$^2$, approximately 46% of which lies in Nepal.

[1] International Centre for Integrated Mountain Development (ICIMOD), Kathmandu, Nepal
[2] Executive Director, Research Centre for Applied Science and Technology (RECAST), and Professor, Central Department of Botany, Tribhuvan University, Kirtipur, Nepal
[3] Research Associate, Southeast Environmental Research Center, Florida International University Miami, USA
[4] CSIRO Land and Water, Adelaide, Australia
[5] Central Department of Zoology, Tribhuvan University, Kirtipur, Kathmandu
[6] World Wildlife Fund, Nepal Office, Kathmandu
[7] Zoological Society of London, Nepal Office
[8] Bird Conservation Nepal, Kathmandu
[9] National Animal Science Research Institute (NASRI) of Nepal Agricultural Research Council (NARC)
[10] Professor of Zoology, Natural History Museum, Tribhuvan University, Swoyambhu, Kathmandu
[11] Senior Research Officer (Freshwater), The Himalaya, Kathmandu
[12] Aquatic Ecology Centre, School of Science, Kathmandu University

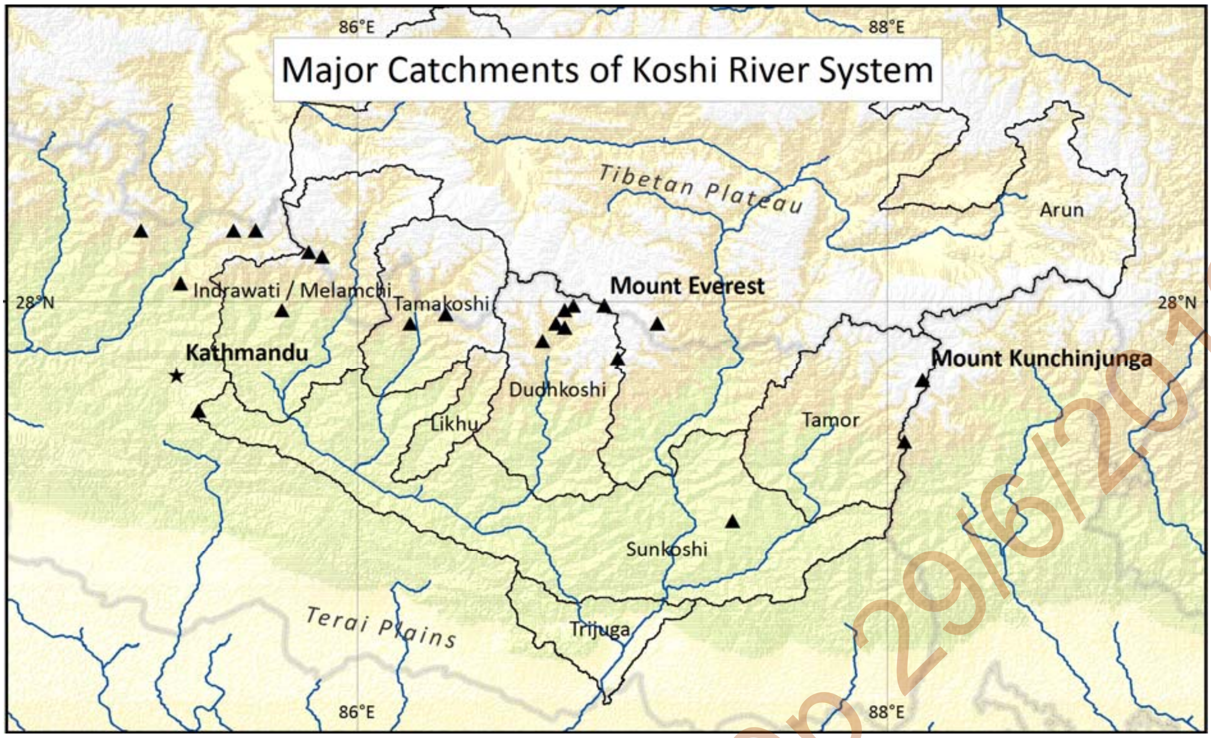



Figure 2-2 The seven rivers of the Sapta Koshi and their catchment boundaries

The Basin has an average discharge of 1931m$^3$ sec-1 (Dixit 2009) where the catchment of the Arun River occupies more than half of the Basin, and provides one-third of the total discharge (Kattelman 1991). Further hydrological information can be found in Chapter 3.

With altitudinal variations (Figure 2-3), almost all climatic conditions of the world are found in the Basin and range from humid tropical in the Terai to arctic on the High Himal (Dixit 2009). In the Mountain and Hill regions, the average daily maximum temperature is highest in June (about 27°C in Mountain and 32°C in Hills) and lowest in December–January (less than 0°C in Mountain and 5°C in Hills) (Agarwal et al. 2015).

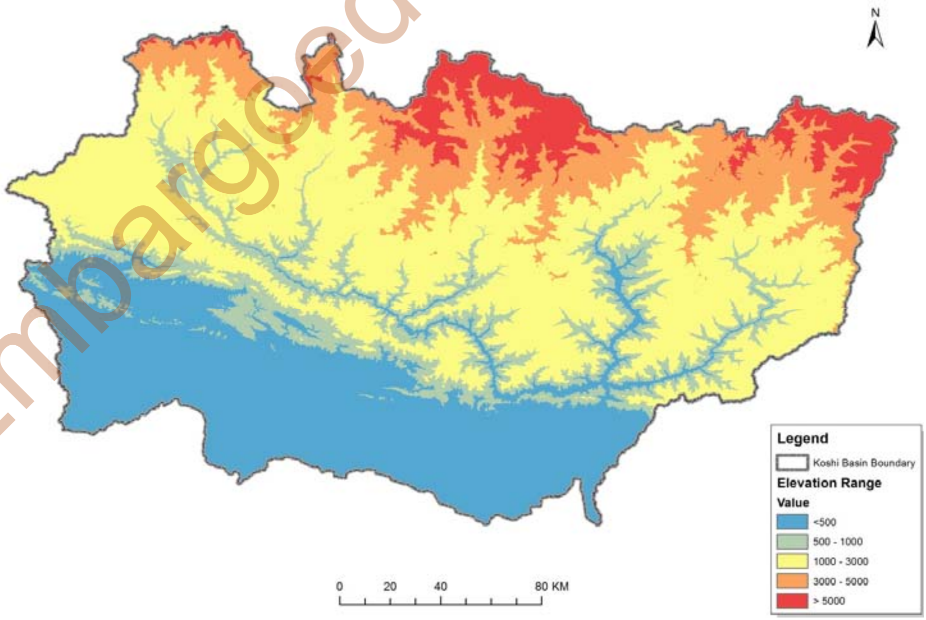



Figure 2-3 Elevation gradient of the Koshi River Basin

Precipitation also varies with topography and monsoon (Chaudhary et al. 2015). In the Basin, precipitation increases with elevation (from the Terai to the mountains) but decreases at higher elevation in the rain shadow region of the high mountains and the Himalayas (Agarwal et al. 2014). Additional climate information can be found in Chapter 3.

## 2.2 Socio economics and demography

According to the latest 2011 census, the total population of the Koshi Basin is just over 11.5 million, 49.6% men and 50.4% women. This is 44% of Nepal's total population and has grown by 17% since 2001. The Basin includes 27 of Nepal's 75 districts. Population density is lowest in the mountain regions as compared to the hills and Terai regions (Annex: Table 2-2). The average household size is just under 5. The average literacy rate was 62% in 2011 which is below the national average of 66% (88.6% for those between 15 and 24 years) – however, it has increased by 18% in males and 31% in females over the last two decades. To contrast this with districts outside the Basin – Kathmandu district has the highest literacy rate for both males (92%) and females (80%), whereas Rautahat district has the lowest for both males (52%) and females (32%) (CBS 2012).

Firewood has been and remains the main source of energy. Of all households in the Basin, 51% depend on firewood for cooking, while consumption of other sources of fuel such as LPG and electricity are increasing in urban areas. Biogas is becoming a major alternative energy source for cooking in the Mid-Hills. In rural areas, more than 90% of the population are dependent on biomass energy (CBS 2014b). Electricity provides services to about 61% of households for lighting (CBS 2014b), however, acute power cuts reduce electricity use.

Agriculture-forest based livelihoods are dominant in the Basin. In urban centres, people have multiple sources of income for their livelihoods. Paddy, maize, millet, buckwheat and wheat are the major cereal crops traditionally grown. The trend in production has been decreasing in recent years except for maize (MoAD 2014). Production of cash crops such as oilseeds and potatoes has increased over the same period of time (CBS 2013). Besides agriculture, about 15% of the population relies on small scale enterprises for livelihood, including the cottage industry, transportation, business and service (CBS 2014b). In recent years, remittance from sources other than agriculture has become a major source of income for many households in the Basin. Additional livelihoods information can be found in Chapter 5.

## 2.3 Land use and land use change in the Koshi Basin

Agriculture is the dominant land use (35% in 2010) with a 1% increase in area in 30 years (Table 2-1), followed by grassland (27%) and forest (23%). In the Terai and the lower altitude regions, agricultural land use is dominant whereas in the hills and at higher altitudes, forests and shrublands are dominant (Figure 2-4). Nearly 6% of the Basin is occupied by snow-covered mountains while 8% of the land in the Terai region is barren.

Forest area has decreased slightly in 30 years. A recent forest survey indicates a decrease in forest cover in the Terai districts, except in Siraha district (DFRS 2014). However, several (earlier) studies reported an increase in forest cover in the mid hills (Virgo and Subba 1994, Gautam et al. 2003), which is the result of a successful community forestry programme (Nepal 2012). Gautam et al. (2003), in his limited study, showed an increase in broad-leaved and conifer forest, and lowland agriculture, but a decrease in shrubland, grassland and upland agricultural area. Similarly, a comparison of forest cover in the Mahabharat and the middle mountain region of the Basin during 1964–1965 and 1978–1979 showed that forest cover has increased by nearly 1.5% (Sharma et al. 2000).

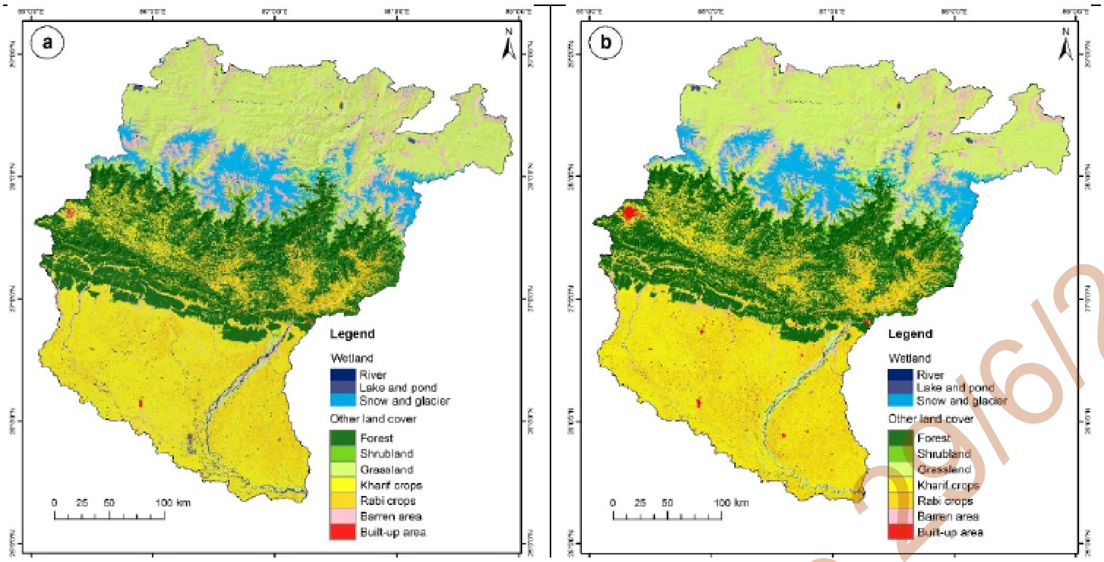



Figure 2-4 Land use in 1990 (a) and 2010 (b) highlighting the distribution of wetland, vegetation, crop and built-up areas in those years. The maps also identifies land use change between 1990 and 2010 (Source: Uddin et al. 2015)

The Basin has witnessed a 200% increase in built-up area especially around Kathmandu (Figure 2-4) and a loss of 27% of freshwater ecosystems (Table 2-1). Similarly, soil loss from different land cover classes in 1990 and 2010 was estimated to be of the order of 40 million tonnes (Uddin et al. 2016). Barren land contributes the highest soil loss of 22 t $ha^{-1}$ $yr^{-1}$ (Table 2-1). Soil loss occurs predominantly through monsoon flooding and wind erosion.

Table 2-1 Land cover and estimation of erosion rate in Koshi Basin from 1990 until 2010 (Source: Uddin et al. 2015)

| Land cover | Land cover area (km) | Land cover area (km) | Annual soil loss (.000t) | Annual soil loss (.000t) | Mean erosion rate (t/ha/yr) | Mean erosion rate (t/ha/yr) |
|---|---|---|---|---|---|---|
| Year | 1990 | 2010 | 1990 | 2010 | 1990 | 2010 |
| Forest | 20,032 | 19,827 | 601 | 991 | 0.3 | 0.5 |
| Shrubland | 679 | 670 | 231 | 261 | 3.4 | 3.9 |
| Grassland | 23,463 | 23,486 | 10,793 | 11,743 | 4.6 | 5 |
| Agricultural land (Kharif) | 17,927 | 15,691 | 4,482 | 5,335 | 2.5 | 3.4 |
| Agricultural land (Rabi) | 11,708 | 14,715 | 5,269 | 8,240 | 4.5 | 5.6 |
| Barren land | 8,245 | 7,081 | 18,057 | 15,437 | 21.9 | 21.8 |
| Built up area | 99 | 268 | 0.5 | 2 | 0.05 | 0.08 |
| Water bodies | 793 | 572 | 56 | 11 | 0.71 | 0.19 |
| Snow/glaciers | 4,595 | 5,235 | 5 | 5 | 0,01 | 0.01 |
| **Total** | **87,541** | **87,545** | **39,495** | **42,025** | | |

## 2.4 Ecosystems and biodiversity

High altitudinal variations across short distances (21 m to over 8800 m) lead to diverse climatic conditions and associated physiographic variations. The Koshi Basin thus harbours important habitats for many floral and faunal species, including aquatic species.

### Ecosystems

As mentioned previously, the Koshi Basin consists of bioclimatic belts ranging from Tropical zone in the Terai to alpine zone (above 4000 m) in the Mountains. The Koshi Basin is characterised by various types of ecosystems and habitats such as glaciers; snow; rock; wetlands; alpine meadows with grasses and sedges, floodplains (Figure 2-5) to name a few.

Figure 2-5 *Typha angustifolia* and *Tamarix dioica* association in the floodplain of the Koshi Tappu Wildlife Reserve provide habitat for wild boar and birds

Forest remains the dominant ecosystem in the Koshi Basin. Bhuju et al. (2007) found that all major forest ecosystems ranging from Khair-Sissoo (*Acacia-Dalbergia*) forest, deciduous mixed riverine forest and lower tropical Sal forest to eastern Himalayan Conifer forest (Figure 2-6), upper alpine and trans Himalayan steppe, all exist in the Basin. Following Miehe et al. (2015b), vegetation and forest types in the Koshi Basin have been described under two broad categories: (i) vegetation of the southern slopes of the Himalayas, and (ii) the vegetation of the inner valleys across six bioclimatic belts (See Chapter 6 for details).

Figure 2-6 Eastern Himalayan Conifer forest, Kanchenjunga Landscape, Nepal

Rangeland is considered a very important ecosystem, particularly for local livelihoods in upper altitude regions and pastoral communities. The Government of Nepal have estimated that about 12% of the country's land consists of rangeland ecosystems which include grasslands, pastures, shrublands and other grazing areas (MoFSC 2014). About 98% of rangelands are located in the Mountains and Himalayas with less than 2% located in the Terai region (Pande 2010). However, there are very few studies on the rangelands ecosystems of the Basin. Small scale research such as that undertaken by Yonzon (2000) found that around 7590 $km^2$ of rangelands are located inside the protected areas of the Koshi Basin.

Wetlands are considered of high ecological significance, as they not only harbour habitat for many flora and faunal species, including migratory birds, they also play an important role in water recharge and purification. Many of the traditional and tribal communities in Nepal, such as the Majhis and Tharu, are heavily dependent on wetlands for their livelihoods (IUCN 2004). The Basin houses the second highest number of wetlands in Nepal, after the Karnali River Basin (Bhandari 2009). Ten of the country's wetlands are listed as Ramsar sites, two of which are in the Koshi Basin (Koshi Tappu, and Gokyo and Associated lakes). Key wetlands of the Terai or Siwalik region include the Koshi barrage, the Koshi River, Titriganchi Tal, Kamalpur Tal and Bhagalpur Tal which all provide habitat for key species such as Asian Wild Water Buffalo, Ganges River Dolphin, Gharial, Marsh Mugger, and the Smooth Coated Indian Otter (Scott 1989).

## Biodiversity hotspots

The Koshi Basin is considered as an important part of the 'Himalaya Global Biodiversity Hotspot' – one of the 34 global Biodiversity Hotspots (Myers et al. 2000, Mittermeier et al. 2004). Faunal and floral diversity (species richness and endemism) in the Eastern Himalaya, including the Koshi Basin, is rich mainly because it lies at the junction of both Indo-Malayan and Palearctic Realms and includes several globally significant ecoregions and centres of plant diversity (Yonjon 2000). In general, habitat heterogeneity is a major structuring agent of ecological assemblages promoting beta diversity and overall higher global diversity (McClain and Barry 2010). The wide coverage of habitats found within the Koshi Basin has supported *in situ* conservation of many primitive, for example *Magnolia campbellii* (Figure 2-7), threatened and rare species (Shrestha 1989) (See Chapter 6 for details). The Basin is also rich in medicinal and food plants and their wild relatives.

Figure 2-7 *Magnolia campbellii*, a primitive species

## Ecoregions

An ecoregion is a large unit of geographical land with a distinct assemblage of species, natural communities and environmental conditions. The Himalaya, particularly the Hindu Kush Himalaya, is considered as one of the high biodiversity areas with four global biodiversity hotspots, 60 ecoregions, 488 protected areas, 13 world heritage sites and 27 Ramsar sites (www.geoportal.icimod.org/symposium2010). The Koshi Basin represents four ecoregions: (i) Eastern Himalayan alpine shrubs and meadows; (ii) Eastern Himalayan conifer forests; (iii) Eastern Himalayan broadleaved forests; and (iv) Terai-Duar grasslands and savannas (Figure 2-8). Conservation status of these ecoregions have been in transition due to various natural and human induced activities.

Figure 2-8 Terai-Duar grassland, Koshi Tappu Wildlife Reserve, Nepal

## Protected areas

The establishment of Protected Areas (PAs) has been fundamental to the conservation of biodiversity globally and in Nepal. These support healthy ecosystems and threatened species and also provide multiple benefits to people (Bertzky et al. 2012). The PA system of the Koshi Basin includes two national parks, namely Sagarmatha (Everest) National Park and Makalu-Barun National Park, two conservation areas namely Kangchenjunga Conservation Area and Gaurishankar Conservation Area, and one wildlife reserve namely Koshi Tappu Wildlife Reserve (Annex: Table 2-3). The Kangchenjunga Conservation Area and the Makalu-Barun National Park and Conservation Area are of particular significance as both PAs are important models of community-based biodiversity management. The PAs within the Koshi Basin cover a total of 8315 $km^2$ (Annex: Table 2-3) which represents 24% of the total area of PAs in Nepal. The Koshi Tappu Wildlife Reserve (17,500 ha) and Gokyo and Associated Lakes (7770 ha) have been designated as Ramsar sites, indicating they are wetlands of international importance.

**Important Plant Areas (IPAs):** Important Plant Areas (IPAs) are sites of exceptional botanical importance for medicinal and aromatic plant species richness, threatened plant species, habitats and vegetation in general (Anderson 2002). In the Koshi Basin, the IPAs complex include: (i) Upper Bagmati (Sindhupalchowk district); (ii) Upper Janakpur (Sindhuli district); (iii) Udaypur (Udaypur district); (iv) Upper Sagarmatha and Kangchenjunga Complex (Solukhumbu, Sankhuwasabha and Taplejung districts); and (v) Lower Kangchenjunga Complex (Terahthum and Panchthar districts). The maximum number of IPAs are found in the Upper Sagarmatha and Kangchenjunga Complex with a total of 36 IPAs (Hamilton & Radford 2007). Commonly found medicinal plant species in the Basin are often found in these IPAs (Figure 2-9).

Figure 2-9 Kangchenjunga landscape, rich in medicinal plant species; *Swertia chirayira*, a medicinal plant transported for trade

**Important Bird and Biodiversity Areas (IBAs):** Important Bird and Biodiversity Areas (IBAs) are globally recognised important areas for the conservation of birds and their habitats. The IBAs in the Koshi Basin include: (i) Sagarmatha National Park; (ii) Makalu-Barun National Park; (iii) Kangchenjunga Conservation Area; (iv) Tamur Valley and Watershed; (v) Dharan forest; and (vi) Koshi Tappu Wildlife Reserve. Khandbari-Num  Forest is also regarded as a potential IBAs (Baral and Inskipp 2005). The Koshi Basin with diverse habitats provides shelter for some restricted range species, globally threatened species, Eurasian High Montane biome species, Sino-Himalayan temperate forest biome species and Sino-Himalayan subtropical forest biome species.

**Wildlife corridor and connectivity:** A wildlife corridor is a conservation tool that maintains connectivity among PAs and other important wild habitats within a country and/or across the border between countries. The conservation objectives are achieved by developing a network of corridors to provide additional resources like food and space to wildlife species and the opportunity of exchanging genes among several populations within the network. Thus, corridors are meant for the successful conservation of biodiversity (CBD 2011).

Despite a number of interventions, various ecosystems in the Basin are under threat. Both climatic and anthropogenic drivers such as over and unsustainable harvesting, alien and invasive species, illegal hunting, river flow alteration, sedimentation, over grazing, channelling, damming and conversion of forest land to other forms of land use are considered most important drivers creating unfavourable ecosystem changes in the Basin. A vulnerability assessment indicates that most of the Basin has a moderate to high ecological vulnerability (Figure 2-10).

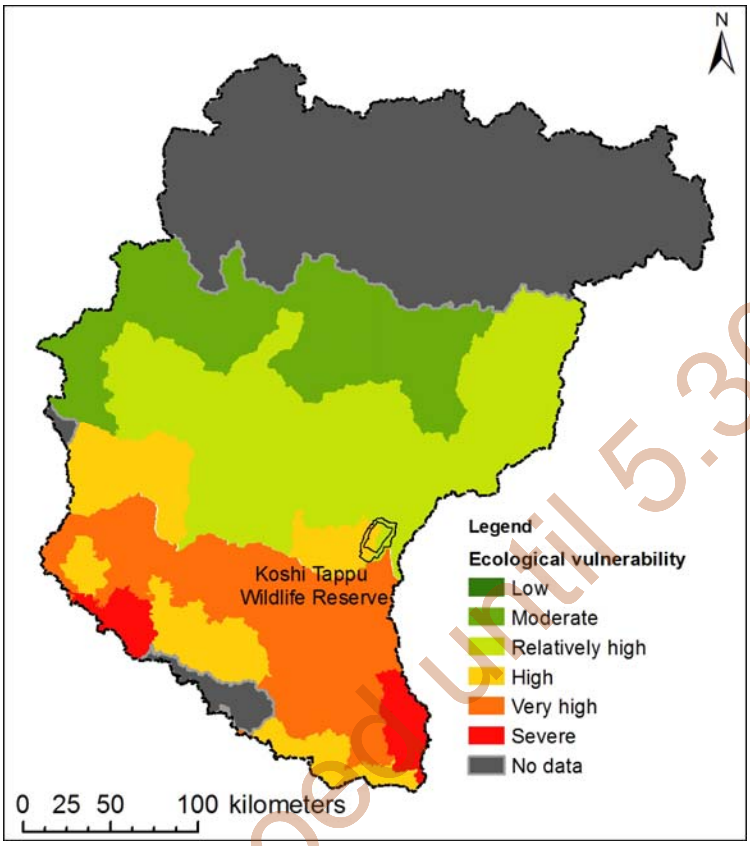



Figure 2-10 Ecological vulnerability of the Koshi Basin and Koshi Tappu Wildlife Reserve (Source: Neupane et al. 2013)

## 2.5 Koshi Tappu Wildlife Reserve

The Koshi Tappu Wildife Reserve is a Ramsar wetland of international importance as it has been supporting and protecting natural systems and processes in the area. Additionally, it is evident that the Reserve offers a wide range of services such as firewood, fodder, foods including irrigation, water storage, carbon sequestration, ollution control etc. to a substantial population living in the Buffer Zone. This dependency is directly contributing to the subsistence livelihoods of people living in the Buffer Zones and helping them to reduce poverty (Shrestha and Alavalapati 2006, CSUWN, 2009). Past analysis shows that dependency of the local people on the Reserve, particularly on provisioning and cultural services, is extremely high (CSUWN 2009, Chaudhary et al. 2014, Sharma et al. 2015).

The Reserve is a heavily studied location in the Koshi Basin and features in several forthcoming chapters.

## 2.6 Sustainability of the Koshi Basin and the Koshi Tappu Wildlife Reserve

The Koshi Basin is an important contributor of fish diversity in the Himalayas with a high proportion of threatened and endemic species (Allen et al. 2010). The Koshi Tappu Wildlife Reserve is a cornucopia of biodiversity supported by numerous wetland, forest and alpine ecosystems within the

Koshi River Basin (Figure 2-11). It is to be noted that the diverse upstream ecosystems are the lifeline for the Reserve and its rich biodiversity as well as a source of valuable ecosystem services that sustain the lives and livelihoods of millions of people (van Oort et al. 2015). However, the Basin has been witnessing changes in the fresh water ecosystems (Uddin et al. 2015) due to land use and land cover change (Uddin et al. 2016) with loss of habitat for many aquatic and terrestrial species (Figure 2-10; Chettri et al. 2013). Moreover, the reserve lost 94% of its original forest cover over a period of 34 years (1976–2010) with 79% increase in grassland during the same period (see Chettri et al. 2013).

The Koshi Basin is an important contributor to the Ganga Basin in terms of water flow (Lutz et al. 2014). However, the increasing trend of precipitation and flows (Agarwal et al. 2014, Bharati et al. 2016, Nepal 2016, Rajbhandari et al. 2016b); variations in glacier dynamics (Wang and Zhang 2014); increasing risk from Glacial Lake Outburst Flood (Khanal et al. 2015); seasonal as well as mean annual minimum and maximum temperature projected for future scenarios (see Smadja et al. 2015, Agarwal et al. 2016); are bringing additional challenges for the future health of the Reserve.

In addition, the persistent and ongoing dependency of people on water and biotic resources in the Reserve (MoFSC 2009b, ICIMOD & MoFSC 2014, Chaudhary et al. 2014) and the Basin as a whole (van Oort et al. 2015, Rai et al. 2015) is making the Reserve vulnerable (Chettri et al. 2010). Bhatt et al. (2014) report that as vulnerability increases, crop production systems are visibly impacted, adding to the food security challenge common in developing countries.

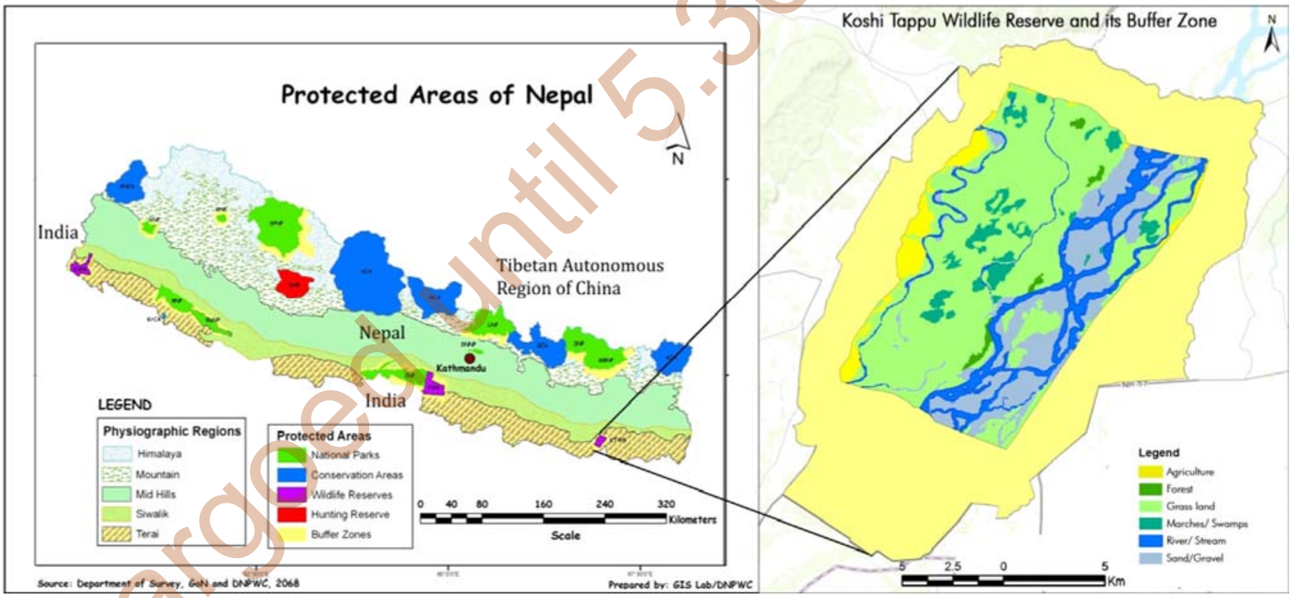



Figure 2-11 Protected areas of Nepal illustrating land cover distribution in the Koshi Tappu Wildlife Reserve (Source: Sharma et al. 2015)

## 2.7 Water use

Availability of water and its wise use has been the major point of discussion in recent years in the Basin. In the Mid-Hills and Mountains, natural springs are the main source of drinking water whereas in the Terai, underground water extracted via tubewells and hand pumps provides water for drinking (CBS 2014a). The Government of Nepal's survey data reveals that around 84% of the Basin's population use improved water sources, included piped, tubewell and well water (CBS 2014b).

However, due to multiple sources of consumption and the possible impact of climate change, natural springs are drying up.

Irrigation and hydropower are considered priorities in the Government's development plan. However, the Basin has not been able to fully utilise the potential water available from the Koshi River. The only large irrigation facility that the country has harnessed is the Morang-Sunsari irrigation schemes that provide irrigation facility to nearly 66,000 ha of agriculture land downstream (Fish et al. 1986). Within the Indo Nepal agreement, India receives irrigation water from the Koshi River to support a command area of 969,119 ha through the Koshi Barrage (Figure 2-12).

Figure 2-12 Koshi Barrage established at Sunsar-Saptari district in Nepal connects to India through water flow

The potential for hydropower development in the Basin is therefore primarily untapped. A study commissioned by the Government of Nepal, estimated that 48 billion cubic metres of water is available annually in the Koshi Basin. This water can potentially generate about 10,086 MW of economically feasible power, while also irrigating approximately 500,000 ha of agricultural land (WECS 1999). Similarly, Jha (2010) observed the power potential of the Koshi Basin is 17,008.3 MW.

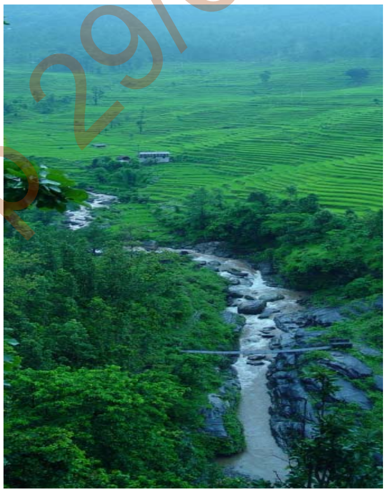
However, from knowledge gathered around the world, increases in irrigation abstraction and hydropower development lead to altered flow regimes in the rivers and streams that are targeted for their water resources. Flow regime changes occur as a result of damming and over-extraction (Magilligan & Nislow 2005) resulting in ecological degradation and loss of biological diversity to the point where the rivers can no longer sustain healthy ecosystems which provide important ecosystem services (Poff et al. 1997).

## 2.8 Policy, governance and institutions

To protect aquatic resources in the future as development increases, it is important to understand the volume of water that is available and when (seasonal differences) and how much is required to meet human and environmental demands. This is best done within an Integrated Water Resource Management (IWRM) framework, which is a process of coordinating development, management and conservation of water, land and related resources across sectors within a given river basin, in order to maximise the economic and social benefits derived from water resources in an equitable manner while preserving and, where necessary, restoring freshwater ecosystems ( 2000).

Nepal lacks a legislation to manage river basins in a holistic way as the existing sectoral policies and planning approaches do not support such a management approach. Nevertheless, Integrated River Basin Management (IRBM) is discussed in many policies and plans although these policies and plans require a thorough analysis on their effectiveness as an approach. There are however, a number of existing legislative frameworks which collectively support an Integrated River Basin Management approach. These include but are not limited to:

- Forest Policy 2015
- National Wetland Policy 2012
- Irrigation Policy 2013
- Water Resources Strategy 2002
- Hydropower Development Policy 2001
- Rural Water Supply and Sanitation National Policy 2004.



Under these sectoral policies and legislation, a number of institutions are contributing towards river management. For example, the Ministry of Forests and Soil Conservation, under its Soil Conservation and Watershed Management Department, has been supporting catchment conservation and management.

There are eight ministries directly working with water related issues in Nepal at the central level (Sudardiman et al. 2015). These include:

- Ministry of Irrigation (MoI)
- Ministry of Energy (MoE)
- Ministry of Urban Development (MoUD)
- Ministry of Agriculture Development (MoAD)
- Ministry of Forests and Soil Conservation (MoFSC)
- Ministry of Physical Infrastructure and Transport (MoPIT)
- Ministry of Federal Affair and Local Development (MoFALD)
- Ministry of Population and Environment (MoPE).

District Development Committees (DDCs) are local governments that function at the district level, with support from other department offices. These Committees are responsible for the coordination and implementation of all development activities at the district level. Sudardiman et al. (2015) stated that at the village level, the Village Development Committee (VDC), Non-Government Organizations and Water User Associations (WUAs) are the important formal water institutions. Community-based natural resource management institutions such as community forestry user groups (CFUGs), leasehold forestry user groups (LFUGs), water user groups, conservation area user groups, and Buffer Zone community forest user groups are the formal community level institutions actively engaged in different sectors within river basin management in the Koshi Basin. Although a comprehensive analysis of these local level institutions would be useful, a number of small scale studies suggest they are effective in conservation and maintaining livelihoods. For example, Sharma et al. (2010) concluded that these institutions are most effective for conservation, development and utilization of natural resources in the Hindu Kush Himalayan region.

With the recent political change and the new constitution in Nepal and with anticipated federal states, it is too early to comment on the possible roles and responsibilities of various institutions at federal, provincial and local levels in relation to water, and river basin management. However, the new constitution of Nepal does attempt to delineate roles, rights and responsibilities of various institution in all three levels.

## 2.9 Summary

Water from river systems is a key element for economic and social development, and for a country like Nepal with huge water resources, water forms a large part of the economy. Water resources play an important role in driving hydropower development and agriculture production as well as provision for drinking, domestic and industrial use. Water is also important to support many dimensions of the environment, such as ensuring contiguity of rivers, wetlands, ecosystems and to maintain ecological biodiversity. It is therefore very important to use these water resources sustainably to ensure environment integrity. It is also critical to understand and maintain environmental flow requirements – the flows required to support water quality, quantity and timing for individual river systems. If water is not used wisely, what is a boon for Nepal in particular, could result in a recourse.

The remainder of this report will focus on building the knowledge base in the Koshi Basin (transferrable to the greater Nepal region and surrounding countries) with respect to understanding the links between river regimes, aquatic ecosystems and livelihoods. Through this process, knowledge gaps are identified which once addressed, will improve our understanding of aquatic ecosystems and their environmental water requirements. The importance of aquatic ecosystems to the maintenance and improvement of livelihoods in the Basin is discussed in many chapters, highlighting the need to preserve ecosystem integrity in the face of future river flow changes to support hydropower and irrigated agricultural development.

### Acknowledgements

Unless otherwise indicated, the photographs and maps in this chapter have been provided by the authors.

Authors express gratitude to their organisations for their support of this initiative. ICIMOD acknowledges the support and cooperation of the Ministry of Forests and Soil Conservation, Government of Nepal, and Conservation and Sustainable Use of Wetlands of Nepal (CSUWN); and their core donors– the Governments of Afghanistan, Australia, Austria, Bangladesh, Bhutan, China, India, Myanmar, Nepal, Norway, Pakistan, Switzerland, and the United Kingdom.

The views and interpretations presented in this chapter are those of the authors and are not necessarily attributable to their organisations.

## Annex: Tables

Table 2-2 Number of households, population (2011) by gender and population density by region – mountains, hills and Terai (adapted from CBS 2012)

| District | Total | Male | Female | Total of country (%) | # of h'holds | Average h'hold size (#) | Area (km²) | Pop'n density / km²) |
|---|---|---|---|---|---|---|---|---|
| **Mountain** | | | | | | | | |
| Dolakha | 186,557 | 87,003 | 99,554 | 0.70% | 45,688 | 4.1 | 2,191 | 85 |
| Sankuwasawa | 158,742 | 75,225 | 83,517 | 0.60% | 34,624 | 4.6 | 3,480 | 46 |
| Sindhupalchowk | 287,798 | 138,351 | 149,447 | 1.09% | 66,688 | 4.3 | 2,542 | 113 |
| Solukhambhu | 105,886 | 51,200 | 54,686 | 0.40% | 23,785 | 4.5 | 3,312 | 32 |
| Taplejung | 127,461 | 60,552 | 66,909 | 0.48% | 26,509 | 4.8 | 3,646 | 35 |
| **Hills** | | | | | | | | |
| Bhaktapur | 304,651 | 154,884 | 149,767 | 1.15% | 68,636 | 4.4 | 119 | 2,560 |
| Bhojpur | 182,459 | 86,053 | 96,406 | 0.69% | 39,419 | 4.6 | 1,507 | 121 |
| Dhankuta | 163,412 | 76,515 | 86,897 | 0.62% | 37,637 | 4.3 | 891 | 183 |
| Kathmandu | 1,744,240 | 913,001 | 831,239 | 6.58% | 436,344 | 4.0 | 395 | 4,416 |
| Kaverpalanchowk | 381,937 | 182,936 | 199,001 | 1.44% | 80,720 | 4.7 | 1,396 | 274 |
| Khotang | 206,312 | 97,092 | 109,220 | 0.78% | 42,664 | 4.8 | 1,591 | 130 |
| Lalitpur | 468,132 | 238,082 | 230,050 | 1.77% | 109,797 | 4.3 | 385 | 1,216 |
| Okhaldhunga | 147,984 | 68,687 | 79,297 | 0.56% | 32,502 | 4.6 | 1,074 | 138 |
| Panchthar | 191,817 | 90,186 | 101,631 | 0.72% | 41,196 | 4.7 | 1,241 | 155 |
| Ramechhap | 202,646 | 93,386 | 109,260 | 0.76% | 43,910 | 4.6 | 1,546 | 131 |
| Terhathum | 101,577 | 47,151 | 54,426 | 0.38% | 22,094 | 4.6 | 679 | 150 |
| **Terai** | | | | | | | | |
| Bara | 687,708 | 351,244 | 336,464 | 2.60% | 108,635 | 6.3 | 1,190 | 578 |
| Dhanusa | 754,777 | 378,538 | 376,239 | 2.85% | 138,249 | 5.5 | 1,180 | 640 |
| Mahottrai | 627,580 | 311,016 | 316,564 | 2.37% | 111,316 | 5.6 | 1,002 | 626 |
| Makwanpur | 420,477 | 206,684 | 213,793 | 1.59% | 86,127 | 4.9 | 2,426 | 173 |
| Rautahat | 686,722 | 351,079 | 335,643 | 2.59% | 106,668 | 6.4 | 1,126 | 610 |
| Saptari | 639,284 | 313,846 | 325,438 | 2.41% | 121,098 | 5.3 | 1,363 | 469 |
| Sarlahi | 769,729 | 389,756 | 379,973 | 2.91% | 132,844 | 5.8 | 1,118 | 469 |
| Sindhuli | 296,192 | 142,123 | 154,069 | 1.12% | 57,581 | 5.1 | 2,491 | 119 |
| Siraha | 637,328 | 310,101 | 327,227 | 2.41% | 117,962 | 5.4 | 1,118 | 536 |
| Sunsari | 763,487 | 371,229 | 392,258 | 2.88% | 162,407 | 4.7 | 1,257 | 607 |
| Udayapur | 317,532 | 149,712 | 167,820 | 1.20% | 66,557 | 4.8 | 2,063 | 154 |
| **Total** | **11,562,427** | **5,735,632** | **5,826,795** | **43.6%** | **2,361,657** | **4.9** | **42,329** | |

Table 2-3 Protected Areas (PAs) in the Koshi Basin, Nepal (Source: modified after Chaudhary 1998; Bajracharya et al. 2015; Chaudhary et al. 2015b)

| Protected area | Core+buffer zone area ($km^2$)/ altitude (m) | Year of notification (core zone) | IUCN mgmt category | Notable biodiversity, forest type /vegetation | Notable biodiversity, fauna | Major problems |
|---|---|---|---|---|---|---|
| **National Parks** | | | | | | |
| Sagarmatha (World Heritage Site 1979) | 1,148+275<br>2945-8848m | 1976<br>1979 | II<br>X | Blue pine, fir, juniper scrub, alpine meadows | Red panda, snow leopard, goral serrow, Himalayan musk deer, Himalayan Black bear, Indian muntjac, pheasant, robin accentor | Environmental pressure from tourism, waste disposal, tree felling, heavy grazing by yak and sheep |
| Makalu Barun | 1,500+830<br>435-8463m | 1991 | I, II, VI | Sal, pine, Schima-Castanopsis, Macaranga, Castanopsis, oak-laurel, Berberis, Rhododendron, oak, birch, fir, junipers | Snow leopard, red panda, musk deer, weasel, Himalayan marten, marmot, woolly hare, thrush, tesia, monal, Darjeeling pied woodpecker | Excessive human encroachment, slash & burn agriculture, poaching for bears, collection of medicinal plants, illegal transboundary timber trade |
| **Conservation Areas** | | | | | | |
| Kangchenjunga | 2,035<br>1200-8598 | 1997 | VI | Larch, juniper, oak, *Magnolia*, fir & hemlock | Snow leopard, red panda, musk deer, blue sheep | Grazing, poaching for musk deer, hunting, collection of medicinal plants, illegal transboundary trade |
| Gaurishankar | 2,179<br>1000-7200m | 2010 | VI | Riverine, *Schima-Castanopsis*, pine, alder, oak, temperate mixed-broadleaved, *Rhododendron*, birch | Snow leopard, musk deer, blue sheep, red panda, Himalayan tahr, Ibisbill | Grazing, poaching for musk deer, hunting, collection of medicinal plants |
| **Wildlife Reserves** | | | | | | |
| Koshi Tappu (Ramsar site 1987) | 175+173<br>80-100m | 1976 | IV | Khair-sissoo, tropical mixed deciduous riverine, grassland, wetland | Wild water buffalo, leopard, fishing cat, Gangetic dolphin, otter, deer, wild boar, swamp francolin, gharial, python | Grazing, genetic erosion of wild buffalo population, over-fishing, high tension electrical transmission, flooding situation |

# 3 Climate and hydrology

*Authors: Michaela M Dolk[1], Dave J Penton[1], Luis E Neumann[2], Hongxing Zheng[1], Nicola J Grigg[1], Danial S Stratford[1]*

The Koshi Basin is the largest catchment in Nepal (WECS 2005), and contains significant inflows from the Tibetan Plateau in China through the Arun. It continues its path through India where it joins with the Bagmati River before draining into the River Ganga (Figure 3-1).

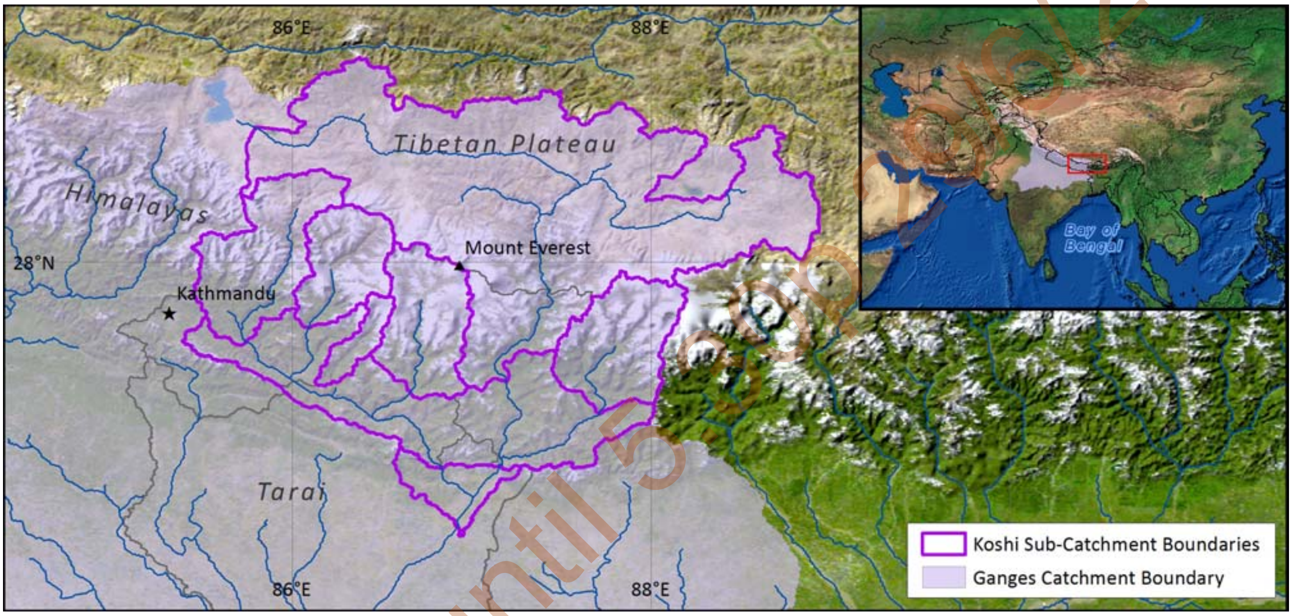



Figure 3-1 The Koshi Basin is a headwater of the Ganges system. It flows from the Himalayas and Tibetan Plateau downstream, where it eventually enters the Bay of Bengal (to the south)

## 3.1 Climate

Rainfall varies substantially across Nepal and the surrounding region (Figure 3-2). The central Himalayan region has a two-step topography, with a parallel arrangement of mountain ranges: the Siwalik Range (Sub-Himalayas) in the south, the Mahabharat Range (Lesser Himalayas), and the Greater Himalayas in the north. This topography significantly influences the precipitation pattern, as described by Shrestha et al. (2012). In the Koshi region, the monsoonal weather systems predominantly travel from the Bay of Bengal northwards delivering precipitation on the southern slopes of the Mahabharat Range and the Himalayas (Figure 3-1). Diodato (2010) reports annual rainfall at stations in Nepal of the order of 1200 mm/year (5th percentile), 2100 mm/year (mean) and 3200 mm/year (95th percentile) at rainfall stations below 1000mASL, down to annual rainfall of 200 mm/year (5th percentile), 1200 mm/year (mean) and 1900 mm/year (95th percentile) above 4000mASL.

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[1] CSIRO Land and Water, Canberra, Australia

[2] CSIRO Land and Water, Melbourne, Australia

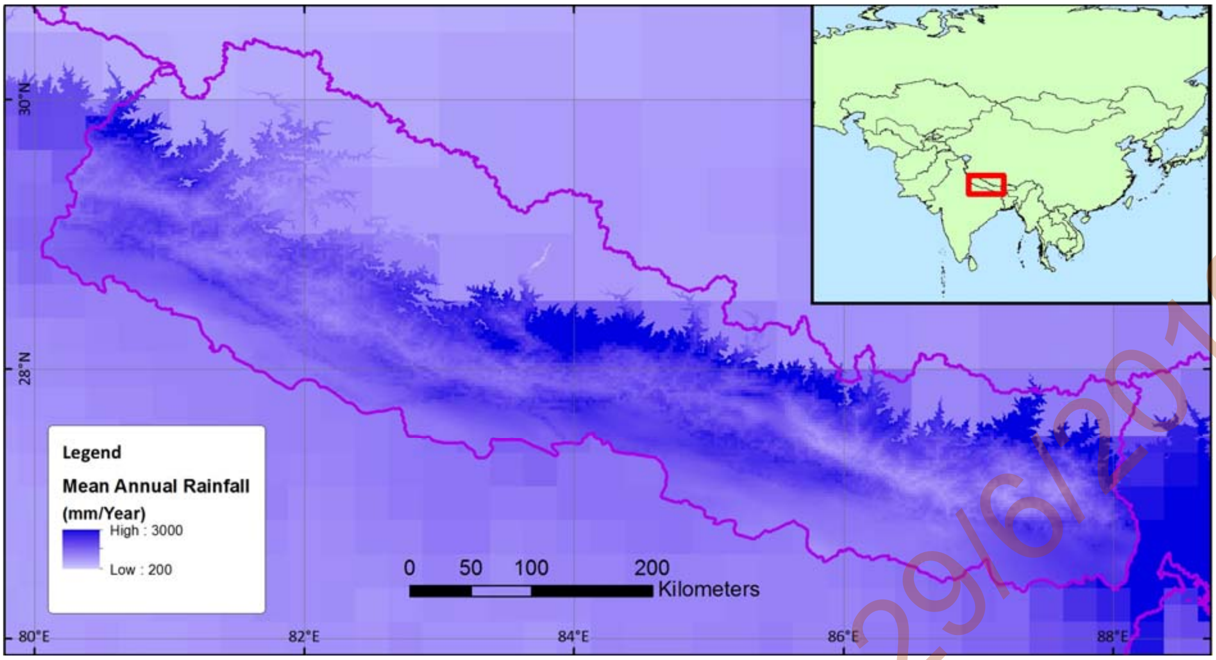


Figure 3-2 Composite of best available information on precipitation in the Nepal/Koshi area. Interpolated station data are used for the area under 3000mASL (Pai et al. 2014 for India and Neumann et al. 2016 for Nepal). WATCH reanalysis (Weedon et al. 2014) is used where a physical model of atmospherics is required to limit the extrapolation of rainfall with elevation

Rainfall in Nepal occurs mostly (80%) during the monsoon period from June to September (Nayava 1974, Aryal 2011). For the rainiest month (July), Diodato et al (2010) found that precipitation varies from ~100 mm over the Tibetan Plateau to ~500 mm in the southern part of Nepal, up to ~900 mm towards the pre-Himalayan range. During this period rainfall events with high intensity occur, sometimes causing landslides and floods. The soils often become completely saturated leading to a high proportion of rainfall to become runoff.

Several studies have investigated the relationship between elevation and precipitation in the Himalayas (e.g. Dhar & Rakhecha 1981, Bookhagen & Burbank 2006, Shrestha et al. 2012). In general, precipitation increases with elevation, as moist air lifted along the slope cools and expands, decreasing its water-holding capacity and causing precipitation. However, as the air continues to rise, its water content drops due the higher precipitation, and above a certain elevation, precipitation decreases due to the reduced water content. Distinct rain shadows occur behind the Mahabharat Range, and also on the Tibetan Plateau.

Maximum temperatures in Kathmandu during summer, April to September, average 28-29°C (MFD 2016). During January, the coldest month, the average maximum temperature is 19°C. The minimum temperatures fluctuate from 2.4°C in January through to 20°C in July. Kathmandu's climate is indicative of the climate at 1400m (see Figure 3-3). According to Kattel et al (2013), the temperature linearly decreases with elevation at observation sites in Nepal according to a lapse rate. The exact lapse rate varies seasonally, and for minimum and maximum temperatures. Kattel et al (2013) reported the lapse rates as being between 4.1 and 6.8 °C per kilometre.

The temperatures in the region are rising. Shrestha et al (1999) undertook an assessment of the rising temperatures. They divided Nepal into 5 physiographic regions: Terai, Siwalk, Middle Mountains, Himalaya and Trans-Himalaya (from south to north). For each region he observed an upward trend from 1971-94 of between 0.009 and 0.075 °C per year.

Figure 3-3 shows long term average temperatures spatially. The north-south gradient is mainly a factor of topography.

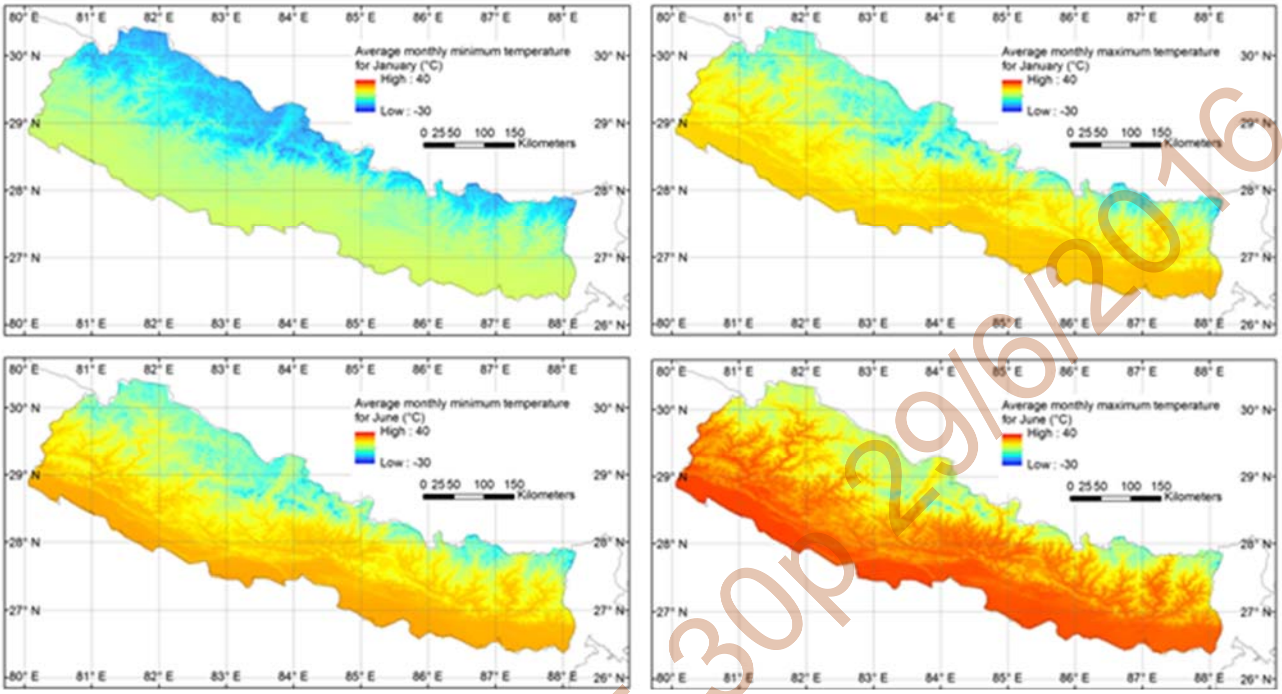


Figure 3-3 Monthly minimum temperatures for January (winter, top left) and June (summer, top right) and monthly maximum temperatures for January (winter, bottom left) and June (summer, bottom right) derived from station data using ANUSPLIN (Hutchinson 1989)

Evaporation occurs mainly during the pre-monsoon, or early monsoon period (March – August) – the northern hemisphere summer – when temperatures are warmer. As shown in Figure 3-4, actual evapotranspiration estimates using MODIS suggest evaporation rates are as low as 400 mm/year in the flat Terai areas. Actual evapotranspiration increases towards the north, reaching as much as 1000 mm/year in some areas. By comparing Figure 3-2 and Figure 3-4, it is also clear that there is a relationship between high evaporation and high rainfall.

Koshi River at Koshi Tappu Wildlife Reserve (photo credit: Dave Penton)

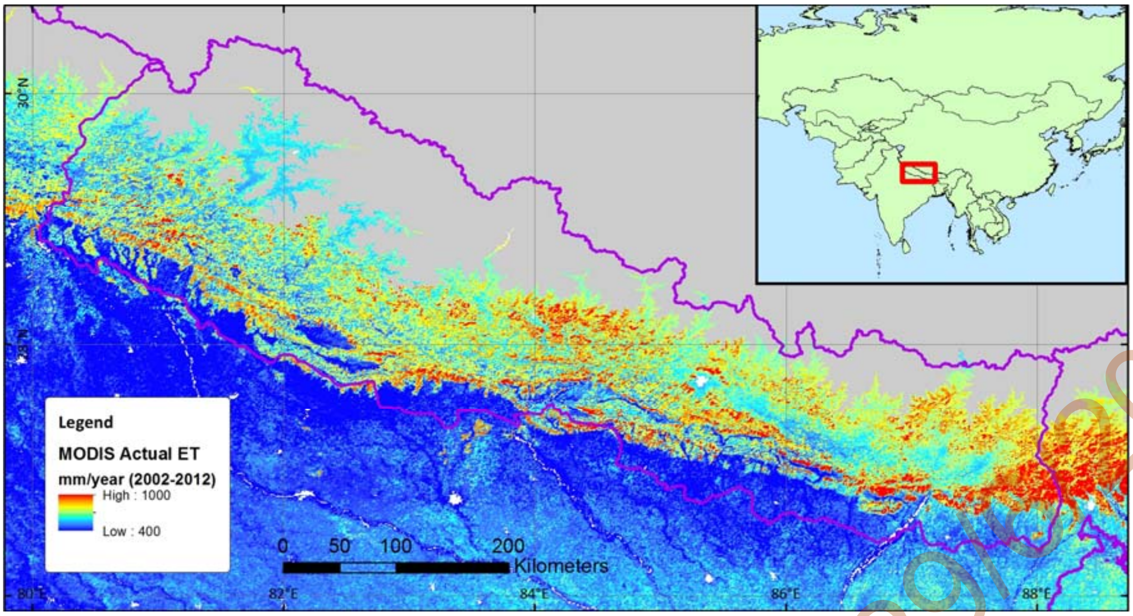


Figure 3-4 Estimated annual actual evapotranspiration 2000–2012 from MODIS satellite observations (Mu et al. 2011)

## 3.2 Hydrology

The rivers of the Koshi Basin have a consistent pattern of high flows during the monsoon in the northern hemisphere summer, followed by a drier period during the northern hemisphere winter. This pattern is shown in Figure 3-5 for the Koshi River at Chatara and Tamor River at Mahjitar, with streamflow rising in the period April-May. Locations of Chatara and Mahjitar gauges are indicated on Figure 3-7.

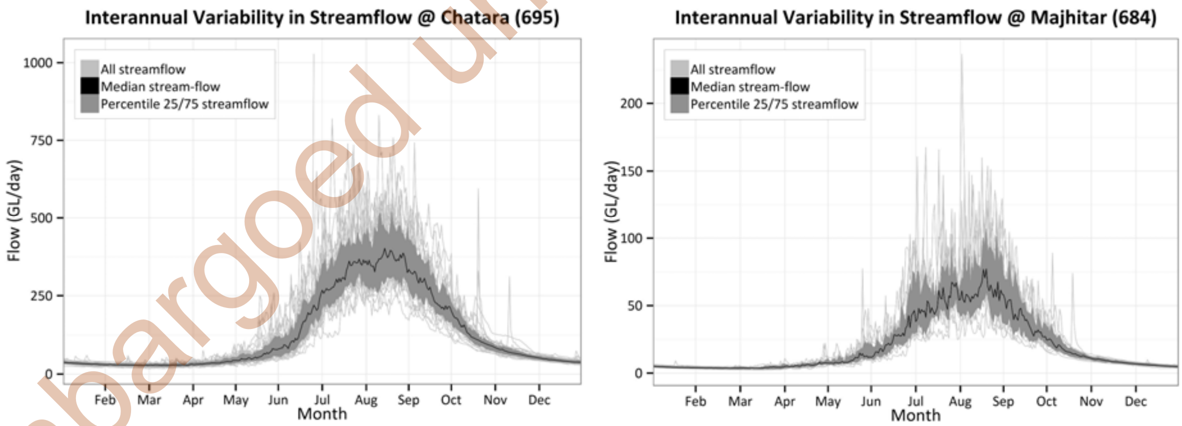


Figure 3-5 Daily streamflow measurements at Chatara on the Koshi River (left, period 1977–2010) and Majhitar on the Tamor River (right, period 1996–2010). The flow regimes are characterised by consistent low flows during the dry season, and large flows of variable amplitude during the monsoon

Generation of runoff across the different catchments and areas of the Koshi Basin is highly variable (Figure 3-6), with the majority of the runoff generation occurring in the southern slopes of the Himalayas between 2000 mASL and 3000 mASL, and lower generation in the upper catchments of the Himalayas and the Tibetan Plateau (Arun) and in the Terai areas. This pattern is generally consistent with the rainfall distribution (Figure 3-2).

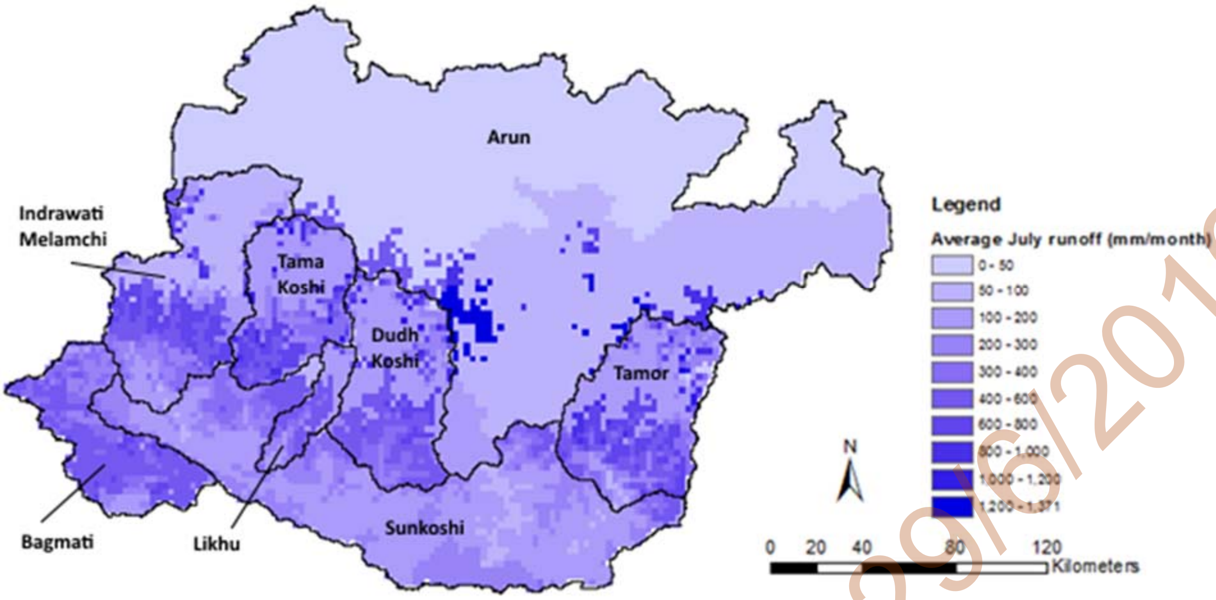


Figure 3-6 Runoff is generated predominantly at elevations between 2000mASL and 4000mASL. The Sunkoshi sits in a rain shadow, so runoff generated below 2000mASL is less. At higher elevations, snow and glacial processes become more important and generate a higher amount of runoff

The upper reaches of the Arun sit in the rain shadow of the Himalayas and therefore receive relatively lower precipitation (Figure 3-2) and thus generate less runoff per unit area. Despite this fact, the Arun's large catchment area means it still contributes about 30% of Koshi's streamflow at Chatara (Figure 3-7). The south-western catchments of the DudhKoshi, TamaKoshi and Indrawati also make significant contributions to the total streamflow at Chatara.

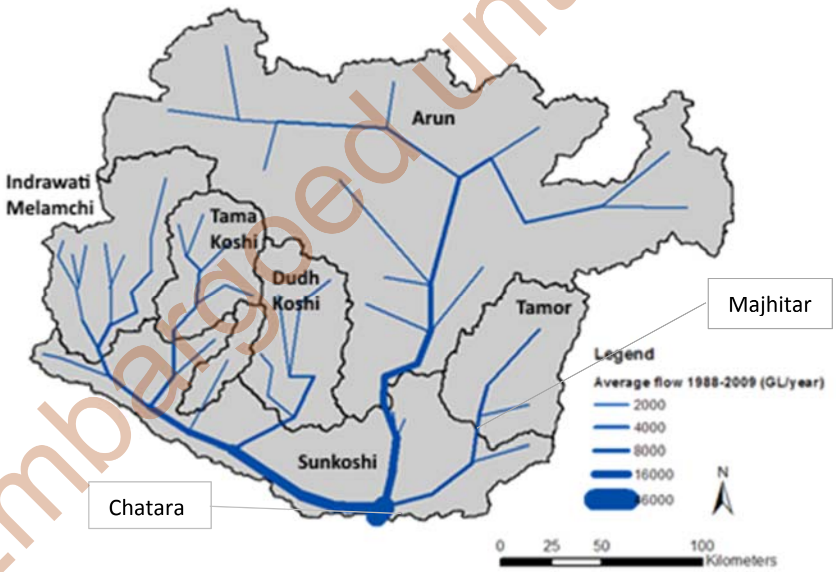


Figure 3-7 The accumulated flow of the tributaries of the Koshi show a significant portion of water coming from the Arun catchments

There are different contributions of rainfall, snowmelt and ice melt to the total runoff (Figure 3-8). Snow that has accumulated through the winter season starts melting from April/May as the temperatures increase, leading to an increase in contribution to streamflow, particularly at higher elevations where the proportion of precipitation that falls as snow is greater. This generation of meltwater is an important process in the hydrological cycle of the Koshi Basin.

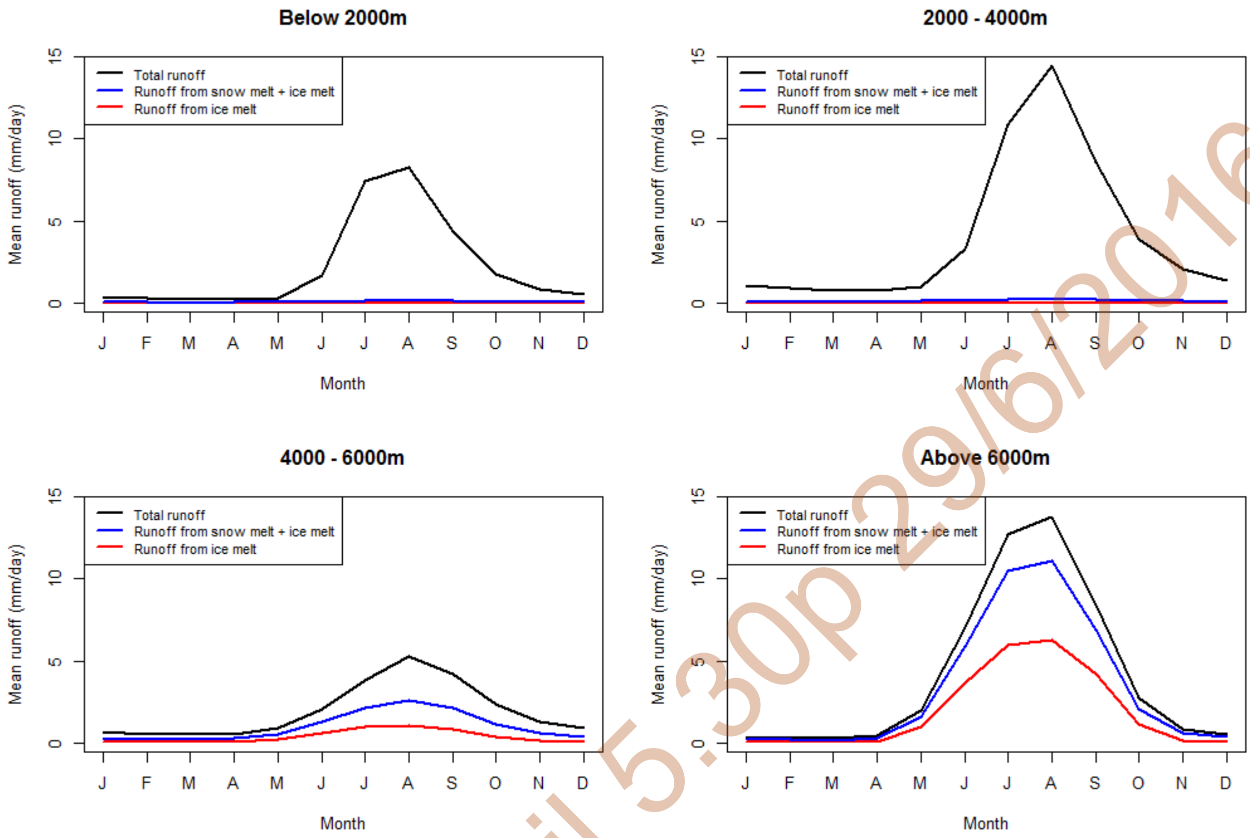


Figure 3-8 Results from the GR4JSG precipitation-runoff model indicate that snow melt processes form a significant proportion of the water balance from above 4000mASL in the east of Nepal (note the 4000mASL to 6000mASL is skewed by the Tibetan plateau which sits in the rain shadow of the Himalayas)

Using the GR4JSG hydrological model (Nepal et al. 2015), we estimate snowmelt contribution to annual streamflow in the Koshi Basin to be approximately 20%, with most of this occurring during the monsoon months (Figure 3-8). Published estimates of snowmelt contribution to annual discharge in the different subcatchments of the Koshi Basin vary greatly (Table 3-1).

Table 3-1 Published estimates of snowmelt contribution to annual discharge in Koshi Basin and its sub-basins

| Sub-basin | Snowmelt contribution estimates | Reference |
|---|---|---|
| Tamor | 7%<br>30% | Bookhagen and Burbank 2010<br>Panday et al. 2014 |
| Arun | 25% | Bookhagen and Burbank 2010 |
| TamaKoshi | 18% | Khadka et al. 2014 |
| DudhKoshi | 29-34% (snow and ice melt) | Nepal et al. 2014; Savéan et al. 2015; Nepal 2016 |
| Koshi Basin | 5% snowmelt; 2% ice melt | Andermann et al. 2012 |

However, there is considerable uncertainty about the contribution of snowmelt and ice melt to streamflow in the Koshi Basin, in part due to internal inconsistencies in models used for hydrological component assessment (Pellicciotti et al. 2012). For example, precipitation underestimation may result in overestimation of melt contributions to streamflow (Pellicciotti et al. 2012).

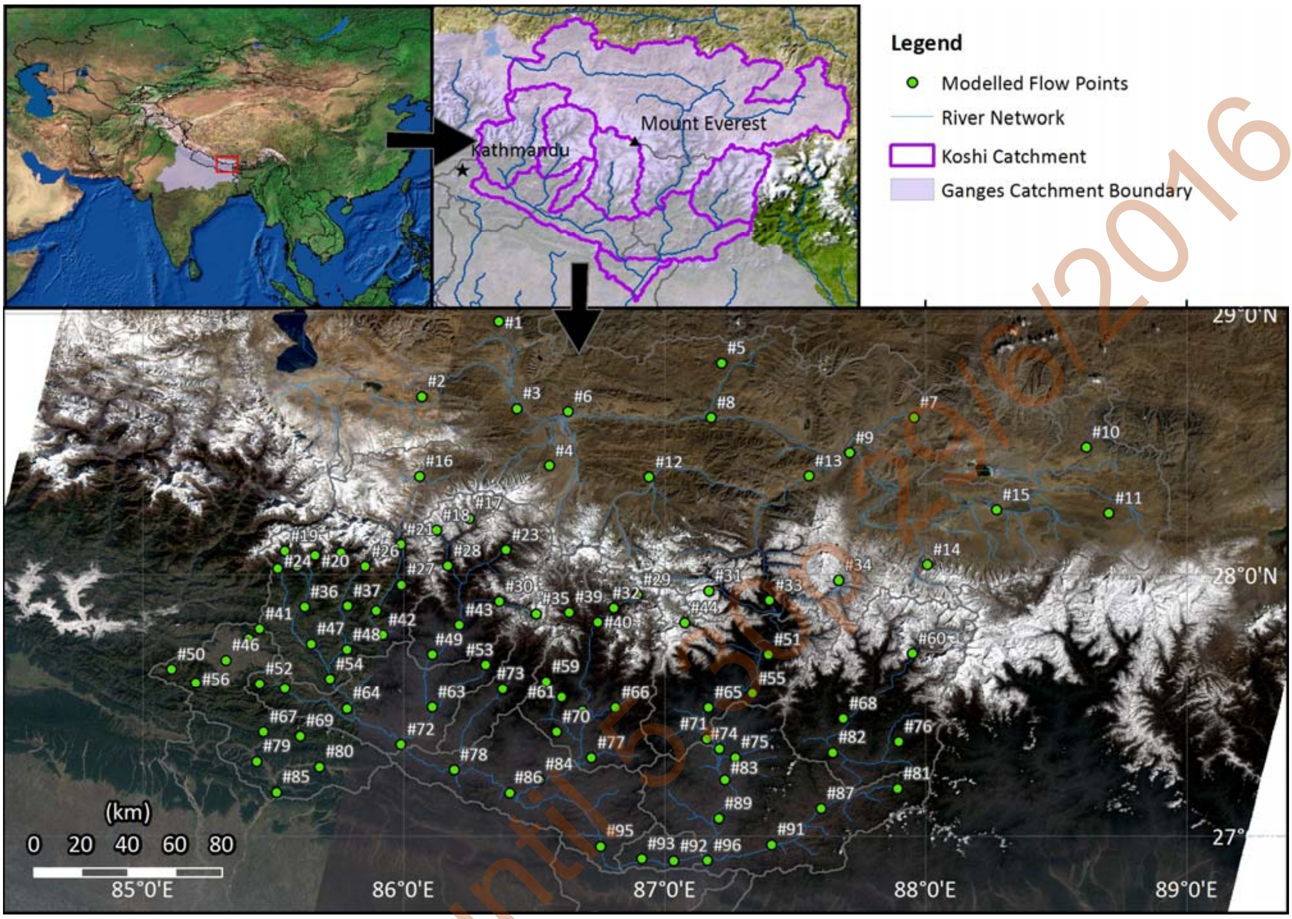


Figure 3-9 The location of modelled flow nodes in the GR4JSR precipitation-runoff model

The hydrological model uses a node-link network structure to represent the flow patterns in the Basin. The location of the nodes is shown in Figure 3-9.

## 3.3 Hydrological metric analysis

Flow forms a template upon which species and ecosystems depend, and so changes in flow can result in changes in species populations or ecosystem health. Bunn and Arthington (2002) identify four principles linking flow regime to ecosystem outcomes:

Principle 1: the flow regime determines the physical habitat in stream (e.g. channel form, habitat complexity), which is a key determinant of biotic composition and diversity.

Principle 2: Aquatic species have evolved life history strategies (e.g. spawning and recruitment) primarily in direct response to the natural flow regimes.

Principle 3: Flow regime shapes both lateral and longitudinal connectivity (and so dispersal of migratory aquatic organisms) and access to otherwise disconnected floodplain habitats.

Principles 4: Invasions by introduced species are more likely to success at expense of local biota if introduced species are adapted to the modified flow regime.

Examples of significant flow variables include flow variability, diurnal flow patterns, changes in flow speed (lotic to lentic habitat), seasonality, timing of rising flows, short-term fluctuations in flows, modified temperature regimes below dams,  frequency of floodplain or wetland inundation, presence of in-stream barriers and water abstraction.

Ecologically relevant characteristics of the flow regime are quantified and communicated through the calculation of metrics. A flow metric is simply a summary measure of a characteristic of the flow regime of interest (i.e. because of its importance for maintaining existing species and ecological function). Through analysing the statistical properties of streamflow, combined with knowledge of species and ecosystems, it is possible to investigate what particular properties of streamflow are important to sustain regional ecosystem health (including river geomorphology, groundwater fluxes and the health of aquatic, riverine, floodplain and associated biota).

Globally, statistical metrics have become important in characterising the needs of different species and ecosystems. Several metrics and classification methods have been developed to assess ecologically-relevant characteristics of flow regimes in Australia (i.e. 120 metrics in Kennard et al. 2010), and the choice of metric and classification method depends on the ecology of the system under assessment. Different changes to the flow regime will have different outcomes for ecology in different locations. The aim of such assessments is to provide a strong evidence base for assessing environmental flow requirements and provide information for frameworks for evaluating future change scenarios (i.e. the Ecological Limits of Hydrologic Alternation (ELOHA) framework, Poff et al. 2010).

Flow metrics can be applied to hydrological modelling scenarios to identify flow components that come under higher levels of change under different scenarios for change. Table 3-2 and Table 3-3 show statistical metrics of streamflow for two points in the Koshi catchment (at Majhitar and Chatara). These are calculated from a surrogate hydrological model of the Koshi built with GR4JSG (Nepal et al. 2015). The flows at Majhitar are significantly smaller because they are generated from a smaller catchment area.

Table 3-2 Streamflow metrics at two sites in the Koshi Basin (using modelled data)

| Metric | Tamor at Majhitar (684) | Koshi at Chatara (695) |
|---|---|---|
| Mean annual daily flow | 16,620 ML | 115,810 ML |
| Median daily flow | 6,950 ML | 55,200 ML |
| High flow discharge (10% exceedance) | 44,770 ML | 302,880 ML |
| Mean occurrence of maximum flow day | 224 (11 August) | 224 (11 August) |
| Low flow discharge (90% exceedance) | 2,830 ML | 23,940 ML |
| Mean annual minimum flow | 2,580 ML | 22,000 ML |
| Mean occurrence of minimum flow day | 85 (25 March) | 103 (12 April) |

Table 3-3 Average daily flows and variability by month at two sites in the Koshi Basin (using modelled data)

| Daily flows | Tamor at Majhitar (684) | | Koshi at Chatara (695) | |
|---|---|---|---|---|
| | Mean (ML/day) | Variability* | Mean (ML/day) | Variability* |
| January | 4,030 | 0.14 | 34,950 | 0.14 |
| February | 3,340 | 0.23 | 28,830 | 0.14 |
| March | 2,940 | 0.25 | 24,860 | 0.14 |
| April | 3,380 | 0.37 | 25,300 | 0.26 |
| May | 5,200 | 0.41 | 42,150 | 0.38 |
| June | 16,200 | 0.71 | 106,860 | 0.62 |
| July | 41,040 | 0.41 | 258,210 | 0.38 |
| August | 53,470 | 0.34 | 359,540 | 0.28 |
| September | 36,850 | 0.34 | 256,930 | 0.28 |
| October | 17,560 | 0.4 | 129,640 | 0.33 |
| November | 8,670 | 0.39 | 68,760 | 0.27 |
| December | 5,480 | 0.16 | 45,750 | 0.16 |

*Characterised by the coefficient of variation, which is the ratio of the standard deviation to the mean

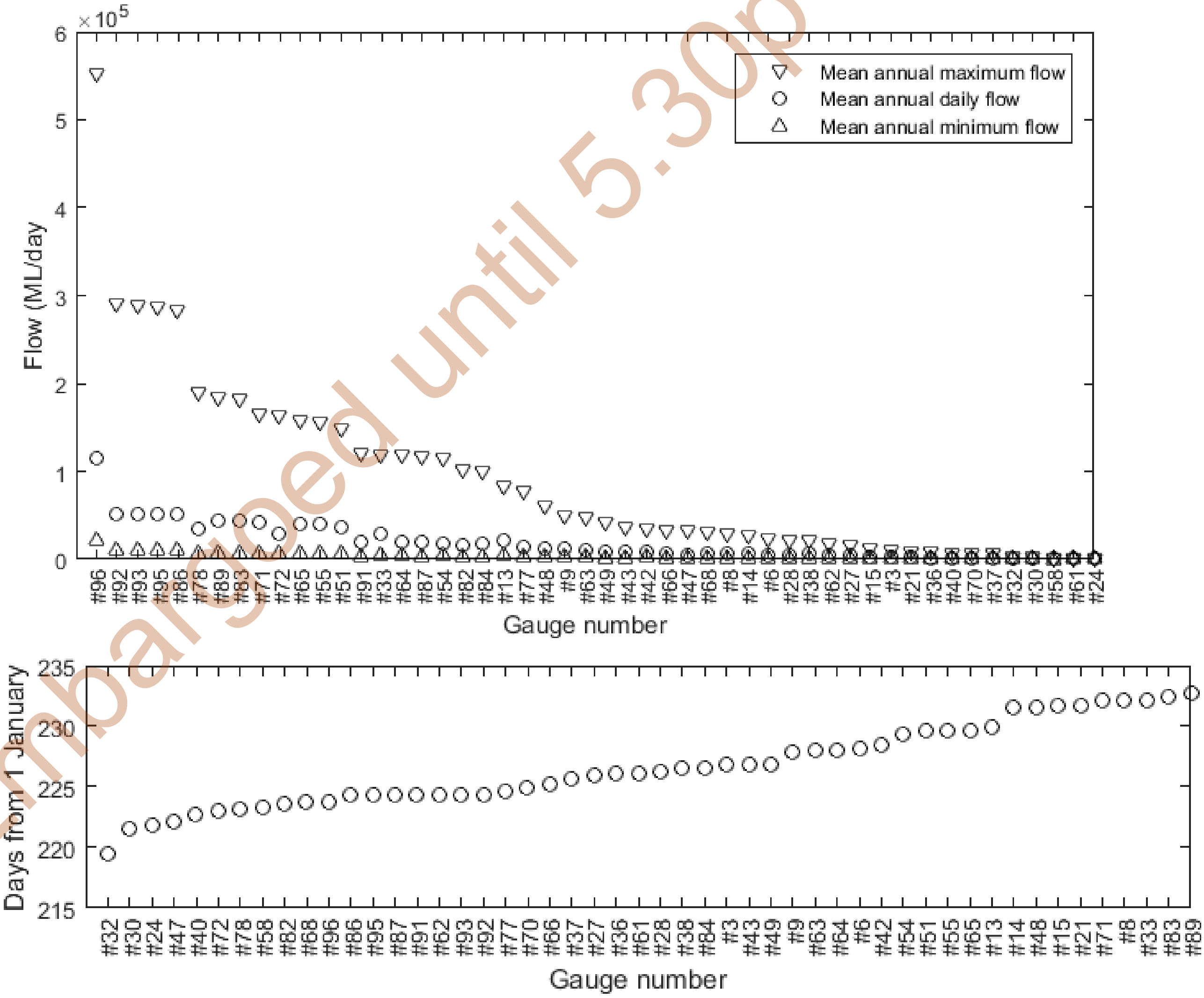


Figure 3-10 Annual flow metrics calculated for each node in Figure 3-9, sorted by mean annual maximum flow (top) and mean timing of the peak flow at each node as number of days from 1 January (bottom)

Outputs from the hydrological model across various locations (Figure 3-9) were used to select a small subset of ecologically relevant metrics calculated from the upper Koshi (Figure 3-10). The graph (Figure 3-10) shows flow metrics calculated for each gauge in the model ranked by mean annual maximum flow, and Figure 3-10 (bottom) shows the mean timing of the peak flow at each gauge flow (as number of days from the start of the year). In future, the model can be used generate streamflow time series for alternative development scenarios. Changes to the streamflow metrics for such scenarios would provide insight into the kinds of changes to expect in stream, and these in turn can be reviewed in light of flow-ecology relationships in order to anticipate downstream impacts of upstream changes. As more knowledge is developed about the flow needs of ecosystems in Nepal, scientists and practitioners can incorporate more sophisticated hydrological metrics in monitoring regimes.

## 3.4 Summary

The rivers of the Koshi Basin are strongly influenced by rainfall during monsoon and prolonged dry seasons in between. Diversions from the Koshi Basin are limited, and the catchment is largely in a natural state. It is likely that the patterns of flows may change. For example, under the influence of climate change, hydropower development, population growth, industrial developments or landuse change. Hydrological metrics are an import tool for evaluating changes to the patters of flow that might take place under future scenarios. Changes to hydrological metrics allow planners to understand what changes are likely to be significant, and in what locations.

### Acknowledgements

We would like to thank our chapter reviewers – Mr Geoff Podger and Dr Tanya Doody (CSIRO, Australia) – for their constructive comments which have served to improve the readability and structure of this chapter. We take the opportunity to thank ICIMOD, and in particular Dr Santosh Nepal and Dr Shahriar Wahid, for their generosity in working with us on the Koshi Basin model (results described in this chapter).

Koshi River (photo courtesy of Himalayan Nature)

# 4 Understanding the environmental water requirements of rivers and wetlands

*Author: Ugan Manandhar*[1]

## 4.1 Introduction

As the need for water increases with population growth, more and more pressure is being exerted on the world's aquatic resources. This is also the case in Nepal, where flow regimes of rivers, streams and wetlands are under threat as a result of natural events or human development, abstraction and regulation. With appropriate management frameworks in place there is a risk of ecological degradation and biodiversity losses (Poff et al. 1997). It is therefore important to understand the ecological (environmental) water requirements of these ecosystems. To do this requires a solid understanding of the natural flow regime for rivers, streams and wetlands. It is recognised widely that variable water regimes are required to maintain a dynamic river system where natural biodiversity and ecological processes are preserved (Poff et al. 1997, Postel and Richter 2003, Lytle and Poff 2004). It is important to determine the flow characteristics, such as flow timing, duration, magnitude, frequency and water quality that are important to maintain ecological integrity. Determination of these criteria is undertaken through a process of environmental flow assessment. Through such assessments, environmental flows can be developed.

According to the Brisbane Declaration 2007 (Brisbane Declaration 2007),
*"environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that are dependent upon these ecosystems".*

Understanding the environmental water requirements of rivers and wetlands then provides a mechanism to manipulate flow regimes which have been altered (from damming for example), to meet ecosystem or species ecological needs that would not otherwise be met if abstraction occurred without some level of water management.

## 4.2 Integrated River Basin Management and environmental water requirements

The Government of Nepal's Water and Energy Commission Secretariat (WECS), endorsed a National Water Plan in 2005 (WECS 2005). The National Water Plan identified river basin planning as a key strategy in 2011. The Koshi Basin was designated as the first river basin to develop a River Basin Management Strategic Plan. The strategic plan is based on Integrated River Basin Management (IRBM) principles which focus on the 3E pillars - Environment sustainability, Economic efficiency and social Equity (GWP & INBO 2009) to promote

[1] World Wildlife Fund, Nepal Office, Kathmandu

sustainable water resource use to meet the needs of the current generation, without compromising the needs of future generations, all the while maintaining freshwater ecosystem integrity.

Whilst the Koshi River Basin Management Strategic Plan conferred to the three IRBM pillars, within the environment sustainability pillar, the strategy has not challenged the 'rule of thumb' whereby at least 10% of mean monthly river flow in the Koshi's river systems should be maintained if water sources are dammed or diverted for different uses (MoWR 2001). This flow is derived using a traditional hydrological method which calculates a fixed percentage of the mean monthly flow or minimum mean monthly flow in the dewatered section of the river. This method does not account for the natural variability of flow in the river (Alfredsen 2015).

The research field of environmental flows has been an emerging science over the past four decades worldwide (Tharme 2003), but with the slow water resource development pace in Nepal, little progress has been made in this field. To date, Environment Impact Assessments (EIAs) are the basis to judge the environmental performance of projects which consume water resources. More recently though, with the high probability of many hydropower and irrigation canal projects forecast (Renewable Energy World 2016), the need to understand aquatic environments and environmental flows is emerging in Nepal. Environmentalists now want to conduct a thorough broad scale scientific assessment across Nepal to understand the detailed characteristics of individual river systems prior to establishing water harvesting infrastructure such as hydropower and irrigation offtakes. This provides a good opportunity to establish a baseline understanding of ecological water requirements of aquatic ecosystems under current conditions (which may be natural or altered flow regimes), so as to ensure the integrity of freshwater ecosystems when water courses are affected by human development and abstraction. In other words, environmentalists in Nepal want to challenge the 10% 'rule of thumb' and understand the IWRM Basin approach to establishing environmental flow parameters, identifying key river channels and tributaries that require future water resource management.

## 4.3 Drivers of flow change

Alterations to river flow regimes occur as a result of natural circumstances as well as anthropogenic influences. In a natural environment, seasonal regime change occurs as wet seasons contribute to the maximum flow and dry seasons contribute to the minimum flow. In all of Nepal's river systems, flow discharge in the Koshi Basin is maximum in the monsoon (June- September) and minimum in winter (December- April). Thus, the ecosystem within each river system are adapted accordingly to these natural seasonal flow regimes. The presence of a species in specific habitats indicates an adaptation to natural flows regimes. Without natural flow regimes, it is unlikely the species will continue as their habitat has been modified.

Natural hazards also have an ability to change river flow regimes. These are often temporary when hazards like landslides flow across a river or may be permanent when large high velocity floods change the course of river channels. The Koshi River has shifted by 120 km westward (WWF Nepal & DHM 2009, Wells & Dorr 1987) in the past two and a half centuries, attributed to both heavy siltation and high flow velocities carried from upstream during monsoon rainfall.

Anthropogenic change from the construction of infrastructure like hydropower plants, dams and irrigation canals are also key drivers of flow regime change through-out Nepal's river systems. Construction of rural roads and dumping of sediment into river systems is further degrading freshwater ecosystems in parts of Nepal and within the Koshi Basin.

Based on some analysis undertaken (WWF Nepal & DHM 2009), major changes to precipitation under future climate change are likely for the monsoon periods in 2040s and 2050s and the post-monsoon periods for 2060s (Figure 4-1a and Figure 4-1b). There is also substantial large inter decadal variability for all seasons, except the monsoon season. For example, post-monsoon projected precipitation change jumps from 0.3 mm/day (10%) in 2040s to 1.2 mm/day (40%) in the 2060s. Therefore, considerable inter-decadal variation could be expected with seasonal change.

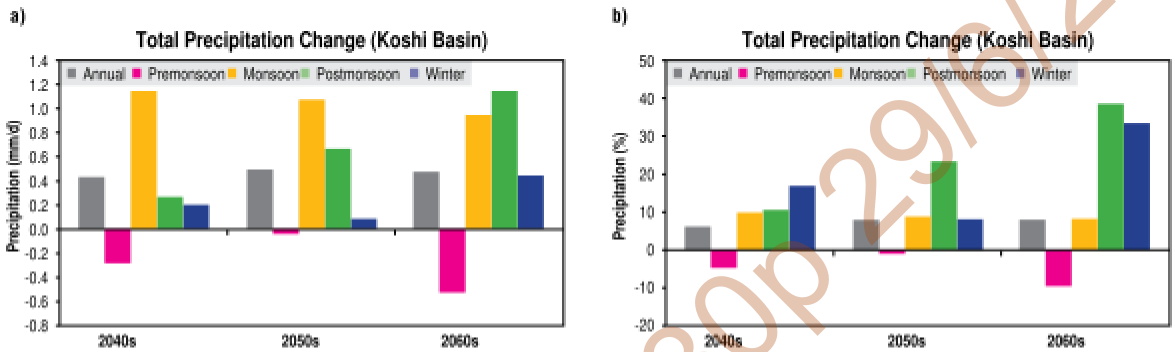


Figure 4-1 Seasonal change in precipitation under future climate change (2040s–2060s) in (a) mm/day and (b) % (Source: WWF Nepal & DHM 2009)

## 4.4 Impacts of river flow change

Changes to natural flow regimes could have both positive and negative effects.

Positive impacts might include a greater capacity to increase and meet the development needs of hydropower generation, irrigation, and access to water for drinking and for domestic needs.

However, the diversion of river systems and flow regime changes can have negative impacts on river ecology and ecosystems, resulting in the deterioration of river health, degradation of aquatic and spawning habitats, and extinction of various flora and faunal that depend on specific flow regimes as well as alteration of migratory routes. Other likely negative impacts include negative change to the economies of small scale fishermen, tourism activities like rafting as well as impacts to religious and cultural events which are vital to Nepalese society. Thus, when identifying environmental flow requirements, it is important to understand all of these dimensions in order to incur minimum environmental damage to the river ecology and various elements dependent on these river systems, while providing opportunities for economic growth.

## 4.5 Environmental flow assessment

The basic concept behind environmental flows is 'Rivers for Life and Life for Rivers' (WWF India 2016). Environmental flow assessments provide an understanding of the REQUIRED flows in river systems (i.e. naturally variable flow regime to sustain freshwater ecosystems) and not just about MINIMUM flow. To help build our knowledgebase in Nepal, it is therefore important to develop an understanding of wet season and dry season flows, natural high flows, extreme low flows, floods and inter annual variability that determine the flow regimes of river systems.

Thus, based on the understanding of environmental flows mentioned above and with additional information related to flora, fauna, aquatic biodiversity, socio-cultural and economic values and ecological functions (including sediment transport), the hydrology and the hydraulics of different river systems in basins will be characterised by different flow regimes. Using a single value to appropriate an environmental flows value is not likely to be a sensible approach (as is currently the process), as flow regimes will vary depending on individual river characteristics and morphology.

Historically, the concept of environmental flows has evolved over time. Environmental flow assessment has developed as an eco-hydrological process since the 1970s. It then developed to consider more aspects of the river system, taking into account hydraulics, water quality and geomorphology and of late the concept is embedded under Integrated Water Resources Management (IWRM).

Global reviews (Tharme 2003, Acreman and Dunbar 2004) of environmental flows assessment methodologies reveals that there are more than 200 existing methods. The Building Block Methodology (BBM) (Arthington et al. 2003) is one of these methods that has some uptake in Nepal.

## 4.6 Environmental flows – the potential metrics

In general, environmental flows are the flows required for maintenance of ecological integrity of rivers and associated ecosystems goods and services (Arthington et al. 2010). They can be described as flows that remain in rivers or flows that are restored to rivers as a result of water management (Arthington et al. 2010).

Based on this understanding, it is important to consider a holistic approach to determine the potential metrics of environmental flows that account for:

a. hydrology based
b. hydraulic rating
c. habitat simulation
d. holistic methodology.

Some potential important metrics, together with the questions they need to answer, are listed in Table 4-1.

Table 4-1 Potential metrics for environmental flows assessment

| Metric category | Questions that the metric needs to answer |
|---|---|
| River connectivity | Does the environmental flow design ensure river connectivity<br>• for the umbrella species (amphibians, reptiles, mammals, fish) to move and migrate?<br>• permit seasonal migration for aquatic species? |
| Flow regime | Does the environmental flow design ensure sufficient flow regimes to<br>• maintain aquatic faunal, floral and macro invertebrate population?<br>• maintain riparian habitat for flora and fauna dependent on the flow regimes?<br>• ensure natural transportation of sediment? |
| Flows and water quality for livelihoods and socio-economic activities | Does the environmental flow design account for water quality and quantity to<br>• maintain fish population for fishermen to pursue their economic activities?<br>• maintain enough water for water based tourism activities like rafting, boating and canoeing?<br>• maintain enough water to pursue religious and cultural activities?<br>• maintain enough water to pursue traditional irrigation systems?<br>• maintain enough water for drinking and domestic purposes? |

## 4.7 Future research to address environmental flow knowledge gaps

Despite the fact that environmental flows form an important perspective of water resources management, there are some knowledge gaps around environmental flows that include:

### Impacts of climate change

Water is a key sector that is going to be impacted by climate change. Based on historical and current data trends of climate parameters, water availability in the long run has to be modelled to inform water resource management and various developments like hydropower and the impacts of irrigation canals on water availability. If not undertaken, the various expensive infrastructure built, may not meet the expectations of project developers to gain their return on investment. Additionally, climate change is likely to impact on aquatic ecosystems. There are large quantitative gaps in understanding the trends in water availability, but speculation suggest it will change drastically with climate change; how and to what scale requires scientific modelling.

### Methodology to identify appropriate flow regimes

Despite the fact that over 200 methodologies exist to assess environmental flow regimes, the Government of Nepal has adopted a 'rule of thumb' methodology to establish environmental flows when developing hydropower – the 'rule' being that flows must be at least 10% of the minimum monthly average discharge. While other provisions in the case of irrigation and conservation areas do exist, there is little scientific evidence that the 'rule of thumb' method for hydropower development provides sufficient flow to maintain the aquatic ecosystem in all areas. Thus, this needs to be challenged by conducting research which takes into consideration a holistic method and the potential metric categories mentioned in Table **4-1**. A current understanding is that environmental flows should mimic natural seasonal variations in the river flow. Hence a flat allocation is not appropriate.

### Environmental Impact Assessment information and monitoring and evaluation

Many large projects must conduct Environment Impact Assessments (EIAs) whether or not they will extract water. Some of these reports are publicly available. EIAs mandate that the project developers comply with environment regulations – however, once the document is approved, there is a weak monitoring mechanism to assess how the EIAs are implemented, monitored and evaluated.

This creates a knowledge gap as to whether environmental regulations are met. There is also a lack of transparent information from project developers related to whether mitigation has been undertaken and whether it has really helped the environment. Thus, limited policy exists to make the environmental regulations stringent. Research is required to develop a rigorous framework to evaluate EIAs to determine their level of compliance with environmental regulations and whether they have actually implemented the proposed mitigation actions effectively.

## 4.8 Summary

It is important that organisations working in the water sector come together and expand the knowledge base to help the government make the right informed decisions and form appropriate policies that are based on science and reality. Based on the information available, Nepal should initiate an environmental flows assessment in key river systems in the country and build on the assessments to provide a basin-wide analysis of environmental flows for the four major river basins in the country. This analysis will inform key decision makers on whether they need to set flow parameters for each river system (and perhaps each river reach), rather than establishing one parameter as a rule of thumb.

Addressing the knowledge gaps above will provide a major step forward in managing future water resources in Nepal and the Koshi Basin, in order to provide equitable water use to the many competing sectors while ensuring environmental and aquatic ecosystem health and sustainability.

### Acknowledgements

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# 5 Connecting flow to livelihoods – Koshi Tappu Wildlife Reserve

*Author: Ishana Thapa*[1]

## 5.1 Introduction

Wetlands support the livelihoods of millions of people through important ecosystem functions such as nutrient cycling and primary production which in turn provide direct and indirect benefits (or ecosystem services) such as clean water, provision of food, regulation of local climate, recreational and spiritual values (Russi et al. 2013).

Koshi Tappu Wildlife Reserve (the Reserve) occupies 17,500 ha of the Sapta Koshi River floodplain at the most northeasterly extension of the Gangetic Plain. The wetland was formed by the construction of the Koshi Barrage on the Nepal side of the Indo-Nepal border in 1958–1964. Two man-made flood-control embankments (spanning 38 km on the east bank from the Indian border to Chatara, and 27 km on the west bank from Bhardah to Pathari) were also constructed. The barrage is controlled by the Indian Government for the purpose of irrigation, flood control and hydropower provision to India, according to the Indo-Nepal Koshi agreement of 1954 (DNPWC 2009).

In 1976 the Reserve was designated as a protected area (IUCN Category IV). It was designated as Nepal's first Ramsar site in 1987 owing to the important biodiversity it supports. The Reserve is an important habitat for 493 resident bird species including the globally threatened Swamp Francolin (*Francolinus gularis*), Lesser Adjutant (*Leptoptilos javanicus*) and Bengal Florican (*Houbaropsis bengalensis)* (Baral 2005, Dahal et al. 2009, Baral et al. 2012a) and for congregations of migratory waterbirds and other biodiversity (Baral & Inskipp 2005). It qualifies as an Important Bird and Biodiversity Area (IBA) for these reasons (BirdLife International 2015). Other species supported by the Reserve include the Ganges River Dolphin (*Platanista gangetica*) and the last remaining population of the endangered Wild Water Buffalo (*Bubalus arnee*) in the country (Hedges et al. 2008, Khatri et al. 2012).

In 2004, a 17,350 ha Buffer Zone was created around the Reserve, incorporating 16 Village Development Committees (VDCs) with 10,693 households and 77,970 people (Shakya et al. 2013). In 1994, in recognition that local communities were being negatively impacted by the development of national parks and wildlife reserves across Nepal, the government amended the National Parks and Wildlife Conservation Act of 1973 to allow the declaration of Buffer Zones to act as an interface between protected areas and people (Budhathoki 2004). The revised policy



[1] Bird Conservation Nepal, Kathmandu

allowed 30–50% of the annual protected area income to be allocated to Buffer Zone VDCs for use towards development activities (Budhathoki 2004).

Significant land cover change has occurred at the Reserve in the past 40 years associated with the naturally changing course of the Koshi River. Inside the Reserve, this has drastically altered the site by reducing the extent of forest and wetland areas and replacing them with more extensive grassland habitats (Chettri et al. 2013). The Reserve is surrounded by cultivated land.

Flock of Black headed Ibis (*Threskiornis melanocephalus*) (photo: Jyotendra Jyu Thakuri)

According to the 2011 census, the number of households within the Buffer Zone had increased to 16,032 (ICIMOD & MoFSC 2014). This rapidly expanding dense rural population, coupled with tensions around historical access rights, continues to put pressure on the Reserve. Current resource use in and around the Reserve is unsustainable. Pressures on people's livelihoods mean that existing patterns of resource use bring people into conflict with the Reserve authorities, because people perceive that the conservation of the site results in reduced benefits to them. These impacts include reduced access to resources as well as increased risk from human-wildlife conflict. As a result, the Reserve is viewed negatively by many and there is non-compliance with Reserve laws, leading to unsustainable exploitation of resources and associated disturbances.

For the long term viability of the Reserve, people living adjacent to the site who depend on wetland resources for their livelihoods must be able to obtain a sustainable livelihood (i.e. a livelihood that is resistant to environmental shocks and does not result in the unsustainable exploitation of those resources).

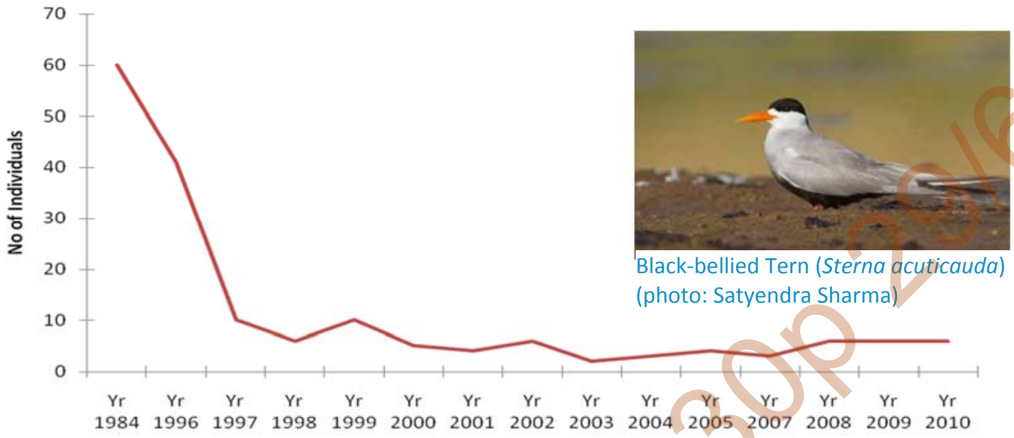
## 5.2 Local communities and their livelihood dependency

Of the population of households in the Buffer Zone, 31% are wetland-dependent communities whose livelihoods rely on these wetland resources with 61% of these belonging to ultra-poor and poor groups who earn their livelihood through wage labour, agriculture, firewood collection and other such activities (CSUWN 2009). Many products are used for subsistence, but income is derived from fishing (almost all of the fish caught is sold in local markets) and also by selling products made from wetland materials. *Typha* is collected especially by Bantar women (indigenous communities) from a localised area and used to make mats that are then sold in local and national markets. Fishing permits within the Reserve are granted to the Malaha community for whom this is a traditional livelihood. Given that the poorest households in the region and certain ethnic groups such as Bantar and Malaha are often those most dependent on the wetland, the Reserve has significant benefits for these ethic groups. Arguably, the current management of the Reserve and the regulations in place

have supported these ethnic minority communities, which is reflected by the significant annual economic value of harvested wild goods to these households.

## 5.3 Local livelihood initiatives at Koshi

Many fish-eating bird species, for instance Black-bellied Tern (*Sterna acuticauda*) and Indian Skimmer (*Rynchops albicollis*), have undergone precipitous declines in the Koshi area during the last ten years (Figure 5-1) and are probably suffering from prey shortage due to overfishing (BCN & DNPWC 2011).




Black-bellied Tern (*Sterna acuticauda*)
(photo: Satyendra Sharma)

Figure 5-1 Numbers of Black-bellied Tern recorded at Koshi between 1984 and 2010 (BCN and DNPWC 2011)

Based on scientific data revealing the existing resource conflict between fish eating birds and the fisheries community in the Reserve area, a joint initiative launched a three year project called ‘Wetland Management for Sustainable Livelihoods at Koshi Tappu, Nepal’ in 2006 (Thapa & Dahal 2009). The aim of the project was to assist local communities around the Reserve to manage Buffer Zone wetlands for sustainable livelihoods, whilst enhancing wetland biodiversity, thus reducing the pressure on resources within the Reserve. The project undertook a detailed study through a Participatory Rural Appraisal exercise and household survey to identify a range of consumptive and non-consumptive uses of the Reserve wetlands (Table 5-1). Fishing was rated as the most important wetland resource by the local communities (Buckton et al. 2009).

Table 5-1 Consumptive and non-consumptive uses of wetlands in Koshi Tappu Wildlife Reserve

| Consumptive uses | Non consumptive uses |
|---|---|
| Fishing | Cooking, drinking |
| Grass collection | Washing |
| Cat-tail *Typha* harvest | Irrigation |
| Cat-tail as fuel wood | Floodplain for rice cultivation |
| Fuel wood | Transportation |
| Aquatic animals for food | |
| Snails as meat | |
| Wild vegetables | |
| Traditional medicines | |
| Chiple mud | |
| Silk cotton | |

A number of innovative and sustainable livelihood options were identified that could deliver benefits to local people whilst preserving the ecological integrity of the wetlands. Initiatives to develop sustainable livelihoods included establishing fish ponds that provided households with a secure livelihood in aquaculture. Alternatives to fishing such as providing training and materials to impoverished women to create handicrafts were also promoted. As an alternative to collecting firewood from the Reserve, Buffer Zone communities were shown how to make charcoal briquettes from invasive plants. The invasive Water Hyacinth *Eichhornia crassipes* was used to produce compost fertilisers as a cheap and safe alternative to chemical fertilisers (Mitra Pandey in BCN & DNPWC 2011).

## 5.4 Ecosystem Services

An assessment of the ecosystem services provided by the Reserve was made in 2011 (BCN & DNPWC 2012). To quantify the net impact of the creation of the Reserve in terms of economic costs and benefits to people, the Toolkit for Ecosystem Service Site-based Assessments (TESSA) was used (Peh et al. 2013a), building on its application at other sites in Nepal (Birch et al. 2014, Peh et al. 2016). TESSA guides non-specialists through accessible, low-cost methods to identify the ecosystem services that are important at a site, and to quantify their value to people, compared with those expected under alternative land uses (Peh et al. 2013b). The assessment compared the value of ecosystem services delivered by the site to those delivered by comparable habitats outside the Reserve. Results showed that local people benefit from

fishing and harvesting grasses which may be having a negative impact on the biodiversity. Benefits from international tourism are low but significant (BCN & DNPWC 2012).

Previous studies at the Reserve have gathered data on the direct use of the Reserve and its Buffer Zone by local communities (CSUWN 2009, Rayamajhi 2009, Sharma et al. 2015). These verified the information obtained by Merriman et al. (submitted) from stakeholder meetings, that dead wood (for firewood), grasses (for fodder and thatch), *Typha comprestis* (for mat-weaving), *Diplazium spp.* (young shoots of edible fiddlehead ferns, known locally as 'neuro') and fish were the most important products. These products are legally collected from the Reserve, according to rules and regulations enforced by the Reserve authorities.

The results from Merriman et al. (submitted) suggest that in total, the population living within the Buffer Zone harvests wild goods with an economic value of $3.54 million annually from within the Reserve whereas tourism has an economic value of $126,000 of which locals are also beneficiaries.

Unsurprisingly for a wetland, flood prevention, groundwater recharge and surface water were considered important services provided by the Reserve by all stakeholder groups. Many people depend directly on the Reserve for drinking and irrigation water and rely on the embankments for flood protection. Provision of fish for nutrition was the highest scored service overall with other wild foods also very important for most stakeholders. Because stakeholders also considered the Buffer Zone area, where predominantly rice is grown, cultivated goods were scored highly. Habitats for species, nature-based recreation and knowledge ranked highest of the supporting and cultural services.

The assessment concluded that local people are highly dependent on the natural resources of the Reserve and it provides many more benefits than the surrounding areas outside of the protected area which have been heavily degraded. However, improving the management of the site for important bird species will require more regulated harvesting within key areas of the Reserve. Where costs for local people are significant, more initiatives may be needed which help redress the imbalance. For example, alternative livelihoods projects based on use of invasive plant species or fish farming and engagement in the tourism sector may help to reduce pressures whilst giving local people a fair share of the benefits (BCN & DNPWC 2012).

## 5.5 Impact of river flow regime change on local livelihoods

Ecosystem service assessments show a considerable amount of economic benefit is obtained by the locals through a number of services, however it is limited to the changes in flow and stock of the

ecosystem services. Most of the important livelihood activities like fisheries, cultivation and mat weaving from *Typha* are highly influenced by the availability of the water in the Koshi River. The fishery at the Reserve is known to support the livelihoods of a significant proportion of nearby households. Seepage of water from the river to the adjacent land area in the Buffer

Zone supports local crop cultivation and fish farming. Siltation of wetlands due to intermittent floods blocked by the Koshi Dam is not only a major problem of habitat degradation but also an impediment to migratory routes of aquatic species. Land use activities, such as agriculture and fisheries, can influence not only the chemical and biological quality of the river or water body but also the character and quality of the habitat. Change in the river flow regime and water quality may affect the locals either by flooding or reduced flows which ultimately impact on their wellbeing and livelihoods.

Water vulnerability is one of the major challenges facing people in the Himalayan river basins and places like Koshi Tappu Wildlife Reserve which is expected to increase with climate change and other change. The water vulnerability assessment model at the district level carried for Koshi Basin showed a relatively high degree of vulnerability where plain areas like the Reserve were more vulnerable in terms of development pressure (Neupane et al. 2013).

## 5.6 Knowledge gaps

There exists inadequate community cooperation for conservation at the Reserve due to unequal benefits realised from conservation. Insufficient political and other local institutional support and commitment are other major concerns (DNPWC 2009). Despite the gravity of the problems, the outstanding natural and cultural features of the Reserve Buffer Zone provide a wide range of opportunities for the development of nature and culture-based recreation tourism. The Reserve can provide perpetual benefits to the local and international community if biodiversity resources are managed and used in a sustainable manner (DNPWC 2009). More needs to be done to support conservation and the people most affected most by conservation policies.

Other opportunities that could benefit the Buffer Zone communities include investment in community-led nature-based recreation and tourism. The distribution of benefits from nature-based recreation at the Reserve is disproportionally in favour of national and global beneficiaries and low tourism rates at the Reserve mean that the absolute value of the 50% benefit-share is poor compared with more popular protected areas in Nepal. Thus, establishing community-led tourism opportunities could be one way to balance the share of the benefits more in favour of the local communities. Efforts to encourage higher numbers of visitors would be needed.

Another opportunity could be through establishing payment for ecosystem services schemes such as carbon payments. Nepal offers some of the best examples of community-based forest management in the world (Bajracharya et al. 2005, Dahal et al. 2014) and benefits have been demonstrated both for biodiversity (Acharya 2003) and for local livelihoods (Birch et al. 2014). Given that the VDCs surrounding the Reserve are managing Community Forest areas, this could be an opportunity to gain direct payments for forest restoration in and around the Reserve.

Nepal's large annual precipitation and dense river networks provide high potential for hydroelectricity resulting in a significant increase in hydropower plants across Nepal in recent years. While this is a positive step towards meeting energy deficits, construction of hydroelectric dams brings substantial threats to wildlife and livelihoods of wetland-dependent communities. Dams can inundate important habitats, act as barriers to migration, lead to associated development, displace people into new sensitive habitats, and can alter local microclimates (Dharmadhikary 1998). Careful planning and consideration of aquatic ecosystems is required where hydropower development is being considered.

## 5.7 Summary

Located in the floodplains of the Sapta Koshi, the Koshi Tappu Wildlife Reserve is a mosaic of diverse ecosystems with rich biodiversity. Even after designation as a protected area, people in surrounding communities remain highly dependent on the Reserve, mainly interacting with water resources for their livelihoods.

The Reserve has experienced various changes since its establishment, the most significant being land cover change, including change in the river course (Chapter 2). This has had a significant impact on biodiversity, ecosystem services flow and livelihoods of the local communities. Climate change and other development activities will most likely worsen the situation in the near future. Detailed assessment of environmental flows and the linkages to the livelihood vulnerability of people combined with adaptation measures supported by policy, will help to ensure sustainable livelihood benefits to the local communities.

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# 6 Plant diversity and environmental flows in the Koshi Basin

*Authors: Ram P Chaudhary[1], Jay P Sah[2]*

## 6.1 Study region

The Koshi Basin is the highest basin in the world, and it extends from the southern part of the Tibetan Plateau in China through mountains and plains in Nepal to the Gangetic plains in north India. It has seven major rivers (the Sun-Koshi, Indrawati, Dudh-Koshi, Tama-Koshi, Bhote-Koshi, Arun, and Tamor (Tamur)), all originating from the Himalayas (Agarwal et al. 2014) (Fig. 6-1). The Koshi Basin lies in between the $25^{0}33'$-$29^{0}15'$ N latitudes; and $85^{0}02'$-$88^{0}95'$ E longitudes, covering an area of 88,518 $km^2$ (Uddin et al. 2015). The Koshi Basin comprises 17 districts of Nepal delineated under three federal provinces: 11 districts (Taplejung, Panchthar, Sankhuwasabha, Terahthum, Dhankuta, Bhojpur, Khotang, Solukhumbu, Okhaldhunga, Udaypur and Sunsari) under province number 1; one district (Saptari) under province number 2; and five districts (Dolakha, Ramechhap, Sindhuli, Kavrepalanchowk, and Sindhupalchowk) under province number 3. The provinces are connected upstream and downstream through environmental flows of the Koshi Basin.

Figure 6-1 Arun River entering to Nepal at Kimathanka village, Nepal

## 6.2 Biodiversity and Ecosystem Services

### Biodiversity conservation

Biodiversity, today, has become a focal point in: (a) economic interests (bioprospecting and commercial use of genetic resources); (b) ecological and environmental interests (environmental problems, extinction rates, sustainability, long-term ideas for the use of genetic resources); (c) political interests (international legal and economic aspects of biodiversity and its preservation); (d) conservation and ecological management (preservation and protection of ecosystems and ecological processes); and (e) ethical matters (right to life) (Birks 2015). The Koshi Basin comprises of rich biodiversity, and high proportion of endemic, rare and threatened species and habitats, and several efforts have been made for their conservation and management within the Basin.



[1] Executive Director, Research Centre for Applied Science and Technology (RECAST), and Professor, Central Department of Botany, Tribhuvan University, Kirtipur, Nepal

[2] Research Associate, Southeast Environmental Research Center, Florida International University Miami, USA

Figure 6-2 *Tetracentron sinense*, a primitive species

The Koshi Basin has supported *in situ* conservation of many threatened and rare species (Shrestha 1989) such as richness of Rhododendron species, Oak forests including *Lithocarpus pachyphylla* and evolutionary primitive species *Tetracentron sinense* (Figure 6-2), *Magnolia campbellii, Talauma hodgsonii, Pandanus furcatus, Michelia* species and relict species *Gnetum montanum* in Makalu-Barun National Park (Shakya et al. 1997), and the *Larix griffithiana* in Kangchenjunga Conservation Area (Chaudhary 1998, Chaudhary et al. 2015a). Different types of medicinal plants for domestic use and trade, food plants and their wild relatives are found within the Basin (Chapter 2 for details).

**Vegetation pattern and forest types**: The Koshi Basin represents wide range of vegetation, and forest types which change abruptly owing to wide variation of topography, climate and edaphic conditions. Stainton (1972) described 35 types of forest in Nepal. Miehe et al (2015a) described 55 vegetation types under three broad categories such as: (i) vegetation types in the southern slope of the Himalayas; (ii) vegetation types of the Inner valleys; and (iii) vegetation types of the arid zone in Nepal from lowland to highland with characteristics floral species. A total of 42 vegetation/forest types have been identified in the Koshi Basin (Annex, Table 6-1 and Table 6-2). They are: (i) vegetation of the southern slopes of the Himalayas comprising four bioclimatic belts and 29 vegetation types; and (ii) vegetation of the inner valleys comprising two bioclimatic belts and 13 vegetation types in the Koshi Basin. The bioclimatic belts in the southern slopes of the Himalayas include: (i) Tropical belt (up to 1000m) with seven vegetation and forest types; (ii) Subtropical belt (1000-2000m) with six vegetation and forest types; (iii) The cloud forest belt (1600-4000m) (Figure 6-3) with 13 vegetation and forest types: and (iv) Alpine belt (4000-5100m) with three vegetation and forest types. The bioclimatic belts of the Inner valley comprises: (i) Temperate belt (2000-4000m) with eight vegetation and forest types; and (ii) Alpine belt (4000-5500m) with five vegetation and forest types (Annex, Table 6-1 and Table 6-2).

Figure 6-3 Cloud forest, rich in floristic and bird diversity

**Protected Areas, and corridors**: There are five protected areas in the Koshi Basin including two national parks, namely Sagarmatha (Everest) National Park (also a World Heritage site) and Makalu-Barun National Park; two conservation areas namely Kangchenjunga Conservation Area and Gaurishankar Conservation Area; and one wildlife reserve namely Koshi Tappu Wildlife Reserve (also a Ramsar site). The PAs within the Koshi Basin cover a total of 8315 km$^2$ (core and buffer zones together) which represents 24% of the total PAs in Nepal (See Chapter 2; and Tables 2-3, and 2-4 for details).

Notable vegetation in the Sagarmatha National Park (Figure 6-4) include Blue pine, fir, juniper, alpine meadows; Makalu-Barun National Park include Sal, pine, Schima-Castanopsis, Macaranga, Castanopsis, oak-laurel, Berberis, Rhododendron, oak, birch, fir, junipers, orchids Figure 6-5); Kangchenjunga Conservation Area include Larch, juniper, oak, *Magnolia*, fir & hemlock.

Figure 6-4 *Juniperus recurva* forest, Sagarmatha National Park, Nepal

Figure 6-5 The Koshi Basin is rich in Orchid species (*Cymbidium longifolium*)

Gaurishankar Conservation Area (Figure 6-6) includes Riverine, *Schima-Castanopsis*, pine, alder, oak, temperate mixed-broadleaved, *Rhododendron*, birch; Koshi Tappu Wildlife Reserve includes Khair-sissoo, tropical mixed deciduous riverine, grassland, wetland (see Chapter 2 for details).

The Koshi Tappu (17,500 ha) and Gokyo and Associated Lakes (7770 ha) have been designated as Ramsar sites, wetlands of international importance (see Chapter 2 for details).

Figure 6-6 *Rhododendron barbatum* is widespread in Gaurishankar Conservation Area

Tinjure-Milke-Jaljale is an important corridor in the Koshi Basin connecting Sagarmatha National Park and Makalu-Barun National Park is an important habitat of *Rhododendron* species (Figure 6-7).

Figure 6-7 Tinjure-Milke-Jaljale Himal (Mt. Makalu on the backdrop), hosts diversity of *Rhododendron* species

## Ecosystem processes and services

Ecosystem processes are the ecological dynamics and links that maintain the integrity of ecosystems. These processes range from interspecific interactions such as the predator-prey relationship, pollination and fruit formation, seed dispersal, to organic matter decomposition, water and nutrients (nitrogen, carbon, etc.) recycles, soil production, air and water purification, and several other critical ecosystem functions. Biodiversity, an important player of ecosystem processes, mainly stabilizes ecosystem productivity and productivity-dependent ecosystem services by increasing resistance to climate events (Isbell et al. 2015). The Koshi Basin is conceived as a corridor that sustains and supports large-scale ecosystem processes such as species migration and hydrological flows, especially between PAs in the north and south.

Figure 6-8 The Arun River links and serves an important migratory route for bird species

Among the river systems, the Arun River links and serves as an important migratory route for bird species across trans-Himalayas (Figure 6-8).

Human well-being and development are based on ecosystem goods and services, i.e. the benefits that people obtain from ecosystems (MEA 2005, Måren et al. 2013, Chaudhary 2014). Ecosystem services are the conditions and processes through which natural ecosystems, and the species that make them up, sustain and fulfill human life (Daily 2000). Plant diversity or biodiversity within the Koshi Basin also provides various types of ecosystem goods and services (ICIMOD & MoFSC 2014, Bhatta et al. 2015, Sharma et al. 2015). Following the MEA (MEA 2005), ecosystem services in the Koshi Basin are grouped as follows:

**Provisioning services**: The Koshi Basin provides raw materials obtained from plant biodiversity as provisioning services. These include goods such as food, fodder, fuel-wood, bamboo (Figure 6-9), natural fiber, timber, natural medicines for household uses and trade, biochemicals, pharmaceuticals, and industrial products, and their precursors; ornamental and genetic resources. In three districts of the Kangchenjunga landscape area (Taplejung, Panchthar and Ilan districts), the forest ecosystem provides provisioning services of approximately USD 98 million, that is an equivalent to the per household ecosystem services of about USD 850 per year (Pant et al. 2012). The Koshi Tappu wetlands has also been regarded as an important area that provide a range of goods and services, including thatch grass, timber, grazing areas, fish and many others for supporting livelihood and human well-beings in the regions (Sah 1997). Provisioning goods and services obtained from plant diversity enable people to settle around the areas, and people maintain such areas as sustainable landscape (Chaudhary et al. 2014).

Figure 6-9 A cowshed made from bamboo in the Upper Arun Valley

**Regulating services**: Plant diversity in the Koshi Basin plays a key role in providing regulating services. These include: (a) regulating climate through carbon sequestration (e.g., in forests, grasslands and wetland ecosystems); (b) enhancing resilient ecosystem and regulating natural hazard through vegetation cover that help prevent erosion and landslides, particularly in the hills and mountains; (c) purifying water as retained in the watershed areas and forests, and later getting discharged into several streams and water pools; (d) breaking down wastes and pollutants and maintain healthy ecosystems; (e) controlling disease as regulated by healthy soils and wetlands; and (f) mitigate threats to biodiversity and livelihoods by improving soil structure and maintaining its fertility, biological control, nutrient cycling, sanitation and waste treatment.

**Cultural services**: The cultural services are non-materials benefits people obtain from ecosystem/biodiversity, such as spiritual enrichment, intellectual development, religious experience, and recreation (Bhagwat 2009). Protected areas such as Sagarmatha National Park, Kangchenjunga Conservation Area and Koshi Tappu Wildlife Reserve provide opportunities for outdoor recreation; and nature-based tourism are becoming an important means of economic source for benefit sharing and enterprise development. Sacred natural sites such as Barah Chhetra (Sunsari district), Jor Pokhari Mahadevsthan (Panchthar district), Pathivara Temple (Taplejung district), Tinjure-Milke-Jaljale Himal (Sankhuwasabha and Taplejung districts) preserve cultural sites, support all forms of life, regulate local atmosphere, provide medicinal plants, and promote cultural integrity.

**Supporting services:** The supporting services are the services that are necessary for the production of all other ecosystem services. These relate to fundamental environmental processes that have intangible values. Supporting services obtained from the Koshi Basin include (a) biomass production and retention; (b) nutrient cycling by the activity of phytoplankton, microbes and fungi, soil organisms; (c) primary production mainly obtained through photosynthetic processes of green plants; (d) generation of biodiversity and maintenance of habitat and refugia; (e) environmental sustainability by reducing peoples' dependency on fuel-wood and establishing energy plant; (f) maintenance of genetic diversity (wild relatives) from which a variety of domestic and commercial species can be developed; and (g) pollination of crops and dispersal of seeds.

## 6.3 Status of floristic biodiversity

**History of plant exploration:** The botanical exploration in Nepal started early in the 19th century. Francis Buchanan Hamilton, a Scottish medical man and an employee of the East India Company visited Nepal as a member of the mission to the Nepalese court from March 1802 to March 1803 (Press and Shrestha 1999). He made a valuable collection of dried plants from the hills around Kathmandu valley. Plant hunting in eastern Nepal, covering the Koshi Basin, for the first time was undertaken by J.D. Hooker and nearly 50 attendants who accompanied him from Ilam up the Tamur River to Taplejung, Wallungchung (Olangchung) on the way to Sikkim from October to December, 1848; Figure 6-10). Balfour (Balfour 1922) published new species of plants collected by A.F.R. Wollaston, a Medical officer and Naturalist, during a 1921 Everest Expedition. M.K. Banerji, the Indian Botanist, made his first expedition to Nepal in 1948, in connection with the Koshi Project and collected plant specimens in the Valley of Tamur River to Taplejung. A total of 7500 specimens were collected from Koshi Basin between 1948 and 1967 in total 12 expeditions by his team (Miehe et al. 2015a).

Figure 6-10 JD Hooker visited Wallungchung (Olangchung) Gola to collect plant specimens in 1848 (Dr. Govinda Basnet)

In the 1950s and 1960s, a huge increase in the number of plant collections took place in Nepal; for example, the collection of A Zimmermann from the Everest region in 1952 and 1954. During the 1970s and 1980s, a few UK expeditions were undertaken, including plant collections by L Beer, CR Lancaster and D Morris from Topke Gola, and KR Rajbhandari and colleagues from Rolwaling Himal. In 1989, Kew Edinburgh Kangchenjunga Expedition led by Japanese botanists (H Hara and H Ohba) concentrated plant collections in central and east Nepal. In 1981, Grey-Wilson collected plant specimens from Makalu Base Camp. During 1990s, the Japanese collectors actively participated in plant collections; for instance, M Suzuki collected plants from Arun Valley in 1988. From 2000 and onwards, the Nepalese Department of Plant Resources has undertaken significant plant collection. Currently, that Department and the Central Department of Botany of Tribhuvan University in collaboration with the Nepal Academy of Science and Technology are actively involved in accomplishing the task of Flora of Nepal (for details see also Miehe et al. 2015a. Rajbhandari 2016a). However, most of the collections have focussed on high altitude, thus Tarai and midlands are comparatively under explored.

**Floristic diversity**: The Koshi Basin is rich in floristic diversity owing to its wide altitudinal gradients and diverse climate (Shrestha and Ghimire 1996; Shrestha and Shengji 1997; Chaudhary et al. 2002; Chettri et al. 2010). The region is phytogeographically unique. The Indo-Malayan realms of South-east Asia contributes many tropical taxa whereas the Palaeotropical realm brings plant species to the higher elevations in the north. Mixed Sino-Japanese and Sino-Himalayan elements predominate in the Koshi Basin.

A comprehensive account of the Flora of the Koshi Basin is lacking. However, based on the sectoral studies it is estimated that about 4000 species of angiosperms, i.e. two thirds of the total flora of Nepal, occur in the Basin. Makalu-Barun National Park alone hosts 3073 species of gymnosperms and angiosperms (Shakya et al. 1997) including 96 species of orchids (Shrestha and Ghimire 1996, Chaudhary et al. 2002) and 25 species of rhododendrons (78% of all Rhododendron species reported from Nepal); 128 species of pteridophytes; and 78 species of lichens. Similarly, Kangchenjunga Conservation Area hosts 2448 species of angiosperms, 15 species of gymnosperms, 257 species of Pteridophytes, 292 species of Bryophytes, and 56 species of lichens (Chaudhary et al. 2015a). Koshi Tappu Wildlife Reserve hosts 670 species of vascular plant species with rich faunal species (Sah 1997). There has been relatively much work carried out in higher groups (angiosperms and gymnosperms) of plants, while research on lower groups of plants, in general, has not been done seriously and systematically in Nepal, including the Koshi Basin.

**Endemic species:** Out of 324 endemic flowering plant species of Nepal, the Koshi Basin contains 86 species belonging to 28 families and 45 genera (Annex, Table 6-3). The largest endemic families are *Saxifragaceae*, represented by seven species; *Scrophulariaceae, Begoniaceae, Gentianacea*e, and *Ranunculaceae* each represented by six species; and *Rosaceae, Compositae* and *Cyperaceae* each represented by five species. Similarly, the largest genus is *Saxifraga* (7 species) followed by *Begonia* (6), *Pedicularis* (6), *Gentiana* (6), and *Impatiens* (4). Endemic species in Nepal are unevenly distributed – the highest numbers are found in the higher altitudes between 3000 to 4000 m asl (Vetaas and Grytnes 2002).

## 6.4 Current research knowledge

The Koshi Basin that covers more than one-third of Nepal Himalayas and a large portion of eastern Tarai has been the focal area of research activities in Nepal. Major research areas that have direct or indirect impact on the flora and vegetation within the Basin include exploration of regional floras (Shrestha and Ghimire 1996, Sah 1997, Shakya et al. 1997, Shrestha and Shengji 1997, Chaudhary and Kunwar 2002, Siwakoti 2006, Chaudhary et al. 2015a), forest and wetland ecosystems (Lacoul and Freedman 2006, Uddin et al. 2015), vegetation productivity (Zhang et al. 2013), land cover and land use changes (Sah 1997, Chaudhary et al. 2014, ICIMOD & MoFSC 2014, Chettri et al. 2013, Uddin et al. 2015), soil erosion (Uddin et al. 2016), community forestry (Chapagain and Banjade 2009), ecosystem services (Pant et al. 2012, Sharma et al. 2015); NTFPs (Ghimire and Nepal 2007); glacier retreat (ICIMOD 2007, Shangguan et al. 2014), and potential impact of climate change on hydrology and its effects on biodiversity and human life (Bharati et al. 2012, 2014, 2016; Agarwal et al. 2014, 2015; Bhatta et al. 2015, Nepal 2016).

## Land use and land cover changes

Land cover change has been considered a major driver of spatio-temporal variation in biodiversity, critical habitats for threatened and endangered species, and ecosystem services. In the Koshi Basin also, land cover has changed over time. For instance, total glacier area in 2009 was about 3225 $km^2$, 19% less than the area present in 1979, and the major cause of the glacier retreat was an increase in temperature and decrease in precipitation, resulting in faster retreat of glacier on the south side of the Himalayas than on the north side (Shangguan et al. 2014). These glacier retreats have been considered as the primary cause of an increase in wetland area, especially of moraine-dammed lakes at high altitudes (Kattelmann 2003). Within the Koshi Basin, total area of wetlands increased from 5319 $km^2$ in 1990 to 5818 $km^2$ in 2010 (Uddin et al. 2015). In contrast, the area covered by the rivers decreased by 2.9%, and that of lakes and ponds, mostly in mid-mountains and Tarai, by 1.9% (Uddin et al. 2015). The changes in wetland area are likely to have a huge impact on wetland-dependent wildlife and the people, especially indigenous communities in lowlands of the Basin.

Forest cover varies in the different regions of Nepal, including the different eco-regions within the Basin. For instance, forest cover in three districts in eastern Nepal in Kangchenjunga Conservation Area ranged between 42.6 to 49.6% (MoFSC 2009a). Over several decades in the 20$^{th}$ century, there was countrywide reduction in forest area, that decreased by 1.7% per year between 1978 and 1994, when the last comprehensive assessment of the forest was carried out in the country (MoFSC 2009a). The reduction in forest cover has been a great concern for policy makers, as more than 70% of the population are dependent on forest resources. In recent years, an increase in forest cover has been reported in several regions, including Dolakha district within the Basin, mainly due to improved management through community forestry (Niraula et al. 2013). However, such an increase in forest cover is mostly concentrated in the mountains, while forest area decreased in the Tarai where community forestry has had minimal success.

In general, human activities are considered as the culprit for the land use and land cover changes. However, natural processes, though mostly, but not always, altered by the human for different purposes, can also significantly impact on land cover. A significant area of forest in six districts of the Basin was negatively impacted by the 2015 Earthquake (NPC 2015a, b). Similarly, over 32 years, from 1959 to 1991, forest cover had reduced by 63% whereas grasslands increased by 35% within Koshi Tappu Wildlife Reserve (Sah 1997). By 2010, forest in the Reserve had reduced by 94% and grasslands had increased by 79% from its original state (Chettri et al. 2013). These land cover changes, caused by both natural and human-induced alteration in flow regime of the Koshi River and consumptive use of forest resources, have profound effects on floral diversity within the Reserve and people's livelihood around it (Sah 1997, Chaudhary et al. 2014).

## Biodiversity assessment

The Koshi Basin is rich in all kinds of biodiversity, primarily because of the wide range of climatic variation along the elevational gradient, and also because the Basin shares the elements from both the Palaearctic and Indo-Malayan biogeographical realms. In a detailed review of the biodiversity of the eastern Himalayas, Chettri et al. (2010) has pointed out that vegetation types are an important climatic expression of biodiversity. In the Koshi Basin, vegetation types are broadly categorized into tropical, subtropical, warm temperate, cool temperate, subalpine, and alpine. A comprehensive list of taxonomic diversity at different levels of biological organizations and spatial scale is lacking (MoFSC 2002, 2014). However, a number of sectoral researches indicate that the area could have more than 4000 species of angiosperms, (Shrestha and Ghimire 1996, Sah 1997, Shakya et al. 1997, Shrestha and Shengji 1997, Chaudhary and Kunwar 2002, Siwakoti 2006, Shrestha et al. 2008, Chaudhary et al. 2015a), and a few of them are endemic (Rajbhandari 2016a).

The Protected Areas (PAs) within the Basin have been the focal area for the study of biodiversity, and recent researches within those areas, especially Makalu-Barun National Park and Conservation Area, Kangchenjunga Conservation Area and Koshi Tappu Wildlife Reserve, have added greatly to the existing knowledge of the biodiversity in the Koshi Basin (Shrestha and Ghimire 1996, Sah 1997, Shrestha and Shengji 1997, Chaudhary et al. 2002, Kunwar and Chaudhary 2004, Duwadee et al. 2006, Chaudhary et al. 2015a). However, similar to other parts of the country, research on the lower plants within the Basin is very scanty. In a recent study carried out within the Kangchenjunga Conservation Area, Chaudhary et al. (2015a) has listed the lower plants (see §6.3).

Very few studies have addressed quantitative measure of the biodiversity in relation to environment along the elevation gradient within the Basin. If a study conducted in wetlands, directly or indirectly connected to the environmental flow, is considered as an indicator, it is likely that plant species richness and diversity decreases linearly with increasing altitude (Lacoul and Freedman 2006). Though, in a study for Nepal as a whole, Vetaas and Grytnes (2002) have shown that the maximum species richness for flowering plants occurs at the elevation between 1500 and 2500 m. Nonetheless, their study was based on the list of flowering plants and elevation range given in three standard literature (Hara et al. 1978, Hara & Williams 1979, Hara et al. 1982), which are the compilation of botanical exploration done in Nepal until 1970s. By then, these explorations were mostly concentrated on middle or high mountains, while the lowland tropical areas were under explored, which might have affected their findings. When a global pattern of biodiversity along the climatic gradient is taken as an example, it is most likely that the pattern observed in wetland plants by Lacoul and Freedman (2006) held true for plant diversity of the Koshi Basin in general.

## Socio-economic assessment

Social capital which encompasses relationships of trust, mutuality and exchange, connectedness in groups, and common rules, norms and sanctions is important for guiding individual action in the society to achieve positive biodiversity outcomes (Pretty and Smith 2004). The Koshi Basin hosts the people of different culture and societies whose economies are based on traditional primary sectors (farming and fishing) to the quasi modern sector of tourism and private and public services. However, the majority of the people are attached to agrarian economy, which has a close relationship with the river flow within the Basin.

The water resources in Koshi Basin has huge potential for hydro electricity generation (Chinnasamy et al. 2015). However, water resource development projects usually alter the water flow and affect water demand. Thus, any potential project in the Koshi Basin will also have huge impact on the biodiversity in the rivers and other wetlands as well as will change highland-lowland relations, ultimately affecting the peoples' socio-economic conditions. For instance, the change in course of the Koshi River over 30 years (1959–1991) had significant impact on the biodiversity of Koshi Tappu Wildlife Reserve and the ecosystem services obtained from the Reserve during that period (Sah 1997), and the trend has continued until recent years (Chettri et al. 2013, Chaudhary et al. 2014).

In Koshi Basin, where peoples' well-beings are mainly dependent on forests and agriculture productivity, the maintenance of healthy soil is important. Traditionally, paaddy, maize, wheat and millet are commonly grown in the lowlands and mid-hills, whereas naked barley (Figure 6-11) and buckwheat are the major cereal crops grown in the high altitudes.

However, in the Basin soil erosion is a common problem. From the Basin, soil erosion has increased annually by 5%, from 40 million tonnes in 1990 to 42 million tonnes per year in recent years (Uddin et al. 2016). Moreover, current trend of land degradation, sedimentation and ecological degradation is likely to cause further increase in soil erosion which will affect the environmental flow, ultimately impacting the biodiversity and economic productivity in agricultural lands.

Figure 6-11 Naked barley is an important crop grown in the Upper Koshi Basin

Forests sustain many rivers which are the life line for the people downstream. Though, extensive efforts in forest conservation and management through community forestry have increased forest cover locally, the level of forest provisional services, in particular availability of fuel wood, fodder and litter, have decreased in recent years because of a strict regulation on forest goods extraction (Pant et al. 2012). In such a case, poor people at the lower level of social hierarchy are most severely affected. Poor communities are also vulnerable to extreme climatic events. Current assessment of projected future flow in response to climate change suggests that the number of extreme events, both low flows and large floods, will increase in future (Bharati et al. 2012), which will have devastating effects on the peoples' well-beings.

## Climate change and biodiversity

Ecosystems in the Himalayas are being increasingly impacted by global climate change. In general, the Koshi Basin will become warmer in coming decades (Agarwal et al. 2015). Temperature will increase by 0.7–0.9°C as early as by 2030 (Bharati et al. 2012), though the change in precipitation is expected to vary by season, as much as by -39% to +51% (Agarwal et al. 2014). Biodiversity and productivity in all kinds of ecosystems will be impacted by the climate change-induced environmental flow. Researchers have shown that vegetation productivity has increased or decreased in different time periods in last 30 years (1982–2011) depending on the variation in precipitation (Zhang et al. 2013). Thus, it is expected to change in response to future climate change, affecting availability of forest and other vegetation resources to the common people.

Recent research has pointed out that overall crop production in the Basin is likely to decrease in response to climate change (Bhatt et al. 2014). Though at relatively high altitude, the production may increase due to effect of warming, provided other conditions, such as water availability and soil fertility, are favourable (Bhatt et al. 2014). There has not been systematic research on the vulnerability of ecosystems to invasion by alien species (Tiwari et al. 2005), however people in the region have already been experiencing increased colonisation of the forests by invasive species, inhibiting regeneration of native forest vegetation in some areas (Bhatta et al. 2015). Forest users cope with these changes on short-term basis, however, to increase the adaptability of poor households in the Basin, it is important to integrate climate change adaptations policy within the local planning process (Bhatta et al. 2015).

## 6.5 Drivers of flow change

The 2005 Millennium Ecosystem Assessment reported that over the past few hundred years, human activities have increased the rate of species extinction by as much as 1000 times (MEA 2005). However, extinction rates are difficult to quantify precisely because of the lack of knowledge about total numbers of species and their global or regional distributions (Ceballos and Ehrlich 2000). Like most developing countries, threats to biodiversity in Nepal are initiated largely by the activities of human beings. Habitat degradation is one of the major causes of loss of plant biodiversity in Nepal (Chaudhary et al. 2015b). Unsustainable harvesting of fuelwood and fodder, forest fire, lopping and grazing, slash and burn cultivation, and timber extraction are generally considered to be the major factors responsible for deforestation and forest degradation, and these are considered responsible for loss of plant biodiversity. Another direct cause is rapid dissemination of alien invasive species. Several other underlying causes include:

- high dependency on forest resources leading to unsustainable harvesting practices
- illegal harvest of forest products
- infrastructure development
- forest fire
- natural calamities
- forest encroachment
- over-grazing
- climate change
- lack of good governance
- low level of peoples' awareness
- conversion of forest into other land use
- ambiguous policy.

Forest loss, degradation, and fragmentation is extensive in the Koshi Basin. In the Basin, the primary sources of threats are unsustainable use of forest resources, forest fires, over-grazing, land cover conversion, and climate induced disasters. Construction of series of hydro-power dams along all rivers prevent desired environmental flows as well as cause virtually irreversible ecological change. Effluents from sources ranging from agriculture and industries to municipalities and households pollute and poison water. These threats and drivers of threats are degrading the Koshi Basin ecosystems that deliver life-giving ecosystem services.

Hydrologic changes in rivers can alter environmental flows and ecosystem services. Climate change is expected to change precipitation regimes with alternating droughts and erratic rainfall, resulting in more frequent and intense fires and floods, respectively. River flows will become unpredictable and unreliable.

In the Koshi Basin, several natural disasters and human-caused factors have severe impact on forests and biodiversity that provide key resources and ecosystem services for local communities. The devastating earthquake of April 2015 has clearly showed that natural disasters are imminent in the

Koshi Basin, indicating a need of strengthening adaptation capacity of the communities. The earthquake and its aftershocks damaged the forest resources, including a large number of non-timber forest products and endemic plant species in 31 districts. FAO Rome estimated 2.2% of forest loss for 14 of the most affected districts of the Koshi River and Gandaki River Basins amounting to approximately 23,375 ha of forest at a value of NRs. 63.9 billion (NPC 2015 a,b). Out of 14 districts of the Koshi Basin, six districts, namely Sindhupalchowk, Dolakha, Ramechap, Kavre, Sindhuli and Okhaldhunga, were strongly affected in terms of forest mainly pine forest and lower temperate broadleaved forest (MoSTE 2015). The Protected Areas in the Koshi Basin that are affected by the earthquake include Sagarmatha National Park, Makalu-Barun National Park and Conservation Area, Gaurishankar Conservation Area, and the Gokyo and associated lakes (MoSTE 2015). Similarly, at least 200 Himalayan yew (mainly *Taxus wallichiana*) trees were lost in landslides triggered by the earthquake in Dolakha district, and cardamom cultivation areas in Kavre district (MoSTE 2015).

Slash-and-Burn or Swidden cultivation practice, commonly called Khoriya cultivation practice, involves one or few years of continued crop production/cultivation in a land followed by variable periods of fallow (Figure 6-12). It is more frequent in Taplejung, Sankhuwasabha and Panchthar districts. The pioneer plant communities that showed up in the fallow lands following Khoriya cultivation include *Eupatorium adenophorum* (= *Ageratina adenophora*), *Saxifraga brachypoda*, *Imperata cylindrica*, seedlings of *Maesa chisia*, *Eurya acuminata*, *Osbeckia nepalensis, Dryopteris cochleata* (Bhandari et al. 2002).

Figure 6-12 Slash and burn practice is widespread in the upper Arun Basin

Indigenous peoples in Koshi Basin are rich in ethnobotanical knowledge for their primary health care, fodder, food and other miscellaneous purposes. However, because of the transformation of societies, local peoples' indigenous knowledge is eroding (Nepal et al. 1999, Chaudhary et al. 2002, Taylor et al. 2002).

Over-grazing by domestic animals, fodder collection, hunting, illegal fishing, disturbance of nesting and feeding areas, poisoning that not only kills fish, but also birds that feed on fish and aquatic insects have together resulted in the deterioration and loss of suitable habitats for birds and other wildlife in Koshi Tappu Wildlife Reserve (Sah 1997). The invasive alien species, water hyacinth (*Eicchornia crassipes*) rapidly cover and choke water surface; whereas *Mikania micrantha* cover trees (Figure 6-13), shrubs and entire forest floor in the Koshi Tappu Wildlife Reserve (Sah 1997, Chaudhary et al. 2006).

Figure 6-13 *Mikania micrantha*, an alien invasive species dominant in Koshi Tappu Wildlife Reserve

Poaching of wildlife and illegal harvesting of non-timber forest products are also high threats, especially for the highly threatened species. Species such as Snow Leopard, Red Panda, Musk Deer, Pangolin, fishes, and several non-timber forest products such as *Ophiocordyceps sinensis* and a variety of alpine and temperate forest plants are especially affected and are at risk. Crop damage by wildlife, especially monkeys and wild boar, has been escalating and so is livestock predation by Common Leopards, Snow Leopards, Grey Wolves and other predators causing retaliatory actions by people.

The indigenous races of agricultural crops and livestock have been traditionally used by the people in the Koshi Basin. Conservation of the indigenous races is, however, important since many of them are likely to be more resistant to diseases, pests, and parasites than the hybrid varieties. Several fishes (especially the large *Labeo* species), have already become locally extinct, most likely due to poor water quality and inadequate water in the rivers.

Built-up areas include settlements and other infrastructure, such as hydropower structures, irrigation and transport and communication structures. Unplanned infrastructure development and operation is already causing severe environmental damage, with consequent negative impacts on socio-economic well-being, jeopardizing chances of socio-economic prosperity.

## 6.6 Conceptual model

The Koshi Basin, as in other parts of Nepal Himalaya, is highly sensitive to environmental degradation – change in environmental flows in the upstream can have large effects in the downstream areas and the region. IUCN defines environmental flow as the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where flows are regulated. Environmental flows play a key role to maintain river health, economic development and poverty alleviation. They ensure the continued availability of the many benefits that healthy river and groundwater systems bring to society (Dyson et al. 2003, Sharfroth et al. 2010).

Water is a central ecosystem service of the Koshi Basin. Thus, water conservation and maintaining environment flows to support and sustain life is one of the most essential conservation and management necessities within the Koshi Basin (Figure 6-14). The current practice of allocating 10% of the average monthly flow as environmental flow is flawed, because minimum flow is not the environmental flows. The Brisbane Declaration (2007) has defined environmental flows as quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that depend on these ecosystems. Therefore, the environmental flows need to be maintained for ecosystem functions, while allocating water for development (e.g., energy, irrigation, and drinking water), livelihoods, and socio-cultural needs.

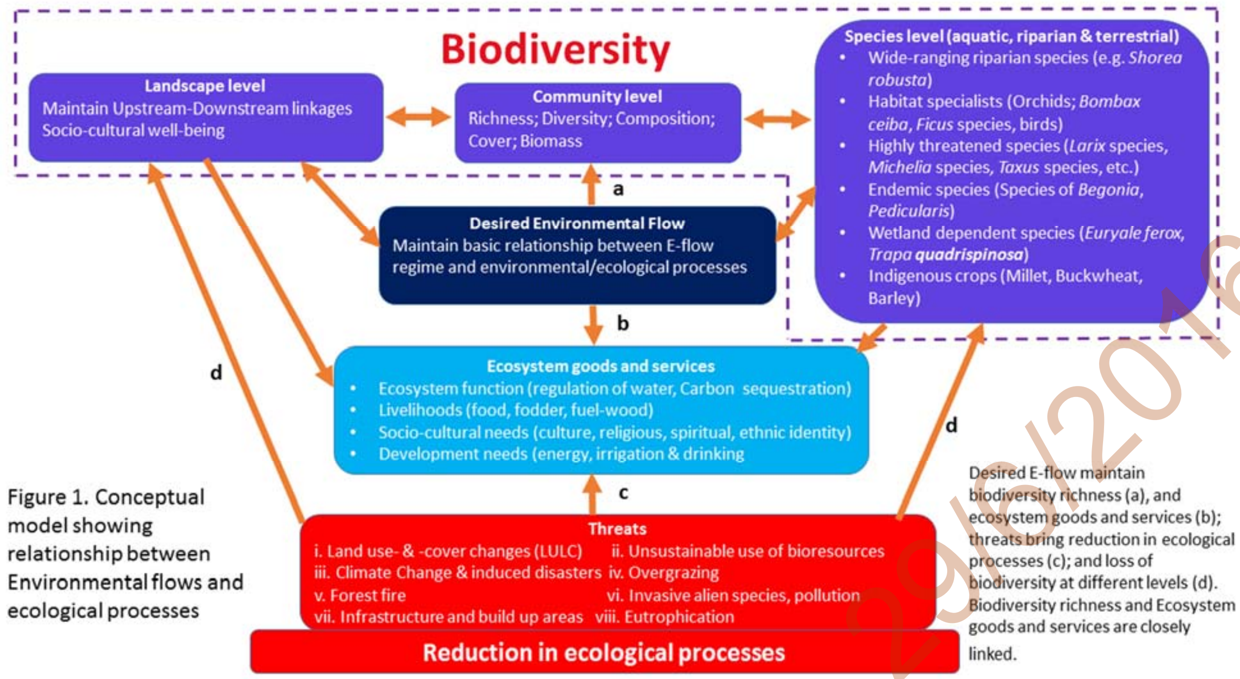


Figure 6-14 Generalised conceptual model demonstrating the importance of environmental flow to flora and vegetation

Desired environmental flows maintain basic hydrology–ecology relationship for diverse taxa including lower groups of flora and fauna, aquatic macroinvertebrates, microorganisms, fish, riparian plants and terrestrial fauna associated with different riparian vegetation types as well as indigenous agricultural crops. Environmental flows also contribute to ecosystem functioning and the provisions of ecosystem services that are crucial for human well-being. It provides basic goods and services for food security, human health, the provisions of clean air and water, and contributes to local livelihoods and economic development that are essential for achieving the Sustainable Development Goals of 2030, including poverty reduction (Figure 6-15).

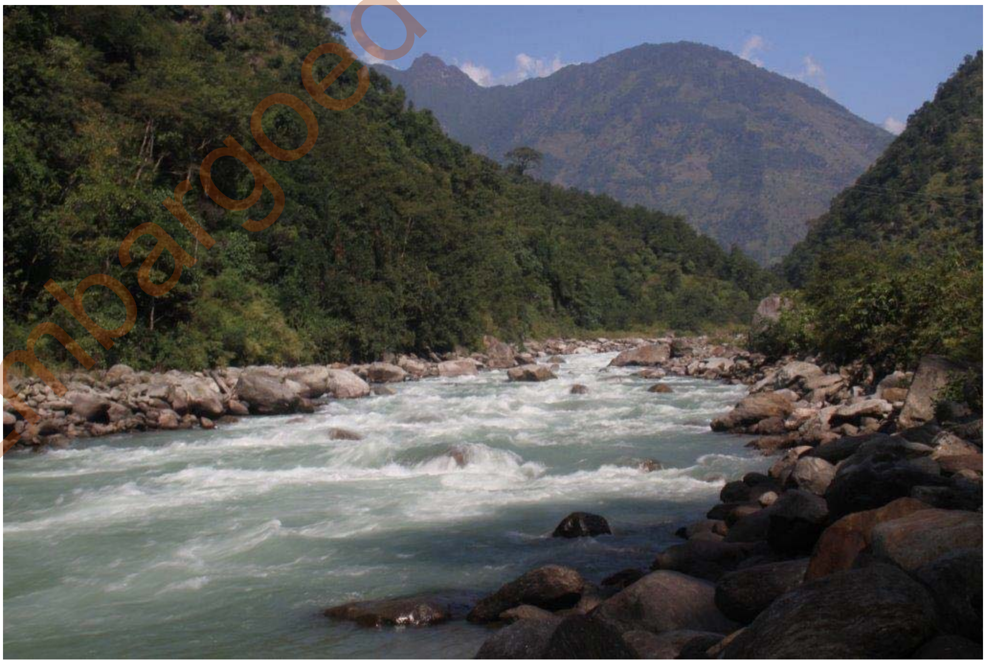

Figure 6-15 Sufficient environmental flow required for downstream ecosystem function

However, threats can damage ecosystems as well as jeopardize livelihoods through loss of biodiversity. Both natural and human induced threats pose risk to the livelihoods and human wellbeing due to loss of ecosystem services, biodiversity and reduction in ecological processes including loss of indigenous agricultural crops.

There are many methods for determining an environmental flow (Acreman and Dunbar 2004). For example, 'look-up tables' and 'desk-top analysis' for environmental flow assessment are used in scoping studies, national audits and river basin planning. Similarly, 'functional analysis' and 'habitat modelling' are widely applied approaches in impact assessment or restoration planning for single or multiple stretches of a river (Dyson et al. 2003). These assessment methodologies can contribute to setting management rules and monitoring their impact on river health.

Implementing environmental flows through active or restrictive flow management is often undertaken which involves management of infrastructure such as dams, or a restrictive management, for example through reducing the abstractions for irrigation. When active flow management is applied, an entire flow regime can be generated, including low flows and floods. In contrast, restrictive flow management involves allocation policies which ensure that enough water is left in the river, particularly during dry periods, by controlling abstractions and diversions. However, both types of interventions depend on people changing their behaviour, and should be based on an informed decision that has broad societal support (Dyson et al. 2003).

Many early applications of environmental flows setting were focused on single species or single issue justifying that the particular species is very sensitive to flow as well as that is appropriate to the species. More and more methods now, however, take a holistic approach that includes assessment of the whole ecosystem, such as associated wetlands, groundwater discharge, all species that are sensitive to flow (e.g. higher and lower plants and algae, vertebrates, invertebrates, etc.), all aspects of the hydrological regime including hydropower and irrigation; floods, droughts and water quality and quantity. Thus, holistic approach is a characteristic increasingly found in all environmental flow methods and place a greater emphasis (Acreman and Dunbar 2004).

In Koshi Basin, rivers are the important migratory route of various animal species. Rivers, pools and marshes are not only important for fish conservation but also provide habitat for threatened birds such as Ferrunginous Pochard (*Aythya ryroca*), Black-headed Ibis (*Threskiorus melanocephalus*), Black-necked Stork (Ephippiorhynchus asiaticus), Lesser Adjutant (*Leptoptilos jananicus*), and Greater Adjutant (*Leptotilos dubius*). Similarly, grassland and marshes on the river floodplains are home to globally threatened bird species such as Swamp Francolin (*Francolinus guleris*), Bengal Florican (*Houbaropsis bengalensis*), Lesser Florican (*Sypheotides indica*), and Hodgson's Bushchat (*Saxicola insignis*). Trees in the riparian habitat such as '*Simal*' or Silk-Cotton tree (*Bombax ceiba*) serves as an important habitat of endangered vultures (*Gyps* species) (Figure 6-16).

Figure 6-16 Silk-Cotton tree (*Bombax ceiba)* in riparian habitat provide shelter for birds (Dr. Yadav Uprety)

Temperate forest and alpine belt are likely to support significant population of bird species. Alpine meadows and dwarf scrub are good habitat for Wood Snipe (*Gallinago nemoricola*). Evergreen forest provide habitat for globally threatened bird species such as Satyr Tragopan (*Tragopan satyra*). Temba (Timbung) Pokhari (Kanchenjunga) and Tamur Valley are good habitat for Satyr Tragopan (*Tragopan satyra*) and Wood Snipe (*Gallinago nemoricola*). The Barahchhetra area (Sunsari district) supports threatened bird species including Yellow-rumped Honey guide (Indicator xanthonotus), White-rumped Vulture (*Gyps bengalensis*), Rufous-throated Wren Babbler (*Spelaecornis caudatus*), Spiny Babblet (*Turdoides nipalensis*) (Baral and Inskipp 2005).

## 6.7 Impacts of river flow change

Environmental flows are an important consideration at every stage in the management of a river Basin. Water is allocated traditionally for consumptive uses but also re-licensed for water storage infrastructure, hydropower production, irrigation and other multiple uses.

It is important to realise there are major uncertainties associated with environmental flows. There will be uncertainties over the science, for example about how much water is needed, when and how. Environmental Impact Assessments are conducted to best address changes in environmental flows as early as possible, though the lack of political attention and relevant information might impede progress. However, if uncertainties associated with environmental flows are left until later, the problems are often more severe and solutions will carry higher economic and social costs.

The different sections of the society accrue direct benefits from continuous environmental flows. Those are as follows (Dyson et al. 2003):

- business and households benefit by commercial use of river for fish, recreation, tourism, water supply and agriculture, transport for income generation and livelihoods
- subsistence households benefit by fulfilling their basic human needs for food, water, transport
- several individuals depend on flows for consumptive and non-consumptive uses for recreation, tourism, sport-fishing
- individuals also value the existence of rivers, and their aquatic habitat and biodiversity, for their own sake
- individuals, households and social groups that were put at risk by previous efforts to regulate rivers desperately need the continuous flow to be maintained.

River flow changes take place as urbanisation, population growth and economic development proceed requiring to reallocate water from one social use, such as agriculture, to another, such as municipal water supply. River flow changes may have impacts on: (i) water quality; (ii) commercial and non-commercial (subsistence) agriculture, timber, wildlife, and fisheries; (iii) on ecosystem and biodiversity; (iv) emissions of pollutants; (v) water-borne disease risks; (vi) social impacts, including impacts on cultural/historic sites, cultural identity, social cohesion, access to social services, etc. (Dyson et al. 2003). Lack of minimal discharge results in severe pollution, and an extreme case is the Vishnumati River in Kathmandu valley (Nepal) (Dyson et al. 2003).

It has been revealed that a ‘win-win’ scenario emerges where the financial flows generated by environmental flows are sufficient and in-line with desired economic results. In such a case, no additional finance is required. This is labelled the ‘trade-off’ scenario as the change to an environmental flow regime implies a negative sum game in which one actor will suffer in financial terms (Dyson et al. 2003).

## 6.8 Environmental flows potential metrics for monitoring

Each country has different experience with assessing environmental flows. Within some countries such as South Africa, Australia, the UK and the USA, specific methods have been developed, expert staff are available in universities, consultancies and government agencies, and national programmes of monitoring are in place (Dyson et al. 2003). For Nepal, there is no such experience and there may be a wish to establish a national environmental flow programme to develop the most appropriate methods, collect the right data and train appropriate personnel.

Following Dyson et al. (2003), it is, therefore, essential to monitor three elements:

- river flow to ensure that the implementation procedures are achieving the defined environmental flow, and in the long-term to determine the year-to-year variability of flows
- response of the ecosystem to assess whether the ecological objectives are being achieved, focusing on key indicator species
- social responses to ecosystem change to identify where and to what degree communities rely for their livelihoods on fish or other river related resources.

## 6.9 Knowledge gaps

### Environmental flow regime

The Nepalese part of the Koshi Basin is linked with China in the upstream and India in the downstream. It has been critically observed that the local communities are heavily interdependent for ecosystem services, biological resources, and cultural relationship. Water is a central ecosystem service of the Koshi Basin. Since, minimum flow is not the environment flow, a critical assessment of minimum environmental flow needs to be developed to maintain characteristic healthy river system as well as maintain other requirements for river health such as reduction of pollution and control of in-stream activities like fishing and recreation.

Environmental flows should therefore be considered as an integral part of the management of the Koshi Basin. However, there is no simple figure that can be given for the environmental flow requirements of the Koshi Basin, its wetlands and associated riparian areas. Much depends on stakeholders' decisions about the future character and health status of these ecosystems (Dyson et al. 2003). Scientists and experts need to conduct research that can help inform such decisions by providing information and knowledge on how the Koshi Basin ecosystem will evolve under various flow conditions. Environmental flow setting can best be done within the context of wider assessment frameworks that contribute to river basin planning as a part of Integrated Water management linking upstream-downstream linkage.

### Comprehensive account of flora and biodiversity

Knowledge status of biological diversity including floristic elements are far from complete for the Koshi Basin. An adequate inventory needs to be conducted to make a comprehensive account of Flora as well as to assess species richness and species diversity at different habitats such as aquatic, riparian and terrestrial. Emphasis should be given to study wide-ranging species, habitat specialists, highly threatened species, endemic species, wetland dependent species, wild relatives of crops, and indigenous crops that support livelihoods and are adapted to suitable environmental conditions.

## Assessment of critical habitat linkage

In addition to the Protected Areas system that play a key role in climate adaptation, new critical habitats and the necessity for linkages of such habitats to existing ones need to be identified (Chettri et al. 2010). There is a need to identify and protect the terrestrial, riparian and aquatic corridors that are essential for conservation of critical habitats for endemic species and habitat specialists as well as critical for sustaining the priority ecosystem goods and services. It is important to connect core areas that harbour viable breeding populations of focal species with habitat corridors to allow dispersal and migration through spatial planning.

An ecosystem approach to water allocation in integrated river basin planning and water resources development and management, using the river basin and sub-basins as the units of management need to be adopted. It is necessary to develop climate change-integrated management plans for Protected Areas including buffer zones, corridors, protection forests, and critical watersheds to guide conservation management.

## Focussed research on peoples' perception on climate change

Local people have often observed many evidences and identified issues related to climate change and its impact on livelihoods and environmental flow. Their perceptions on climate change is somewhat similar in many respects (Chaudhary and Bawa 2011, Macchi et al. 2011). For instance, in Kangchenjunga landscape, local communities have experienced a gradual increase in temperature in recent years; the rainfall pattern has been irregular, rainfall amount decreased in monsoon season and dry seasons have prolonged, less snowfall and snow cover prevail, conflict mostly due to drying-up of water sources have emerged (Chaudhary et al. 2015a); all affecting environmental flow regime and finally livelihoods of local communities. Focused research has to be conducted to understand current adaptive responses of biodiversity, and indigenous practice and coping mechanism of communities.

## Policy and enabling environment

Policies and Acts formulated in different sectors such as forest resources, biodiversity, protected areas, water resources, wetland, agriculture, and general development create enabling environment for the development and implementation of programs. The constitution of Nepal 2015 has given stress on prioritizing national investments in water resources based on people's participation and making multiple use of development of water resources as well as developing and producing renewable energy, ensuring cheap, easily available and dependable supply of energy, and making use of it to meet the basic needs of the citizens. The state is also directed to formulate and pursue a policy of designing a pre-warning system, disaster preparedness, rescue, relief works and rehabilitation in order to minimize the risk of natural disasters including holistic management of the river systems. However, minimum environmental flows regime for the effective management of river basin has not been mentioned. A serious attempt to manage for environmental flows will not occur unless clear policy decisions have been taken at the appropriate level of the government.

As per the constitutional provisions the following legislative matters related to natural and water resources fall under the federal list: international treaties and agreements, international boundary river, preservation of water resources, big hydro-electricity and irrigation projects, environment management, national forests within provinces, water use, environment management, land use policy, national parks and reserves, wetlands, forest policy, and carbon services.

The provincial governments will enact laws on the following matters applicable to the concerned provinces: provincial road, trade, land management records, research and management, agriculture and livestock development, national forest within provinces, water use, environment management, transportation, industry, and trade.

The local governments are authorized to make law on the following matters within their respective jurisdiction: watershed, wildlife, environment conservation, biodiversity, mining protection, small hydro projects, alternative energy, disaster management, and issues of environment.

The constitution does not only guarantee freedom and rights of the people, but also imposes a duty on citizens to protect and preserve public property. Therefore, policy need to be carefully designed within the context of the Koshi Basin which is shared mainly by Nepal and India as well as China.

## Conservation and development trade off

The Koshi Basin is extremely diverse in terms of biophysical and cultural aspects, and very potential with regard to multiple uses of water resources; thereby posing challenges to conservation targets. The resources and their linkages with human needs at spatial scale including upstream–downstream levels is still at a very low level of understanding. Competing interests will emerge between various consumptive users, and between upstream and downstream environmental and user benefits. Competition will also arise between parts of the river environment that require different natural flow regimes. Therefore, one of the challenges of providing environmental flows will be to determine which elements of the natural flow regime are critical to achieving the identified flow objectives. Variability in flow quantity, quality, timing, and duration are often critical to maintain river ecosystems. Identifying and making trade-offs are at the heart of setting and implementing environmental flows (Dyson et al. 2003). In the Koshi Basin, sustainable conservation and development in context to globalization and industrialization will require to address on-going processes and mainstreaming plans into national programmes. The Constitution of Nepal 2015 envisions regional and provincial balances in terms of development.

## Long-term socio-ecological and environmental monitoring

For the Koshi Basin there has been long-term socio-ecological and environmental monitoring information data gaps that are extremely important to help policy and decision makers, and planners to develop science based conservation and development policy. The Koshi Basin has been identified as one of the most biodiversity rich areas, culturally rich, serves as water tower for the region, and is the source of a wide range of ecosystems, both locally and globally (Xu et al. 2009). Long-term research is needed to provide a reliable source of information and knowledge, leading to innovations, solutions to challenges, and more effective management of resources (Chettri et al. 2015). Long-term consistent and monitoring of both climate change and its impact on biodiversity is clearly realized, and permanent plots and/or units need to be established on an altitudinal transect from tropical to alpine regions in order to monitor diverse ecosystems (Chettri et al. 2010).

## 6.10 Livelihoods

Nepalese societies rely on biodiversity for their livelihoods. The indigenous peoples and local communities have shaped the unique cultural landscape of the Nepal Himalayas that have been maintaining environmental flow and delivering ecosystem goods and services for centuries. However, human induced environmental flow changes, from the local to the global scale, have serious impacts on biodiversity at all levels as well as ecosystem goods and services (Figure 6-14). It is in particular indigenous people and local communities, who suffer most when environmental flows are changed leading to loss of biodiversity. Biodiversity provide directly or indirectly various types of ecosystem services ranging from habitat conservation and essential materials linked to livelihoods of people and economic development to maintenance of genetic diversity, such as maize diversity (Figure 6-17).

Figure 6-17 Farmers maintain maize diversity

The Koshi Basin, a hotspot of biodiversity, hosts a series of climatically different zones and a range of micro-habitats over short distances. Various initiatives have been undertaken to improve the livelihood of the local people through sustainable use of natural resources. Cardamom cultivation in eastern hills including the Koshi Basin has been promoted in ecologically suitable areas (Figure 6-18). Fish farming in lakes and reservoirs by indigenous and local communities such as Majhi, Danuwar, Bote, Mushhar and Tharus is being encouraged (Figure 6-19).

Figure 6-18 Cardamom cultivation, a source of economy in the Koshi Basin

Figure 6-19 Community dependent on fish for livelihoods, Koshi River

The cultivation of Seabuckthorn (*Hippophae salicifolia* and *H. tibetana*) in mountains districts such as Solukhumbu and Taplejung has been encouraged (Figure 6-20). The juice is used as beverage and contains high percentage of vitamin C, A and B12 (Pant et al. 2014).

Figure 6-20 Seabuck thorn (*Hippophae salicifolia*), an important plant species for domestic use as well as for trade

Figure 6-21 Raw materials of Lokta (*Daphne* species) and Argeli (*Edgeworthia gardneri)* bark collection

The government has encouraged the sustainable harvesting of yar-tsa-gunbu (*Ophiocordyceps sinensis*) by reducing the royalty. In the hills, such as Sankhuwasabha district, some of the species such as Allo (*Girardinia diversifolia*), and Maling (*Arundinaria* species), Lokta paper (species of *Daphne* and *Edgeworthia*) have supported livelihoods to generate income of the rural people (MoFSC 2009a) (Figure 6-21); as well as support enterprises in the urban areas (Figure 6-22). Caffeine free tea like beverage called ‘chhasing’ in Sherpa language and ‘bhote chiya’ in Nepali is prepared from leaves of an evergreen shrub *Cleyera japonica* var *wallichiana* (Theaceae) by Sherpa communities living in the Makalu-Barun region (Chaudhary et al 2004) (Figure 6-23).

Figure 6-22 Paper factory in urban areas obtain bark of Lokta and Argeli

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Figure 6-23 Bhote chiya (Tea-beverage) prepared from *Cleyera japonica*

Energy production and use remains a major challenge to ensure environmental sustainability for Nepal because 53.8 % of households use firewood for cooking purpose (CBS 2015). As many as 280,000 biogas plants have been installed in Nepal (NPC/UNCTN 2013) to meet the demand of fuel-wood. Progress to achieve sustainable energy is insufficient due to decrease in water level in the dam and river; and thus adversely affecting the livelihood and economic development in Nepal.

Little attention has been given to the importance of the floras and faunas that are used by the indigenous people in the form of important biological resources as medicines, food, grazing and hunting. Indigenous and other local people are vital and active partners of conservation of biological resources and cultural diversity. For example, indigenous people in Nepal possess rich traditional knowledge on the use of biological resources, whereas cultural heritage which is reflected in the form of over 123 distinct languages in Nepal (CBS 2012) is also at threat. The indigenous peoples, 'Sherpas', 'Gurungs' and others living in the high mountains would not survive without subalpine and alpine grasslands where they graze their Yaks and sheep, and Amchis who collect medicinal plants, like in TAR, China (Salick and Byg 2007).

## 6.11 Summary

There is an emerging trend worldwide to conserve flora and vegetation that are linked to livelihoods of peoples and economic development of the country. The Koshi Basin is highly diverse and rich in flora and vegetation. But the Basin is highly sensitive to environmental degradation. A change in environmental flows in the upstream can have large effects in the downstream areas and the region.

The Koshi Basin is also a critical corridor for the downstream and upstream passage of aquatic and riparian organisms. Therefore, desired environmental flows need to be maintained to understand basic hydrology-ecology relationship of diverse taxa including lower groups of flora and fauna, aquatic macroinvertebrates, microorganisms, fish, riparian plants and terrestrial fauna such as Wild Water Buffalo (*Bubalus bubalis arnee*) (Figure 6-24) associated with different riparian vegetation types as well as indigenous agricultural crops.

In general, the current practice of allocating 10 percent of the average monthly flow as environmental flow is misleading. However, there is no simple figure that can be given for the environmental flow requirements of the Koshi Basin, its wetlands and associated riparian areas. For Nepal, there is no such experience too, and much is still to be learnt, but environmental flows should be considered as an integral part of the management of the Koshi Basin. A holistic approach includes assessment of all species and the whole ecosystem rather than a single species or single issue. There is an urgent need to develop methods and frameworks for environmental flows in Nepal in general and the Koshi Basin in specific using the best knowledge and with the involvement of all relevant stakeholders and local communities.

Figure 6-24 Environmental flow is essential for sustenance of endangered wildlife (such as Wild Water Buffalo (*Bubalus bubalis arnee*) downstream, Koshi Tappu Wildlife Reserve (Dr. Yadav Uprety)


## Acknowledgements

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## Annex: Tables

Table 6-1 Vegetation of the southern slope of the Himalayas (Sources: Stainton (1972), Miehe et al. (2015a))

| Bioclimatic belt (altitude m) | Vegetation & Forest types (altitude m) | Major floristic species |
|---|---|---|
| Tropical (up to 1000m) | Shorea robusta forest (up to 1200m) | *Shorea robusta, Terminalia alata, T. bellerica, T. chebula, Adina cordifolia, Ficus racemosa, Dillenia pentagyna, Lagerstroemia parviflora, Cassia fistula, Mallotus philippensis, Semecarpus anacardium, Syzygium cumini* |
| | Terminalia and Anogeissus forest (up to 1200m) | *Terminalia tomentosa, Anogeissus latifolia, Mallotus philippensis, Dodonaea viscosa, Woodfordia fruticosa* |
| | Riverine grassland (up to 400m) | *Saccharum spontaneum, Narenga porphyrocoma, Themeda arundinacea, Phragmites karka, Arundo donax, Imperata cylindrica, Cymbopogon jwarancusa, Bothriocloa intermedia* |
| | Dalbergia sissoo-Acacia catechu riverine forest (up to 1000m) | *Dalbergia sissoo, Acacia catechu, Tamarix dioica, Saccharum spontaneum, S. bengalense, Zizyphus species, Murraya koenigii, Callicarpa macrophylla* |
| | Bombax riverine forest (up to 1400m | *Bombax ceiba, Grewia disperma, Celtis tetranda, Croton roxburghii, Holarrhena pubescens, Colebrookea oppositifolia, Pogostemon bengalensis* |
| | Swampy grassland (in lowland) | *Typha angustifolia, Vetiveria zizanoides, Scoparia dulcis, Spilanthes calva, Urena lobata, Phragmites karka, Spiranthes sinensis, Cyperus sanguinea, Fimbrystylis aestivalis* |
| | Aquatic/marshy vegetation (in lowland) | *Eichhornia crassipes, Pistia stratiotes, Nelumbo nucifera, Nymphaea stellata, Typha angustifolia, Persicaria hydropiper, Ipomoea carnea* |
| Subtropical (1000-2000m) | Schima-Castanopsis forest (1000-2000m) | *Schima wallichii, Castanopsis indica, C. hystrix, C. tribuloides, Engelhardia spicata, Stereospermum tetragonum, Magnolia champaca, M. campbellii, Eurya acuminata* |
| | Quercus lanata forest (1500-2400m) | *Quercus lanata, Rhododendron arboreum, Ilex dipyrena, Symplocos paniculata, Lindera pulcherimma, Lyonia ovalifolia, Zanthoxyllum* species, *Viburnum cylindricum* |
| | Pinus roxburghii forest (800-2000m, up to 2700m) | *Pinus roxburghii, Woodfordia fruticosa, Pyracantha crenulata, Rhododendron arboreum, Lyonia ovalifolia, Caryopteris foetida, Quercus incana, Q. leuchotrichophora* |
| | Toona ciliata-Albizia julibrissin riverine forest (600-1700m) | *Toona ciliata, Albizia julibrissin, Pandanus nepalensis, Cyathea spinulosa* |
| | Alnus nepalensis riverine forest (1000-2450m) | *Alnus nepalensis, Boehmeria platyphylla, B. rugulosa, B. macrophylla, Debregeasia salicifolia, Girardinia diversifolia, Clematis* species |
| | Thickets and pastures (1000-2500m) | *Eupatorium adenophorum (=Ageratina adenophora), Lantana camara, Ageratum conyzoides, Cynodon dactylon, Chrysopogon aciculatus, Setaria pallidefusca, Pteridium aquilinum, Callicarpa macrophylla, Colquhounia coccinea, Zanthoxyllum armatum, Hypericum uralum, Berberis asiatica* |
| The cloud forest (1600-4000m) | Quercus lamellosa forest (1600-2800m) | *Quercus lamellosa, Q. glauca, Lithocarpus elegans, Castanopsis tribuloides, Litsea* species, *Cinnamomum* species, *Neolitsea* species, *Lindera* species, *Euonymous* species, *Himalayacalamus falconeri, Yushania maling, Drepanostachyum* species |
| | Lithocarpus pachyphylla forest (2400-2900m) | *Lithocarpus pachyphylla, Quercus lamellosa, Magnolia campbellii, Betula alnoides, Neolitsea foliosa, Litsea elongata, Lindera pulcherrima, Ilex dipyrena, Daphniphyllum himalense* |

| Bioclimatic belt (altitude m) | Vegetation & Forest types (altitude m) | Major floristic species |
|---|---|---|
| | Quercus semecarpifolia forest (2400-3000m) | *Quercus semecarpifolia, Betula utilis, Rhododendron arboreum, Lyonia ovalifolia, Pieris formosa, Viburnum cotinifolium, Cotoneaster microphyllus* |
| | Tsuga dumosa forest (2100-3600m) | *Tsuga dumosa, Quercus lamellosa, Q. semecarpifolia, Abies spectabilis, Lithocarpus pachyphylla, Magnolia campbellii, Sorbus cuspidata, Hedera nepalensis, Rubus nepalensis* |
| | Rhododendron arboreum forest (1200-3400m) | *Rhododendron arboreum, Pieris formosa, Lyonia ovalifolia, Abies spectabilis, Quercus semecarpifolia, Fragaria nubicola, Hemiphragma heterophyllum* |
| | Rhododendron hodgsonii forest (3000-4000m) | *Rhododendron hodgsonii, R. grande, R. falconeri, Sphagnum* species, Lichens |
| | Abies spectabilis forest (3000-4200m) | *Abies spectabilis, Rhododendron barbatum, R. campanulatum, Betula utilis, Lyonia villosa, Sorbus cuspidata, Juniperus recurva, Daphne bholua, Viburnum grandiflorum, Cotoneaster acuminatus, Rosa macrophylla* |
| | Juniperus recurva forest (3000-4300m) | *Juniperus recurva, Rhododendron campanulatum, R. lepidotum, Cotoneaster microphyllus, Berberis* species, *Rosa sericea, Bistorta amplexicaulis* |
| | Juniperus recurva thickets (3600-4200m) | *Juniperus recurva, Berberis concinna, Rhododendron lepidotum, Rosa sericea, Saxifraga hispidula, S. parnassifolia, Anaphalis contorta* |
| | Rhododendron thickets (3800-4400m) | *Rhododendron wallichii, R. fulgens, R. campylocarpum, Sorbus microphylla, Boschniakia himalaica, Lobaria psedopulmonarica, Neopicrorhiza scrophulariiflora* |
| | Bamboo thickets (3000-3600m) | *Yushania* species, *Arundinaria* species, *Thamnocalamus spathiflorus, Drepanostachyum falcatum* |
| | Tall forb communities of cattle resting places (2000-4300m) | *Rumex nepalensis, Cynoglossum glochidiatum, Poa annua, Capsella bursa-pastoris, Malva verticillata, Elsholtzia eriostachya, E. strobilifera, Primula obliqua, Anemone rivularis, Iris kemaonensis, Scopolia straminifolia, Sambucus adnata* |
| | The upper treeline (3900-4440m) | *Juniperus recurva, Betula utilis, Larix* species, *Picea* species, *Betula* species, *Sorbus* species, *Potentilla fruticosa, Rosa* species, *Caragana* species, *Cotoneaster* species, *Lonicera* species |
| Alpine (4,000-5,100) | Rhododendrom dwarf thickets (3800-5100m) | *Rhododendron setosum, Neopicrorhiza scrophulariiflora, Cassiope* species, *Bergenia* species, *Bistorta macrophylla, B. affinis, Caltha palustris, Potentilla macrophylla, Kobresia nepalensis, Primula obliqua, Leontopodium jacotianum, Anaphalis triplinervis, Euphorbia stracheyi, Nardostachys jatamansi* |
| | Kobresia nepalensis mats (4600-5600m) | *Kobresia nepalensis, Bistora macrophylla, Saussurea* species, *Primula* species, *Pedicularis* species, *Potentilla macrophylla, Festuca* species, *Poa* species, *Elymus* species, *Juncus* species, *Cyananthus* species, *Leontopodium* species, *Anemone* species, *Ranunculus* species, *Primula* species, *Euphorbia* species |
| | Crustose lichen covers of rock walls (5000 and above) | *Lecidea vorticosa, Lecanora polytropa, Sporastatia testudinea, Ascicilia* species, *Rhizocarpon geographicum* |

Table 6-2 Vegetation of the Inner valley (Sources: Stainton 1972, Miehe et al. 2015a)

| Bioclimatic belt (altitude m) | Vegetation & Forest types (altitude m) | Major floristic species |
|---|---|---|
| Temperate (2000-4000m) | Pinus wallichiana forest (3000-3600m) | *Pinus wallichiana, Alnus nepalensis, Abies spectabilis, Pteridium aquilinum, Zanthoxyllum* species, *Rubus* species, *Elsholtzia* species, *Mahonia napaulensis , Berberis* species, *Themeda triandra, Andropogon munroi. Hemiphragma heterophyllum, Fragaria nubicola, Anaphalis contorta, Halenia elliptica* |
| | Betula utilis forest (3600-4200m) | *Betula utilis, Pinus wallichiana, Quercus semecarpifolia, Rhododendron campanulatum, R. fulgens, Lonicera* species, *Ribes* species, *Cotoneaster acuminatus, Allium prattii, Bistorta amplexicaulis, Carex lehmanni* |
| | Juniperus indica forest (3000-3700m) | *Juniperus indica, Spiraea arcuata, Potentilla fruticosa, Lonicera* species, *Cotoneaster* species, *Viburnum cotinifolium, Artemisia santolinifolia, Rosa sericea, Caragana* species, *Ribes* species |
| | Larix forest (3000-4100m) | *Larix griffithiana, Hippophae tibetana* |
| | Hippophae riverine woodland (2000-3400m) | *Hippophae salicifolia, Pinus wallichiana* |
| | Caragana sukiensis thickets (2400-3700m) | *Caragana sukiensis, Leptodermis kumaonensis, Viburnum cotinifolium, Philadelphus tomentosus, Leycesteria tomentosa, Deutzia staminea, Spiraea bella, Rhododendron lepidotum, Elsholtzia fruticosa* |
| | Rhododendron lepidotum shrubland 2500-4850m) | *Rhododendron lepidotum, Strobilanthes atropurpureus, Dipsacus inermis, Saxifraga parnassifolia, Primula glomerata, Polygonatum verticillatum* |
| | Rosa-Berberis-Cotoneaster shrubland (2000 and 3500-4050m) | *Rosa* species, *Berberis* species, *Cotoneaster* species, *Podophyllum hexandrum, Arisaema jacquemontii, Polygonatum cirrhifolium, Fritillaria cirrhosa, Princepia utilis, Morina polyphylla, Pleurospermum rotundatum, Primula gracilipes* |
| Alpine belt (4000-5500m) | Juniperus squamata dwarf shrublands (4000-5200m) | *Juniperus squamata, Berberis concinna, B. murcrifolia, Lonicera myrtillus, Ephedra gerardiana, Rosa sericea, Artemisia santolinifolia, Anaphalis royleana, Aster albescens* |
| | Kobresia pygmaea dwarf mats (4700-5960m) | *Kobresia pygmaea, Thalictrum alpinum, Astragalus confertus, Taraxacum officinale, Pedicularis* species, *Rhodiola coccinea, Swertia multicaulis, Bistorta macrophylla, Potentilla macrophylla* |
| | High alpine cushion communities and highest plant records (5000-5960m) | *Delphinium* species, *Gentiana* species, cushions of *Caryophyllaceae (Arenaria & Stellaria* species), *Androsace* species, *Saxifraga* species, *Rhodiola* species, *Sibbaldia* species, *Potentilla* species, *Rhododendron nivale, Saussurea gossypiphora, Ophiocordyceps sinensis* |
| | Hippophae tibetana riverine dwarf thickets (3500-5000m) | *Hippophae tibetaa, Myricaria* species, *Koenigia nepalensis, Oxyria digyna, Senecio albopurpureus, Stellaria decumbens, Hypecoum leptocarpum, Epilobium* sp., *Veronica cephaloides, Rumex* sp., *Rheum* species, *Artemisia wallichiana* |
| | Pioneer plant succession in glacial forelands (5000-6000m) | *Bryum* species, *Stellaria decumbens, Oxyria digyna, Epilobium* species, *Rhizocarpon geographicum, Myricaria* species, *Senecio albopurpureus* |

Table 6-3 Endemic plant species in the Koshi Basin (compiled from Rajbhandari & Adhikari 2009, Rajbhandari & Dhungana 2010, Rajbhandari & Dhungana 2011, Rajbhandari 2016a). There are a few taxa not yet registered in the tropicos.org and other global database; as well as a few names (marked*) yet to be resolved.

| Family (Genus/species) | Species |
|---|---|
| Acanthaceae (2/2) | *Aechmanthera claudiae* Bernerdi (= *Strobilanthes tomentosa* (Nees) J.R. I Wood); *Justicia tukuchensis* V.A.W. Graham |
| Balsaminaceae (1/4) | *Impatiens arunensis* Grey-Wilson; *I. harae* H. Ohba & S. Akiyama; *I. kharens* S. Akiyama, H. Ohba & Wakabaya; *I. mallae* S. Akiyama & H. Ohba |
| Begoniaceae (1/6) | *Begonia dolichoptera* S. Rajbhandary & KK Shrestha; *B. leptotera* H. Hara; *B. minicarpa* H. Hara; *B. tribenensis* C.R. Rao; *B. leptoptera* H. Hara; *B. panchtharensis* S. Rajbhandary |
| Berberidaceae (1/1) | *Berberis murcrifolia* Ahrendt |
| Boraginaceae (1/1) | **Onosma verruculosum* I.M. Johnst. |
| Campanulaceae (1/1) | *Cyananthus hayanus* C. Marquand |
| Compositae (3/5) (Asteraceae) | *Saussurea bhutkesh* K. Fujikawa & H. Ohba; **S. rolwalingensis* K. Fujikawa & H. Ohba; **Senecio brunneo-villosus* Kitam., **S. topkegolensis* Kitam., *Synotis panduriformis* C. Jeffrey & Y.L. Chen |
| Cruciferae (2/2) (Brassicaceae) | **Aphragmus hinkuensis* (Kats. Arai. H. Ohba & Al-Shehbaz) Al-Shehbaz & S.I. Warwick; *Solms-laubachia nepalensis* (H. Hara) J.P. Yue, Al-Shehbaz & H. Sun |
| Cyperaceae (1/5) | *Carex himalaica* T. Koyama; *C. esbirajbhandari* (K.R. Rajbh.  & H. Ohba) O. Yano; *C. himalaica* T. Koyama; *C. harae* K.R. Rajbhandari & H. Ohba; *K. kanaii* K.R. Rajbhandari & H. Ohba |
| Eriocaulaceae(1/4) | *Eriocaulon exsertum* Satake; *E. obclavatum* Satake; *E. staintonii* Satake; *E. trisectoides* Satake |
| Euphorbiaceae (1/1) | *Euphorbia schillingii* Radel.-Smith |
| Gentianaceae (2/6) | *Gentiana chateri* T.N. Ho; *G. pentasticta* C. Marquand; *G. radicans* H. Sm. ; *G. sagarmathae* Miyam. & H. Ohba; *Swertia acaulis* H. Sm.; *S. barunensis* P. Chassot |
| Gramineae (2/2) (Poaceae) | *Borinda emeryi* Stapleton; *Poa imperialis* Bor |
| Labiatae (3/4) (Lamiaceae) | *Eriophyton nepalense* Hedge; *E. staintonii* (Hedge) Ryding; *Isodon dhankutanus* Murata; *Microtoena nepalensis* Stearn |
| Lauraceae (1/1) | *Litsea doshia* (D. Don) Kosterm. |
| Leguminosae (2/2) (Fabaceae) | *Cotulea multiflora* Shap. ex Ali; *Oxytropis arenae-ripariae* Vass. |
| Lythraceae (1/1) | *Rotala rubra* (Buch.-Ham. ex D. Don) H. Hara |
| Oleaceae (1/1) | *Jasminum amabile* H. Hara |
| Orchidaceae (1/1) | *Malaxis tamurensis* Tuyama |
| Papaveraceae (1/1) | *Corydalis megacalyx* Ludlow |
| Polygonaceae (1/3) | *Bistorta confusa* (Meisn.) Greene; *B. diopetes* H. Ohba & S. Akiyama; *B. milletioides* H. Ohba & S. Akiyama |
| Primulaceae (1/2) | *Primula didyma* W. W. Sm.; *P. wigramiana* W. W. Sm. |
| Ranunculaceae (3/6) | *Aconitum angulatum* Tamura; *A. bhedingense* Lauener; *A. deltoideum* Lauener; *A. staintonii* Lauener; *Anemone fusco-purpurea* H. Hara; *Ranunculus makaluensis* Kadota |
| Rosaceae (4/5) | *Potentilla makaluensis* H. Ikeda; *Prunus taplejunica* H. Ohba & S. Akiyama; *P. topkegolensis* H. Ohba & S. Akiyama; *Sibbaldia emodi* H. Ikeda & H. Ohba; *Sorbus sharmae* M.F. Watson, V. Manandhar & Rushforth |
| Salicaceae (1/2) | *Salix plectilis* Kimura; *S. staintoniana* Skvortsov |
| Saxifragaceae (1/7) | *Saxifraga amabilis* H. Ohba & Wakab.; *S. harae* H. Ohba & Wakab.; *S. jaljalensis* H. Ohba & S. Akiyama; *S. mallae* H. Ohba & Wakab.; *S. rolwalingensis* H. Ohba.; *S. williamsii* H. Sm.; *S. zimmermannii* Baehni |
| Scrophulariaceae (1/6) | **Pedicularis anserantha* T. Yamaz.; **P. cornigera* Yamazaki; **P. oxyrhyncha* Yamazaki; **P. tamurensis* Yamazaki; **P. terrenoflora* Yamazaki; **P. yalungensis* Yamazaki |
| Umbelliferae (Apiaceae) (4/4) | *Acronema cryptosciadeum* Farille & Lachard; *Chamaesium shrestaeanum* Farille & Malla; *Cortia staintoniana* Farille & Malla; *Cortiella lamondiana* Fullarton & M.F. Watson |

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# 7 Biodiversity values of the Koshi Tappu Wildlife Reserve

*Authors: Nakul Chettri[1,] Sunita Chaudhary[1,2], Kabir Uddin[1], Bikash Sharma[1], Pratikshya Kandel[1], Top Bahadur Khatri[3], Maheswar Dhakal[4], Wu Ning[1], Eklabya Sharma[1]*



## 7.1 Introduction

Biodiversity (the variability among the living organisms) and ecosystem services (the benefits people obtain from ecosystems) are declining worldwide (Vitousek et al. 1997, Hoekstra et al. 2005, Butchart et al. 2010), spurring scientists and policymakers to act together to identify effective policy solutions (Görg et al. 2010, Díaz et al. 2015). Recently, the recognition that these two forms of environmental change are inextricably linked is widely documented (Daily 1997, MEA 2005, TEEB 2010). They are also considered as products of coupled and nested social–ecological systems in which humans depend on biodiversity for the generation of goods and services that contribute to human wellbeing (MEA 2005, Daw et al. 2011, Reyers et al. 2013, Hicks et al. 2015).

The growing popularity of the ecosystem services concept can be seen primarily as a reaction to the long-term disconnect between biophysical and ecosystem integrity in societal systems, and also partly as a response to growing concern in relation to degradation of ecosystems that are the basis for providing these services (Boyd and Banzhaf 2007). This anthropocentric approach to biodiversity promotes new thinking about the contribution of the coupled system to human wellbeing (Costanza et al. 1987, Daily and Matson 2008, Scholes et al. 2013, Chaudhary et al. 2015c). In recent years, ecosystem services have also been recognized based on the ecological and social values separate to the economic values (Castro et al. 2014, Maes et al. 2016) and have been considered as an important factor for poverty alleviation where the dependency of people on ecosystems is much higher (Grêt-Regamey et al. 2012, Sandhu and Sandhu 2015, Suich et al. 2015).

Wetlands, which are well recognized for their significant role in supporting high biodiversity and providing food, water and livelihoods security to the people living around them (Rebelo et al. 2009), are subject to over-exploitation and continuous degradation (Gopal 2013, Lamsal et al. 2014). During the 20$^{th}$ and the beginning of the 21$^{st}$ century, about 87% of wetlands worldwide have already been lost compared to losses in the 18$^{th}$ Century (Davidson 2014). Of the remaining wetlands, more than 60% are being degraded or used unsustainably, especially from land conversion, pollution and over-harvesting (MEA 2005). This is a prominent issue in many developing countries, including Nepal, where people are highly dependent on natural resources, especially on wetlands, for their

1 International Centre for Integrated Mountain Development, Kathmandu, Nepal
2 Macquarie University, Department of Geography and Planning, Australia
3 Department of Hydrology and Meteorology, Government of Nepal, Kathmandu, Nepal
4 Ministry of Forests and Soil Conservation, Government of Nepal, Kathmandu, Nepal

subsistence livelihoods (Chettri et al. 2013, Chaudhary et al. 2015c, Lamsal et al. 2015). However, these wetland ecosystems, though some are designated and managed as protected areas, are considered as islands for biodiversity repository without linking them to the surrounding landscapes (Chettri et al. 2013, ICIMOD & MoFSC, 2014).

With these considerations, we have used a driver, pressure, state, impact and response (DPSIR) Framework following Pinto et al. (2013) to review the biodiversity and ecosystem services values and the socio-ecological linkages of the wetlands of the Koshi Tappu Wildlife Reserve (the Reserve), to understand the following key questions:

1. What is the significance of the Reserve in terms of its biodiversity value?
2. In what way does the Reserve support the local communities in terms of ecosystem services?
3. How is the surrounding Koshi Basin related to the Reserve for its sustainability?

## Material and methods

To address the above research questions, we primarily relied on published literature available for the Koshi Basin with special reference to the Reserve. To answer the first question, major conservation values in terms of species of global significance and major fauna reported until 2013 were discussed along with recent analysis by Chettri et al. (2013). Likewise, the ecosystem services provided by the Reserve were included from the recent study by Chaudhary et al. (2014) and the economic values from Sharma et al. (2015). The third question regarding the state of the Basin in terms of risk to the Reserve was articulated from other basin-level studies (i.e. Neupane et al. 2013, Uddin et al. 2015, 2016).

## Study area

Koshi Tappu Wildlife Reserve is one of the most important wildlife reserves of Nepal. The Reserve, a protected area established in 1976 under IUCN category IV, spreads over an area of 175 km$^2$ (IUCN 1990).

Before its declaration as a Reserve in 1976 by the Government of Nepal, the area was accessible to local communities for fishing, hunting, grazing, livestock, and collecting fodder, fuelwood, and other resources (CSUWN 2009). However, their access was restricted with the declaration of the Reserve, resulting in illegal harvesting of resources (Heinen 1993b). To halt illegal harvesting and meet the basic needs of people, the Reserve established a buffer zone of 173.5 km$^2$, encompassing 16 village development committees (VDCs) from Sunsari, Saptari, and Udayapur districts with a total population of 77,970 people from 10,693 households (Shakya et al. 2013). The overall literacy rate is less than 50% and agriculture is the dominant mode of production for just over 87% of households. Only 20% of households are food secure. Livestock density is very high with 1.5 cattle per household. The harvest and use of resources from this important floodplain play a prominent role in local people's occupations and way of life. Besides subsistence farming, livestock rearing is a major economic activity, and income from livestock contributes a substantial proportion of local household income (Sah 1997, CSUWN 2009). A large proportion of communities still directly or indirectly depend on the Reserve for various goods and services (ICIMOD & MoFSC 2014).

### Review framework

We used a driver, pressure, state, impact and response (DPSIR) Framework (Figure 7-1) to understand the coupled socio-ecological linkages in the Koshi Basin. The framework elements used to develop the linkages were taken from the published literature (e.g. Pinto et al. 2013).

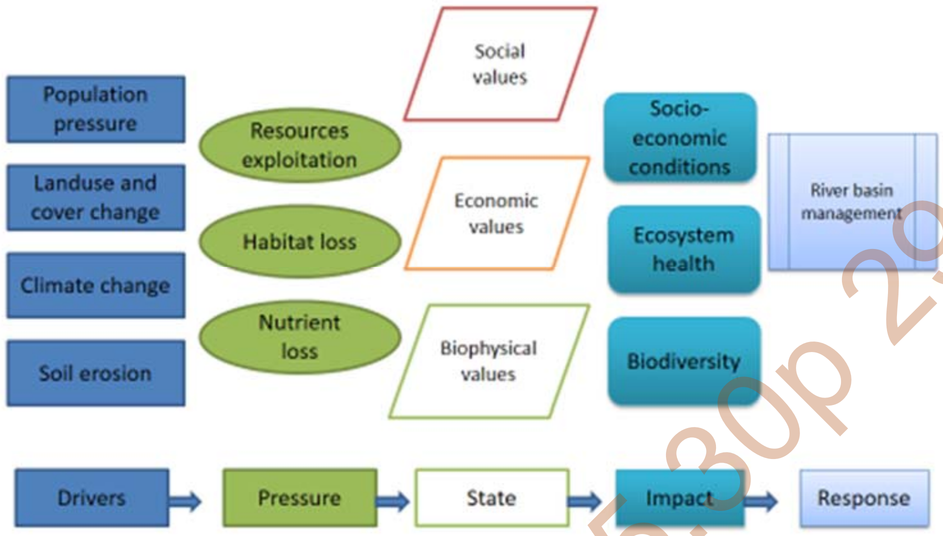


Figure 7-1 DPSIR Framework used to understand the coupled socio-ecological system in Koshi Basin. Drivers can include flow regime change, hydropower development, drought (for example)

## 7.2 Biodiversity and ecosystem outcomes

### Biodiversity value

The Reserve was designated as a wetland of international importance by the Ramsar Convention in 1987 for its special value in maintaining the genetic and ecological diversity of the region (Sah 1997). Located in the floodplains of Sapta Koshi river, the Reserve is a freshwater, natural and permanent river system. The Reserve is rich in biodiversity with 670 species of vascular plants (Siwakoti 2006), 21 species of mammals (Chhetry and Pal 2010), 23 species of herpetofauna (Chhetry 2010), 77 species of butterflies (DNPWC 2009), 494 species of birds (BCN 2011) and is habitat for a large number of globally and nationally threatened species (CSUWN 2009). The Reserve is also designated as one of the Important Bird Areas of Nepal with habitat for a number of endangered bird species. The wetland is also home to Ganges River Dolphin (*Planatnista gangetica*), Gharial crocodile (*Gavialis gangeticus*) and Smooth coated Otter (*Lutrogale perspicillata*). These globally important species play a vital role in maintaining the ecological integrity of the area.

A land cover/ecosystem and habitat matrix indicated that the majority of species use a wide variety of land cover or ecosystems and in many cases they are overlapping (Chettri et al. 2013). For example, Rock Python (*Python molurus)*, Red-crowned Roof Turtle (*Batagur kachuga*), Yellow-headed Tortoise (*Indotestudo elongata*), Greater Adjutant (*Leptoptilos dubius*) and Swamp Francolin *(Francolinus gularis*) were reported from more than three land cover types or ecosystems. Many species have narrow habitat ranges. Gharial Crocodile (*Gavialis gangeticus*) and Mugger (*Crocodylus palustris*) were restricted to swamps/marshes and river/lakes. In a matrix analysis (Table 7-1), swamps/marshes scored the highest species number with 15, followed by forest (14), river and lake (13) and grassland (12) and the least by agriculture (2). It was observed that forested ecosystems of the Reserve are one of the most important habitats used by 15 globally significant species followed by rivers/lakes and grassland. These matrix ranking values were then converted to raster maps prepared for land cover of 2010 to show their potential richness (number of species) to each of the ecosystems types defined earlier (Figure 7-2).

Table 7-1 Species Habitat Matrix of the Koshi Tappu Wildlife Reserve, Nepal.● indicates the species has been recorded as occurring in that land cover/use (Source: Chettri et al. 2013)

| Species | Status* | | Land cover / land use | | | | | |
|---|---|---|---|---|---|---|---|---|
| | IUCN | CITES | Grass land | Swamps /marshes | Forests | River /lakes | Sand/ gravels | Agri-culture |
| Wild Water Buffalo (*Bubalus arnee*) | EN | III | ● | ● | | ● | | |
| Ganges River Dolphin (*Platanista gangetica*) | EN | I | | | | ● | | |
| Black Giant Squirrel (*Ratufa bicolor*) | NT | I | ● | | ● | | | |
| Hog Deer (*Axis porcinus*) | EN | I | ● | | ● | | | |
| Smooth coated Otter (*Lutrogale perspicillata*) | VU | II | | ● | ● | ● | | |
| Fishing Cat (*Prionailurus viverrinus*) | EN | II | | ● | ● | ● | | |
| Asian Elephant (*Elephas maximus*) | EN | I | ● | ● | ● | | | |
| Indian Bison or Gaur (*Bos gaurus)* | VU | I | ● | | ● | | | |
| Spotted Leopard (*Panthera pardus*) | NT | I | ● | | ● | | | |
| Gharial (*Gavialis gangeticus*) | CR | I | | ● | | ● | | |
| Mugger *(Crocodylus palustris)* | VU | I | | ● | | ● | | |
| Rock Python *(Python molurus)* | NT | II | ● | ● | ● | ● | ● | |
| King Cobra (*Ophiophagus hannah*) | VU | II | ● | ● | ● | | | |
| Red-crowned Roof Turtle *(Batagur kachuga)* | CR | II | ● | ● | ● | ● | | |
| Yellow-headed Tortoise *(Indotestudo elongata)* | EN | II | ● | ● | ● | ● | | |
| Indian Softshell Turtle *(Nilssonia gangetica)* | VU | I | | ● | | ● | | |
| Greater Adjutant *(Leptoptilos dubius)* | EN | | | ● | ● | ● | | ● |
| Pallas's Fish Eagle *(Haliaeetus leucoryphus)* | VU | II | | ● | ● | ● | | |
| Bengal Florican *(Houbaropsis bengalensis)* | CR | I | ● | ● | | | | |
| Swamp Francolin *(Francolinus gularis)* | VU | III | ● | ● | ● | ● | | ● |

(*) Status
IUCN (International Union for Conservation of Nature). CR=Critically Endangered; EN=Endangered; NT=Near Threatened; VU=Vulnerable
CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) status. (Appendix) I = species that are threatened with extinction; II = species not necessarily threatened with extinction, but may become so if trade is not regulated; III = species listed by one member country to request other countries to assist in controlling their trade

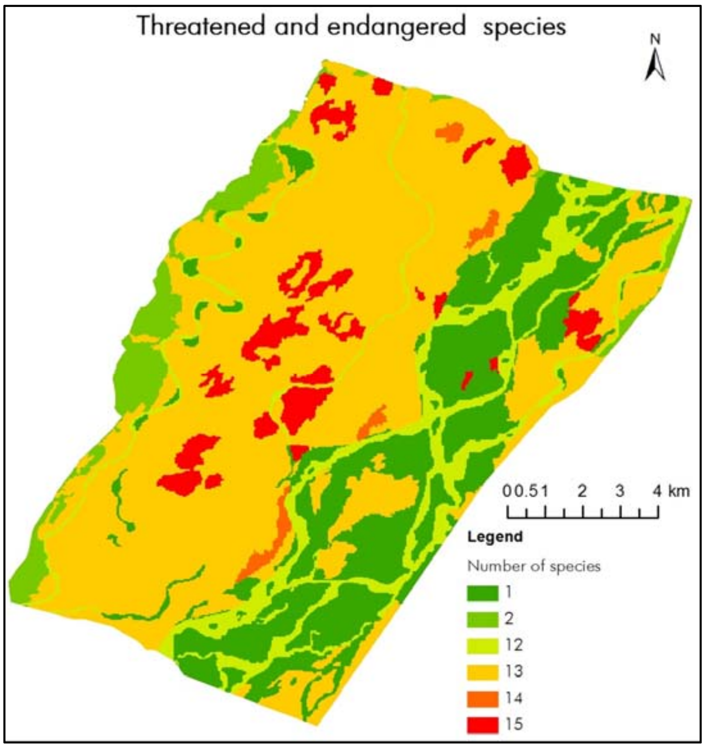


Figure 7-2 Map showing distribution and habitat use pattern by 20 threatened species in the Reserve (Source: Chettri et al. 2013)

## Social value

There is high dependency of local people on the ecosystems of the Reserve and it has important social values. Of the forest products, firewood is the top dependent product of the reserve where 91% of the local populations are dependent. The dependency for thatch (dry wild grass) is the second highest (82%) followed by timber (54%), then grasses (51%). (Figure 7-3). Likewise, people are also dependent on wetland ecosystems such as rivers/streams and swamps/marshes for a variety of goods and services such as fish (38%), driftwood (31%), pater (*Typha angustifolia L.*) (30%) and snails (23%). The dependency chart (Figure 7-3) clearly shows how much the local people are dependent on the products of the Reserve. Not only contributing to their subsistence livelihoods, the collection of these products also contributes to the local economy thus reducing poverty in the area, also reported by Rayamajhi (2009).


Figure 7-3 Dependency on products from the Reserve (Source: Chaudhary et al. 2014)

The listed ecosystem goods and services, which were categorized into social and cultural services, revealed that swamps/marshes, forest, river/lakes and agriculture are sources for a range of ecosystem goods and services on which the local people are highly dependent. River/lakes and swamps/marshes are the most productive ecosystems for provisioning services with 24% scores each followed by forest (21%), grassland (13%) and agriculture land (11%) (Figure 7-4). It is also interesting to note that the river/lakes covering 10% of the total area of the Reserve, and swamps/marshes with 12% of the total land area, have high capacity to provide social services to the people (Figure 7-4). Similarly, forest land with about 8% coverage has an equally high capacity in comparison to other land uses with a greater area in the Reserve. This means that the land use with less coverage has intense pressure from the people due to higher dependency as well as due to high production capacity. Similarly, the dependencies of local people on cultural services of the Reserve have also been analysed and similar results were found (Figure 7-4). The forested areas, swamps/marshes and grassland are the most valuable for these services for the local people. However, it was observed that the cultural and supporting scores are lower than the other two services mainly due to fewer variables used to score these services.

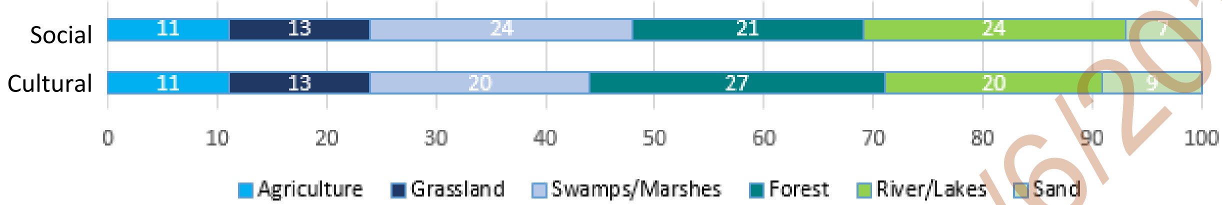


Figure 7-4 The subsistence values supporting socio-economic development: Social and dependency for cultural practices; and Cultural services being provided by each ecosystem of the Reserve (Source: Chaudhary et al. 2014)

## Economic values

The overall economic benefit generated from the major types of provisioning, regulating, and cultural services assessed was estimated to be approximately USD 16 million per year (Table 7-2; NRP 1.38 billion) (see Sharma et al. 2015), equivalent to around USD 959 per household per year (based on a total of 16,710 households residing in the buffer zone) or about USD 916 per ha (based on a total the Reserve area of 17,500 ha). This translates to a net present value (NPV) of around USD 444 million, estimated from the future benefit over a period of 60 years at an assumed discount rate of 3% and constant flow of current benefit (i.e., no degradation and depletion of current benefit).

Table 7-2 Aggregate economic value of wetland ecosystem services provided by the Koshi Tappu Wildlife Reserve (Source: Sharma et al. 2015)

| Ecosystem services | Total value (USD/yr) | Average value/ha/yr (USD) | Value /ha/yr (USD) | % share of total ecosystem services assessed |
|---|---|---|---|---|
| Provisioning services | $13,675,225 | $818.4 | $781.4 | 85.3% |
| Regulating services | $1,152,003 | $68.9 | $65.8 | 7.2% |
| *Flood control/prevention* | *$952,075* | *$57.0* | *$54.4* | *5.9%* |
| *Carbon sequestration* | *$199,928* | *$12.0* | *$11.4* | *1.2%* |
| Cultural services -ecotourism | $1,201,216 | $71.9 | $68.6 | 7.5% |
| **Total economic value** | **16,028,444** | **$959.2** | **$915.9** | **100.0%** |

This estimation demonstrates the long-term economic value of the Reserve (Stuip et al. 2002). Clearly, the economic benefit generated from provisioning services ranks first in terms of contribution to estimated total economic value (85%), followed by recreational services from tourism (7.5%), and regulating services from flood control and carbon sequestration (7.2%). The benefits of different services accrue to different stakeholders. For example, the benefits of provisioning services accrue entirely to the local people, while the benefit of the regulating services such as carbon sequestration goes to the global communities. Even though many of the ecosystem services do not enter directly into household income, the finding that a large part of the estimated total value of the wetland ecosystem services accrues locally is a clear manifestation of the vital importance of these wetland ecosystem services for the livelihoods of the local people. Ensuring a sustainable flow of these ecosystem services is therefore critical for supporting the local livelihoods and protecting the global significance of the Reserve as a Ramsar site.

## 7.3 Challenges and opportunities

In the Koshi Tappu Wildlife Reserve, the sources of socio-cultural services are mostly coming from rivers, swamps and forest ecosystems. This is obvious as forest and wetland ecosystems are the most productive ecosystems in terms of providing services (Biswas et al. 2010, Gopal 2013, Lamsal et al. 2015). This is very much relevant in the Reserve as dependency of local people on forest and wetland ecosystems is substantial as other alternatives for energy and livelihood options are limited (ICIMOD & MoFSC 2014, Sharma et al. 2015). It is also evident that wetland ecosystems in any human dominant landscapes have higher dependency of local people (e.g. Ambastha et al. 2007, Lamsal et al. 2014).

The Reserve has witnessed significant changes in its ecosystems over the last three decades. The changes are manifested by human pressure (Chettri et al. 2013), climate change (Agarwal et al. 2014, Bharati et al. 2016, Rajbhandari et al. 2016b); land use and land cover change (Chettri et al. 2013, ICIMOD & MoFSC 2014, Uddin et al. 2016) with loss of habitat for many aquatic and terrestrial species (Chettri et al. 2013). Interestingly soil loss from different land cover classes (Uddin et al. 2016) and higher vulnerability (Neupane et al. 2013) are bringing numerous challenges to the Reserve and the Basin. Some of the major challenges are on water availability, ecosystem vulnerability and poor adaptive capacity of the people living in the buffer zone of the Reserve and the basin (Bharati et al. 2016). Thus, the natural and human activities are bringing various management challenges in the Reserve as also reported by others in the region (Chettri et al. 2013, Lamsal et al. 2014). It is evident that the forest ecosystem is strongly linked to wetland ecosystems and plays an important role as an interface (Kollár et al. 2011). It was observed that some of the critical ecosystems such as forest have significantly changed during the past three decades. The land use and land cover changes, through anthropogenic or natural processes, bring visible changes in ecosystem functions of a given ecosystem, leading to a decrease in its capacity to provide services (Crossman et al. 2013, Baral et al. 2014). The dynamic nature of mosaic ecosystems is important, i.e. its change through time – however, if any of the ecosystems are lost beyond their threshold level, then that will have an irreplaceable impact on the society dependent on such ecosystems (Gopal 2013, Davidson 2014).

Unfortunately, due to human use and their changing capacities to provide services there is a common challenge faced by wetland ecosystem to thrive (Zhoali and Wu 2005, Deka et al. 2011, Romshoo and Rashid 2014). Apart from the Reserve, even the Koshi Basin has been witnessing changes in its ecosystems (Uddin et al. 2016). Such spatio-temporal change and the use of geospatial tools have been instrumental in understanding the dynamic nature of ecosystems (e.g. Rebelo et al. 2009, Chettri et al. 2013). Though the Government of Nepal has been proactively working with the local communities for participatory conservation and management of the Reserve (CSUWN 2009, MoFSC 2011), the dynamic nature of ecosystems needs special attention for management interventions as the fate of the Reserve is directly linked to the ecosystem health of the Basin. Therefore, understanding the monetary and non-monetary values, including people's dependency on the ecosystem services and the dynamics of the ecosystems itself, could be highly beneficial for implementing adaptive management measures. This may further improve the flow of ecosystem services and management of the reserve.

## 7.4 Summary

Biodiversity and ecosystem services are declining worldwide. Wetlands, which are well recognized for their significant role in supporting high biodiversity and providing food, water and livelihood security to the people living around them, are subject to various drivers of change with continuous degradation. With increasing evidence of climate change and other drivers of change in the Koshi Basin, the Koshi Tappu Wildlife Reserve seems to be highly vulnerable.

The Reserve is an important repository of biodiversity and ecosystem services, especially for the local communities. The present review revealed that the Reserve is an integral part and strongly influenced by the Koshi Basin and any subtle change in the Basin results in direct impacts on the Reserve. Being aware of this vulnerability and the changes reported, we recommend to the planners and managers to take urgent and necessary measures for conservation of the Reserve by providing a better understanding of the catchment for sustained environmental flow provision, which will otherwise have detrimental consequence to remaining biodiversity of the Reserve.

As it seems that habitat degradation within the Reserve is also caused by river course change related to high sediment loads and occasional flash floods, a river basin management approach is recommended as a prerequisite to various management and planning activities to aid holistic understanding. It has assumed greater importance in view of the shrinkage and degradation of ecosystems and associated biodiversity values and human sustenance



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Except where otherwise indicated, photographs in this chapter have been provided by the authors.

# 8 Water-dependent birds of the Koshi Basin

*Authors: Hem Sagar Baral[1], Ishana Thapa[2]*



## 8.1 Introduction

An environmental flow is the water regime provided within a river, wetland or coastal zone to maintain ecosystems and their benefits where there are competing water uses and where the flow is regulated. Environmental flows provide critical contributions to river health, economic development and poverty alleviation. They ensure the continued availability of the many benefits that healthy river and groundwater systems bring to society (Dyson et al. 2003). Water resources that we harvest are most vital to our life; examples are fishes, other food items, plant materials for household uses. Moreover ecosystem health (for example of forests) as well as air quality are also directly related to river flow. Forests provide a range of direct benefits – firewood as fuel, non-timber forest products, building materials, aromatic and medicinal plants, and food items. The overall environment regulated with natural flow provides clean water, air and environment to live in. All these qualities enhance the quality of life that we live in.

Plumbeous Water-Redstart (*Rhyacornis fuliginosa*) (Photo: Susheel Shrestha)

The World Bank has conducted an analysis of how different countries have incorporated environmental flows in plans, policies and individual projects carried out (Hirji & Davis 2009). While much study and efforts have been carried out on environmental flows elsewhere in the world, work on this topic is still in its infancy in Nepal. Environmental flows are a relatively new concept in the country and many remain unaware. For example, the second Nepal National Biodiversity Strategy and Action Plan (MoFSC 2014) for 2014–2020, which is a national guiding document for biodiversity conservation, does not mention environmental flows. Most national documents concerned with this subject remain rather broad or vague and do not mention environmental flows or minimum flows or natural flows in any form (WECS 2002, 2005, 2011).

The large altitudinal variation in the Koshi Basin has created a diverse landscape and topography in a dramatic style within a distance of 60km or so. The altitudinal variation with diverse landscapes and slope faces has given rise to different ecosystems and resulting habitats. A continuum of such habitats is regarded to be the best refuge for human and wildlife in today's era of climate change that is threatening life on earth. Koshi Basin is an open university where within north to south in a short distance there is vast knowledge to be explored and learnt.

Throughout the river basins, riverine habitats have been created which include riverine forests, grasslands and wetlands. The lower river basin of the Koshi River is a highly productive and

1 Zoological Society of London, Nepal Office
2 Bird Conservation Nepal, Kathmandu

biodiverse area. Unfortunately, much of the grasslands and wetlands and their associated fauna have been lost over time and continue to do so in the lower basin area (Inskipp et al. 2016).

Avian diversity in the Koshi Basin is unparalleled. Of the 884 bird species reliably recorded in Nepal (Grimmett et al. in press), as many as 828 species can be attributed to the region. Koshi's lower floodplains, south of the Siwalik Hills all the way down south to the Koshi barrage, have a high total of 526 species (Baral 2016). This is one of the highest bird totals recorded for any lower river basin area in Nepal. Moreover, the nine extirpated avian species from Nepal (Inskipp et al. 2016) also show affinity to the Koshi Basin region, therefore indicating persistent disturbance to the area over long periods and highlighting the sensitive nature of the ecosystems (Cronin 1979, Inskipp 1989, BCN & DNPWC in prep).

The Koshi region is very important for Important Bird and Biodiversity Areas (IBAs; Chapter 2). There are six IBAs in the mountains and three in the floodplains. Two in the lowlands remain outside of the protected area network with one being partially protected.


Swamp Francolins (*Francolinus gularis*)
(Photo: Courtesy Himalayan Nature)

The Koshi (Arun) River marks a distinct geographical barrier for species' distribution. Seventeen (17) bird species have their distribution ranges confined to this area (Inskipp & Inskipp 1991). The Koshi River is regarded as the westernmost part of the eastern Himalayan range (Ali & Ripley 1987). Furthermore, the Basin marks the westernmost part of the Kanchenjungha-Singhalila Biological Corridor Complex, and its eastern section forms a part of the eastern Himalaya Biological Hotspot (Chapter 2; CEPF 2005).

At least three of the 238 global eco-regions are included in the Koshi Basin, namely Eastern Himalaya Alpine Shrubs and Meadows, Eastern Himalayan Broadleaf Forests and Terai-Duar Savannas and Grasslands (Olson and Dinerstein 2002). Similarly, BirdLife International's classic document, Endemic Bird Areas of the World, has identified that three of these endemic bird areas occur in Nepal (Stattersfield et al. 1998). These are the Central and Eastern Himalayas and the Assam Plains Endemic Bird Areas.

Studies in Nepal have shown that bird species richness decreases with increasing altitude (Hunter & Yonzon 1993, Inskipp et al. 2016). It is also highlighted that where bird species richness is highest, namely in the lowlands, many of the bird species are also highly threatened (Inskipp et al. 2013, 2016).

The Koshi Basin is thus of importance on a global as well as on a national scale. This chapter aims to discuss the river flows in the Sapta Koshi river system and their possible impacts on birdlife.

## 8.2 Current research knowledge

Very little is known about biodiversity and flows in the Koshi Basin. Protected areas (Chapter 2, Table 2-3) are the best researched places in the Basin and this seems to also be the case over wider scales across the entire country. Studies range from species-level to compilation of summaries of information from the overall work in protected areas, usually produced in the form of theses or reports. The Important Bird and Biodiversity Areas report (IBA) is an ongoing compilation of work that includes all the protected areas of Nepal, providing a fine example of synthesis of the work in the area (BCN & DNPWC in prep).

Sah (1997) provides one of the most comprehensive overviews on the biodiversity of lower floodplains of the Koshi Basin, especially the Koshi Tappu Wildlife Reserve. In the period after the publication of this work, Bird Conservation Nepal has documented sustainable wetland management guidelines (Buckton 2007, Buckton et al. 2009, Thapa & Dahal 2009) as well as a fish identification booklet (Rijal et al. 2009). MoFSC (2009b) carried out extensive research in the lower Koshi Basin with a focus on the Koshi Tappu Wildlife Reserve. The project also focused on monitoring the key indicator species in Koshi Tappu, including Swamp Francolin (*Francolinus gularis*) and Wild Water Buffalo (*Bubalus arnee*), documenting population increases for both species during the project period (MoFSC 2012, 2013).

Bengal Florican (*Houbaropsis bengalensis*)
(Photo: Ben Bahadur Khadka)

Swamp Francolin (Baral 1998, Dahal 2002ab, 2007, 2009, 2010, Dahal et al. 2009, Singh 2007), Lesser Adjutant (*Leptoptilos javanicus;* Pokharel 1998, Baral 2004ab, Baral 2005, Allay 2009, Karki & Thapa 2013, Thapa & Thakuri 2015), White-rumped Vulture (*Gyps bengalensis*, Gautam & Baral 2004, Baral et al. 2011, Pandey 2014, Subedi 2014, Himalayan Nature 2015 ) and Bengal Florican (*Houbaropsis bengalensis;* Baral et al. 2003, 2012a, 2013, BCN 2014, 2015) are the key species that have been studied to some extent in the past.

According to the most recent status assessment of Nepal's birds, many of the bird species currently listed as threatened are found in the Koshi Basin (Inskipp et al. 2016). Species dependent on fluvial habitats such as wetlands and grasslands are regarded to be the most threatened species in the country compared to other habitats such as forests (Inskipp et al. 2016). These examples and facts further highlight the importance of the region for avian conservation.



## 8.3 Habitats and birds

For the purpose of this chapter, it is necessary to make a general distinction between various species of birds that utilise different habitats. These birds are categorised very broadly based on their principal usage of three habitats: wetlands, grasslands, forests. The wetland habitat is further classified into two subcategories to highlight flows and related issues better.

Wetland birds are those species which spend significant periods of their life cycle in or close to water. Nearly 200 species are said to be dependent on wetlands in Nepal, and therefore classified as wetland birds (Bhandari 1998). Within wetland birds, we make a further distinction between river birds and water birds for the purpose of this study.

## River birds

At the interface of the wetland habitat there exists a group of birds classified as river birds. These species are found mainly along rivers and are mostly passerines (except kingfishers). They lack webbed feet but may be syndactyle (kingfishers). The Nepal Himalayas boast the most diverse river bird assemblages in the world (Buckton 1998, Buckton & Ormerod 2002, 2008). More than a dozen species of river birds are commonly found in Nepal (Buckton 1998; Table 8-1). It is important to recognise river birds especially when we talk about environmental and river flow matters as these species will be those impacted in a uniform way from upstream to downstream.

Table 8-1 Some resident river birds in Nepal (adapted from Buckton 1998)

| English name | *Scientific name* | Remarks |
|---|---|---|
| Little Forktail | *Enicurus scouleri* | Midhills to foothills |
| Slaty-backed Forktail | *Enicurus schistaceus* | Midhills to foothills |
| Black-backed Forktail | *Enicurus immaculatus* | Foothills to lowlands |
| Spotted Forktail | *Enicurus maculatus* | Midhills to foothills |
| White-capped -Redstart | *Chaimarrornis leucocephalus* | Highlands to lowlands |
| Plumbeous Water-Redstart | *Rhyacornis fuliginosa* | Midhills to lowlands |
| White-breasted Dipper | *Cinclus cinclus* | Highlands only |
| Brown Dipper | *Cinclus pallasii* | Midhills to lowlands |
| Grey Wagtail | *Motacilla cinerea* | Highlands to lowlands |
| White-browed Wagtail | *Motacilla maderaspatensis* | Foothills to lowlands |
| Blue Whistling Thrush | *Myophonus caeruleus* | Highlands to lowlands |
| Crested Kingfisher | *Megaceryle lugubris* | Midhills to foothills |
| Common Kingfisher | *Alcedo atthis* | Midhills to lowlands |
| Blyth's Kingfisher | *Alcedo hercules* | Midhills to foothills |


Grey Wagtail (*Motacilla cinerea*) (Photo: Susheel Shrestha)

The river bird group is very interesting as its distribution is along a north-south river gradient. Much of the derived knowledge comes from studies carried out on river birds in the mid-1990s (Buckton 1998). The main Koshi River as well as its snow-fed and other smaller spring-originated tributaries, provide good habitat for this collective species. Some species show distinct altitudinal migration (e.g. Grey Wagtail, *Motacilla cinerea*), whereas others show a very wide range of distribution from lowlands/foothills to highlands (Blue Whistling Thrush, *Myophonus caeruleus* and White-capped-Redstart, *Chaimarrornis leucocephalus*). Because of their confinement to river courses and rather contiguous distribution compared to other birds and wider altitudinal coverage, this group of birds may present interesting facets to monitor temporal changes in water regimes.

## Water birds

Water birds are primarily non-passerines and they have special physical modifications suited for life in aquatic habitats. They are usually colonial nesters with a medium to high tendency to be totally aquatic birds. These include large wading birds (storks, ibises and spoonbills, sandpipers, stints, plovers) as well as waterfowls (moorhens, waterhen, rails and crakes, ducks and geese; Table 8-2).

Table 8-2 Some water birds in Nepal (adapted from Bhandari 1998)

| English name | *Scientific name* | Remarks |
|---|---|---|
| Great Cormorant | *Phalacrocorax carbo* | Lowlands, winter |
| Lesser Adjutant | *Leptoptilos javanicus* | Lowlands |
| Black-necked Stork | *Ephippiorhynchus asiaticus* | Lowlands |
| Asian Woollyneck | *Ciconia episcopus* | Lowlands |
| Asian Openbill | *Anastomus oscitans* | Lowlands |
| Red-naped Ibis | *Pseudibis papillosa* | Lowlands |
| Black-headed Ibis | *Threskiornis melanocephalus* | Lowlands |
| Eurasian Spoonbill | *Platalea leucorodia* | Lowlands, winter |
| Pallas's Gull | *Ichthyaetus ichthyaetus* | Lowlands, winter |
| Indian Skimmer | *Rhynchops albicollis* | Lowlands |
| Caspian Tern | *Hydroprogne caspia* | Lowlands, winter |
| Black-bellied Tern | *Sterna acuticauda* | Lowlands |
| River Tern | *Sterna aurantia* | Lowlands |
| Little Tern | *Sterna albifrons* | Lowlands |
| Ibisbill | *Ibidorhyncha struthersii* | High altitude to foothills |
| River Lapwing | *Vanellus duvaucelii* | Foothills to lowlands |
| Little Ringed Plover | *Charadrius dubius* | Lowlands |
| Black-tailed Crake | *Porzana bicolor* | Middle altitude |
| Brown Crake | *Amaurornis akool* | Lowlands |
| Purple Swamphen | *Porphyrio porphyrio* | Lowlands |
| Watercock | *Gallicrex cinerea* | Lowlands, summer |
| Great Thick-knee | *Esacus recurvirostris* | Lowlands |
| Small Pratincole | *Glareola lactea* | Lowlands |
| Bar-headed Goose | *Anser indicus* | Lowlands, winter |
| Comb Duck | *Sarkidiornis melanotus* | Lowlands |
| Lesser Whistling Duck | *Dendrocygna javanicus* | Lowlands |
| Ruddy Shelduck | *Tadorna ferruginea* | Lowlands, winter |
| Cotton Pygmy Goose | *Nettapus coromandelianus* | Lowlands |
| Baer's Pochard | *Aythya baeri* | Lowlands, winter |
| Goosander | *Mergus merganser* | Foothills to lowlands, winter |

These birds depend entirely on water and riverine floodplains. Lesser Adjutant (*Leptoptilos javanicus*), Asian Woollyneck (*Ciconia episcopus*), Indian Skimmer (*Rhynchops albicollis*), Black-bellied Tern (*Sterna acuticauda*) and Baer's Pochard (*Aythya baer*i) are examples of globally threatened species. There are several other nationally threatened species that occur in the same water areas. These species are sensitive to fluctuation in water level and most dwell in the lower Koshi Basin.

Ruddy Shelducks (*Tadorna ferruginea*)
(Photo: Susheel Shrestha)

Other than the actual water birds, which get their feet wet in water, there are several fringe feeders. These include various species of kingfishers, e.g. the Stork-billed Kingfisher (*Pelargopsis capensis*), as well as birds of prey that feed on fish or take waterfowls such as White-tailed, (*Haliaeetus albicilla*), Pallas's (*H. leucoryphus*), Imperial Eagles (*Aquila heliaca*), and Lesser Fish Eagles (*Ichthyophaga humilis*) that occur in the Koshi area (Baral 2016) and may be directly impacted by altered flow regimes.

## Grassland birds

A variety of tall or short riverine grasslands, or those in disturbed sites comprise grasslands as a whole. Its inhabitant avian fauna are commonly referred to as grassland birds. Although it is stated that natural grasslands cover approximately 14% of the country's land mass (Richard et al. 2000), lowland grasslands are only a tiny fraction of this large area (Baral 2001). Grassland area in the Koshi Basin is shown in Figure 2-4. Grass height is a major variable affecting associated avian fauna, varying from very short (few centimetres) to a staggering height of eight metres (Peet et al. 1999). The latter is found only in the lowland plains as most grass species in the midlands/highlands tend to be usually less than two metres or so. Although grasses and grasslands are plentiful in the high altitude and lowlands, they are less so in the mid hills. Here we are specifically concerned with lowland grasslands, followed by highland grasslands or pastures. The biodiversity value of Nepal's grasslands is better studied in lowland Nepal (Richard et al. 2000).

Table 8-3 Grasslands birds in Nepal (adapted from Baral 2001)

| English name | *Scientific name* | Remarks |
| --- | --- | --- |
| Indian Courser | *Cursorius coromandelicus* | Lowlands |
| Wood Snipe | *Gallinago nemoricola* | Highland to midhills |
| Swamp Francolin | *Francolinus gularis* | Lowlands |
| Bengal Florican | *Houbaropsis bengalensis* | Lowlands |
| White-tailed Stonechat | *Saxicola leucura* | Lowlands |
| Hodgson's Bushchat | *Saxicola insignis* | Lowlands |
| Striated Babbler | *Turdoides earlei* | Lowlands |
| Yellow-eyed Babbler | *Chrysomma sinense* | Lowlands |
| Bristled Grassbird | *Chaetornis striata* | Lowlands |
| Striated Grassbird | *Megalurus palustris* | Lowlands |
| Rufous-rumped Grassbird | *Graminicola bengalensis* | Lowlands |
| Nepal Rufous-vented Prinia | *Prinia burnesii nepalicola* | Lowlands |

| English name | *Scientific name* | Remarks |
|---|---|---|
| Yellow-bellied Prinia | *Prinia flaviventris* | Lowlands |
| Grey-crowned Prinia | *Prinia cinereocapilla* | Foothills to lowlands |
| Graceful Prinia | *Prinia gracilis* | Foothills to lowlands |
| Golden-headed Cisticola | *Cisticola exilis* | Lowlands |
| Pale-footed Bush Warbler | *Cettia pallidipes* | Lowlands |
| Spotted Bush Warbler | *Bradypterus thoracicus* | Highlands to lowlands |
| Clamorous Reed Warbler | *Acrocephalus stentoreus* | Lowlands |
| Smoky Warbler | *Phylloscopus fuligiventer* | Highlands to lowlands |
| Baya Weaver | *Ploceus philippinus* | Foothills to lowlands |
| Black-breasted Weaver | *Ploceus benghalensis* | Lowlands |
| Finn's Weaver | *Ploceus megarhynchus* | Lowlands |
| Streaked Weaver | *Ploceus manyar* | Lowlands |
| Yellow-breasted Bunting | *Emberiza aureola* | Midhills to lowlands |



Most species presented in Table 8-3 are breeding residents for the eastern part of Nepal and all are grassland specialists (Baral 2001). Only three are winter visitors; Clamorous Reed Warbler, Hodgson's Bushchat and the Yellow-breasted Bunting. The latter two species as well as several others listed (Table 8-3 lists an additional six species) are globally threatened (Inskipp et al. 2016).

Indian Courser (*Cursorius coromandelicus*) (Photo: Darren Clark)

The largest grassland areas which sustain these important avian taxa are now only confined to protected areas. The majority of Nepal's subtropical riverine grasslands are maintained by a combination of fire, grazing and flood, the latter being an even more important modifying factor for vegetation. In the absence of regular flooding regimes, the grass species usually give way to tree species and in the medium to long term future all riverine grasslands may be lost altogether. Relations between the groundwater table and much of the operation of the hydrological cycle for the sustenance of globally important habitat such as these, is very poorly known.

In addition to the avian list above, several species of vultures: White-rumped (*Gyps bengalensis*), Slender-billed (*G. tenuirostris*) and Egyptian Vultures (*Neophron percnopterus*), are primarily birds that can often be seen in open country which essentially constitute short grasslands. All the vulture species mentioned are globally threatened with the Indian Courser critically threatened at national level (Inskipp et al. 2016).

## Forest birds

A wide array of birds that inhabit forest of different kinds, pristine to degraded, small to big, broadleaf to coniferous, evergreen to deciduous, lowland to highlands fall under this category.

Within forest birds, there are bird species that depend on forests fully to complete their life cycle (specialist types) as well as species that depend partially on other habitats such as wetlands and grasslands or similar edge habitats to complete their life cycle (generalist types). In Table 8-4 we present a wide range of birds that depend on forests to complete their life cycle, from the plains to the highlands. Nearly all are resident species.

Table 8-4 Some examples of resident forest birds in Nepal (adapted from Inskipp 1989)

| English name | *Scientific name* | Remarks |
|---|---|---|
| Emerald Dove | *Chalcophaps indica* | Lowland |
| Great Slaty Woodpecker | *Mulleripicus pulverulentus* | Lowland |
| Bay Woodpecker | *Blythipicus pyrrhotis* | Midhills to foothills |
| Crimson-breasted Woodpecker | *Dendrocopos cathpharius* | Midhills |
| Red-headed Trogon | *Harpactes erythrocephalus* | Foothills |
| Great Hornbill | *Buceros bicornis* | Foothills to lowland |
| Blue-eared Barbet | *Megalaima asiatica* | Lowland |
| Large Wood Shrike | *Tephrodornis virgatus* | Lowland |
| Bar-winged Flycatcher-shrike | *Hemipus picata* | Lowland |
| Sultan Tit | *Melanchlora sultanea* | Foothills to lowland |
| Puff-throated Babbler | *Pellorneum ruficeps* | Foothills to lowland |
| Black-faced Laughingthrush | *Garrulax affinis* | Highlands |
| Spotted Laughingthrush | *Garrulax ocellatus* | Higland to midhills |
| Greater Necklaced Laughingthrush | *Garrulax pectoralis* | Foothills to lowlands |
| Lesser Necklaced Laughingthrush | *Garrulax monileger* | Foothills to lowlands |
| Golden-breasted Fulvetta | *Lioparus chrysotis* | Midhills |
| Nepal Fulvetta | *Alcippe nipalensis* | Midhills to foothills |
| Rufous-winged Fulvetta | *Pseudominia castaniceps* | Midhills |
| White-browed Fulvetta | *Fulvetta vinipectus* | Highland to midhills |
| Nepal Wren Babbler | *Pnoepyga immaculata* | Midhills to foothills |
| Grey-bellied Tesia | *Tesia cyaniventer* | Midhills to foothills |
| Chestnut-headed Tesia | *Oligura castaneocoronata* | Midhills to foothills |

Several species listed as forest specialists including the Great Hornbill, the Great Slaty Woodpecker and the Red-headed Trogon are threatened primarily due to the loss of habitat (Inskipp et al. 2016). Although there are no reliable records of the occurrence of the Great Slaty Woodpecker in the Koshi Basin, it has been included in Table 8-3 as an indicator species of good quality, old growth lowland forests of Nepal. Specialist species are affected by selective logging of mature trees, especially those containing features that promote nesting, food, repeated fires and other anthropogenic disturbances, including hunting. Certain species, for example Tesias and Wren Babblers prefer moist, shady overgrowth of vegetation. Specialist species may also suffer from forest fragmentation, structure of the habitat and its size but this could be applicable also for generalist forest birds.

Species like Bar-winged Flycatcher-shrike, Puff-throated Babbler, Nepal Fulvetta, Rufous-winged Fulvetta and White-browed Fulvetta are relatively generalist forest birds compared to the birds above. Many of the forest specialists are found only in protected areas whereas other forest generalists are also equally abundance in community managed forests outside the protected areas.

Studies have revealed that the maintenance of diverse bird assemblages in forest regions depends on complimentary management of forests in protected areas which preserve old growth forests and community managed forests which preserve a mix of old growth and secondary habitats (Dahal et al. 2014).

Parameters such as soil moisture, aspect, and altitude determine the type of vegetation that grows in any particular locality. In areas where the natural hydrological cycle is unbalanced, rapid change of vegetation species can occur. These changes are triggered by new patterns of flow regimes that become more dominant and influence ecological change. For example, due to heightened anthropogenic activities and intense forest fires in eastern Nepal, there has been widespread loss of evergreen forests (Cronin 1979). These repeated forest fires have paved the way for more fire resistant forest types (*viz.* drier *sal* dominated forests) and loss of more sensitive and less fire tolerant species to form tropical evergreen forest types. Hence, lessons and experience learnt from the past provide important insights as to how we can develop our plans related to future water usage.

## 8.4 Impacts of river flow change

Any change in river flow will bring some impact on biodiversity which will be felt downstream as well as some way upstream. The larger the disturbance size, the greater the area it is likely to affect. There are very few positive facets related to changed (decreased) water flow. These changes are mostly enjoyed by generalist species that are generally non-threatened taxa and whose populations may even flourish due to the new habitats created as a result of development. Changes in habitats due to intermediate disturbances may support a set of different habitat niches for a wide range of species, in particular habitat generalist species. Examples of the generalist species include Red-vented (*Pycnonotus cafer)* and Himalayan Bulbuls (*P. leucogenys)*, various species of pipits, wagtails and buntings, Black Drongo (*Dicrurus macrocercus)*, Red Jungle Fowl (*Gallus gallus)*, and Blue Peafowl (*Pavo cristatus)*.

However, overall the negative impact caused by changed river flows will surpass many benefits given to the generalists. Most specialists will suffer gradual to rapid decline leading to emigration of the species which then will lead to local extinction. Habitat change caused from development will cause many birds to leave and find suitable habitats elsewhere. Other species may come in slowly to exploit modified or altered ecosystems. In the long run, the entire ecosystem and its functioning will also change.

The immediate effects on habitats will most likely be seen in downstream areas, especially in the floodplains. Here, naturally flowing rivers create braided channels and create large inundated floodplains. A predicted river flow or minimized water flow to the floodplains will lead to the loss of grasslands and wetlands as well as gradual loss of riverine vegetation due to changes in floodplain connectivity.

Grasslands in northern India and southern Nepal are said to thrive due to a few major management regimes; flood, fire, grazing and associated disturbances (Peet et al. 1999, Baral 2001). Changes associated with altered flows, means alteration of the above management regimes which in the long run means loss of grassland habitats. Additionally, many forest birds including a high proportion of threatened forest species, depend on moist forests and they are likely to lose their habitat if it becomes drier due to river regime change. Habitat inundation and loss may occur due to excessive flow and flood which might have a greater impact on colonial nesting birds in riverine forest and on river islands. Flooding may result in loss of nesting trees to waterbirds such as herons, egrets, storks, cormorants as well as birds that nest on the banks such as terns and pratincoles.

Based on the broad four categories of birds as mentioned above, the threats to each group have been conceptualised in Figure 8-1 to Figure 8-4. In the following section we aim to explain how these models capture the effects of river regime change on up to three selected species per category.

## 8.5 Conceptual models based on existing knowledge

### River birds

A suite of river birds is presented in Figure 8-1 to show their specific niche in terms of the habitat they use and their food and feeding habits. The Little Forktail (*Enicurus scouleri*) and Brown Dipper (*Cinclus pallasii*) share similar habitats, with the former feeding above water on wet boulders while the latter exploits the same area but feeding underwater. Both species require considerable flow to create cascades and pools, hence they are found in small to large rivers. Changes in habitat and thereafter diet, may change due to altered flow. These two species will be the first ones to show the immediate effects of altered flow. Black-backed (*Enicurus immaculatus*) and Slaty-backed Forktails (*E. schistaceus*) feed on channel margins of rivers and lakes. In this respect, these two species are not as specialised compared to the Little Forktail and Brown Dipper. Slaty-backed Forktail occurs at a slightly higher elevation compared to Black-backed Forktail. The former effectively replaces the latter, although both have been recorded on the same stream several times Figure 8-1.

Spotted Forktail (*Enicurus maculatus*) (Photo: Darren Clark)

Both species may show the effects of altered flows within a medium-term time scale. The Spotted Forktail (*Enicurus maculatus*) prefers to forage in small and shaded streams with lots of leaf litter. In terms of water requirements, this species does not need a visible water flow, however, it will always be found in damp/moist ravines or forest floors with leaf litter. When in streams and rivers, it prefers to feed on riparian margins. This species may show effects of altered flow in the medium-term time scale.

The Plumbeous Water Redstart (*Rhyacornis fuliginosa*) prefers small to large rivers to forage. It is very similar in feeding habit and food to that of the Little Forktail (Buckton 1998). It differs slightly from White-capped Redstart (*Chaimarrornis leucocephalus*) in terms of diet and often feeds on wet boulders in the middle of streams and rivers. Otherwise, both the Plumbeous Water and the White-capped Redstarts are very similar in other aspects. The Blue Whistling Thrush (*Myophonus caeruleus*) and White-capped Water Redstart are among the river birds most on the outer rim of the habitat. Because of this, their diet consists mostly of terrestrial prey. Because of their more generalist character, these species may show the effects of altered flow only in the long-term. It is likely that in the short-term future both of these species may benefit due to decreased flow regimes.


Figure 8-1 Conceptual model showing representative river bird species with their characteristics and possible threats

Three species of kingfisher listed in Figure 8-1 are directly dependent on river fish stock with flow changes showing an immediate effect on them. The other two species of wagtails are only marginal feeders and may take a longer time to show population changes in response to flow alteration. Threats outlined for river birds can be more specific compared to water bird threats as a whole. The altitudinal gradient and physical structure of the river and riparian habitat are said to be the best predictors of river birds and their abundance (Manel et al. 2000). Other factors that may affect them include pH and conductivity of water, as well as stream pollution. Because of their widespread and contiguous distribution most species are not threatened. Blyth's Kingfisher (*Alcedo hercules*) and Blue-eared Kingfisher (*A. meninting*) are the only nationally threatened species in this bird group (Inskipp et al. 2016), while Blyth's Kingfisher is also Near-Threatened globally (BirdLife International 2015).

## Water birds

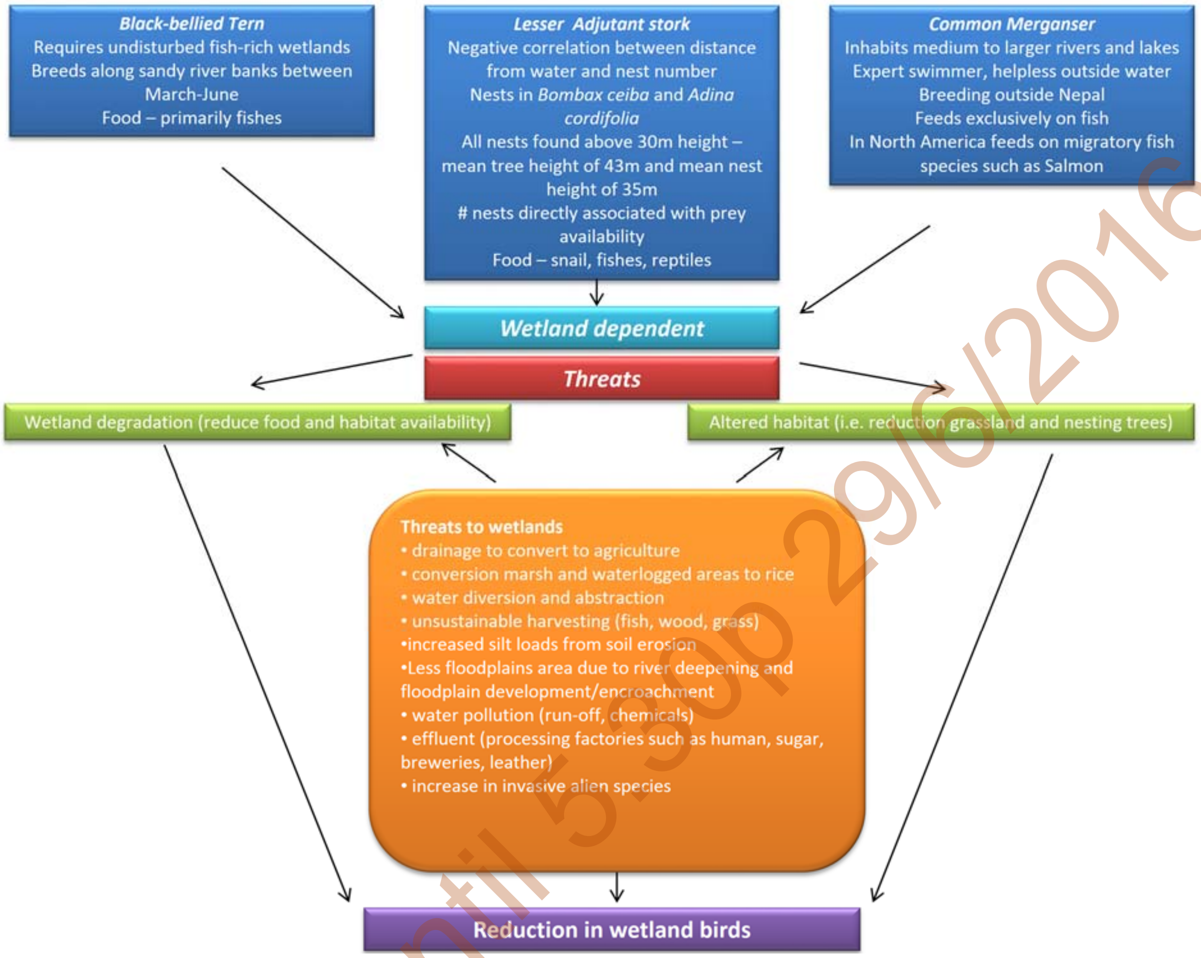


Figure 8-2 Conceptual model showing representative bird species (Black-bellied Tern, Lesser Adjutant Stork and Sarus Crane) of the wetland habitat with their characteristics and possible threats

As many as 200 species of waterbirds are said to be dependent on Nepal's wetlands in different forms (Baral 2009). We have taken as examples, three species whose populations have been monitored in the wetlands of Nepal for several years primarily through nationwide midwinter waterbird counts: these are Black-bellied Tern (*Sterna acuticauda*), Lesser Adjutant (*Leptoptilos javanicus*) and Common Merganser (*Mergus merganser*). Each species is unique in the way it depends on wetland resources to complete its life cycle. In addition, the first two are globally threatened and the last species is listed as Least Concern (BirdLife International 2016). Wetlands as a whole, face enormous pressure and threats are quite wide-ranging and complex (IUCN Nepal 2004). Wetland birds have been a major subject of discussion due to their widespread loss and decline across the country and threats to them have been discussed in detail (BCN & DNPWC 2011, Inskipp et al. 2016). Threats outlined in this model are species specific, yet similar to each other in many ways.

The Black-bellied Tern is found along undisturbed river stretches rich in fish stock (Figure 8-2). It prefers sandy river banks for resting as well as for breeding. Unlike the majority of tern species which nest colonially, nests of this species are spaced far away from one another. Each nest is a simple scrape on the ground and is totally exposed to disturbances. The species (adults, eggs and chicks) are highly vulnerable to predation, from various sorts of predators (Cuthbert undated).

Decreased water flow in the rivers means less inundation and flooding which means loss of sandy river banks in the long run. Similarly, any type of barrier structure is going to cause the already depleted fish stock to further decline. This species is predicted to suffer the most among the three species chosen, with immediate effects and consequences.

Lesser Adjutant (*Leptoptilos javanicus*)
(Photo: Susheel Shrestha)

Lesser Adjutant Stork is a wetland-dependent bird which also uses other types of terrestrial habitats (Figure 8-2). It feeds on a variety of food items from wet ground, shallow marshes and cultivated lands (Pokharel 1998). The stork chooses to nest on tall Silk-Cotton trees (*Bombax ceiba*) or Karma trees (*Adina cordifolia*; generally >30m). It nests colonially, with largest nest numbers in the Tarahara and Sunsari District where the colony seems to have increased compared to previous years (Karki and Thapa 2013). Here, a total of 95 birds were counted in January 2014, during a midwinter waterbird count which is the largest count for this species from a single site in Nepal (Baral 2014). Once this species reaches adulthood, there are very few aerial predators that pose a threat. Since the species is dependent on wetlands, it will change its behaviour as a result of altered water-related effects, and will need to look for new suitable habitats. This species might be affected in the long-term.

The Common Merganser is a fairly common winter visitor to Nepal (Inskipp et al. 2016) and a species that is heavily dependent on water (Ali and Ripley 1987). The species inhabits lakes and rivers (Inskipp & Inskipp 1991). Increased water turbidity caused by soil erosion resulting from overgrazing, ploughing and work on irrigation channels by farmers may be making it difficult for Common Merganser to locate their prey and Illegal hunting, disturbance and poisoning threaten the species (Inskipp et al. 2016). Elsewhere, this species is known to feed on migratory fish species (Wood 1987, Guy & Lawrence 1995). Studies have shown that Common Merganser prefer to take migratory fish species where competition occurs (Sjöberg 1995). Nothing is known about their food preference in the region other than that they exclusively feed on fish (Ali and Ripley 1987). A recent assessment of Nepal's birds has shown that this species is currently listed as of Least Concern (Inskipp et al. 2016). If these birds are dependent on migratory fish species similar to the studies in North America, altered flow and obstruction to rivers may directly impact the species.

## Grassland birds

Three species as examples of grassland birds are included in the grassland bird model (Figure 8-3), two of which are globally threatened and are currently monitored at regular intervals. These include Swamp Francolin (*Francolinus gularis*) and Bengal Florican (*Houbaropsis bengalensis*). The Indian Courser (*Cursorius coromandelicus*) is critically threatened on a national scale and is recorded only from a few localities (Inskipp et al. 2016). All three species are found along the floodplains of the Koshi River, as soon as the river exits the hills into the flatter regions.

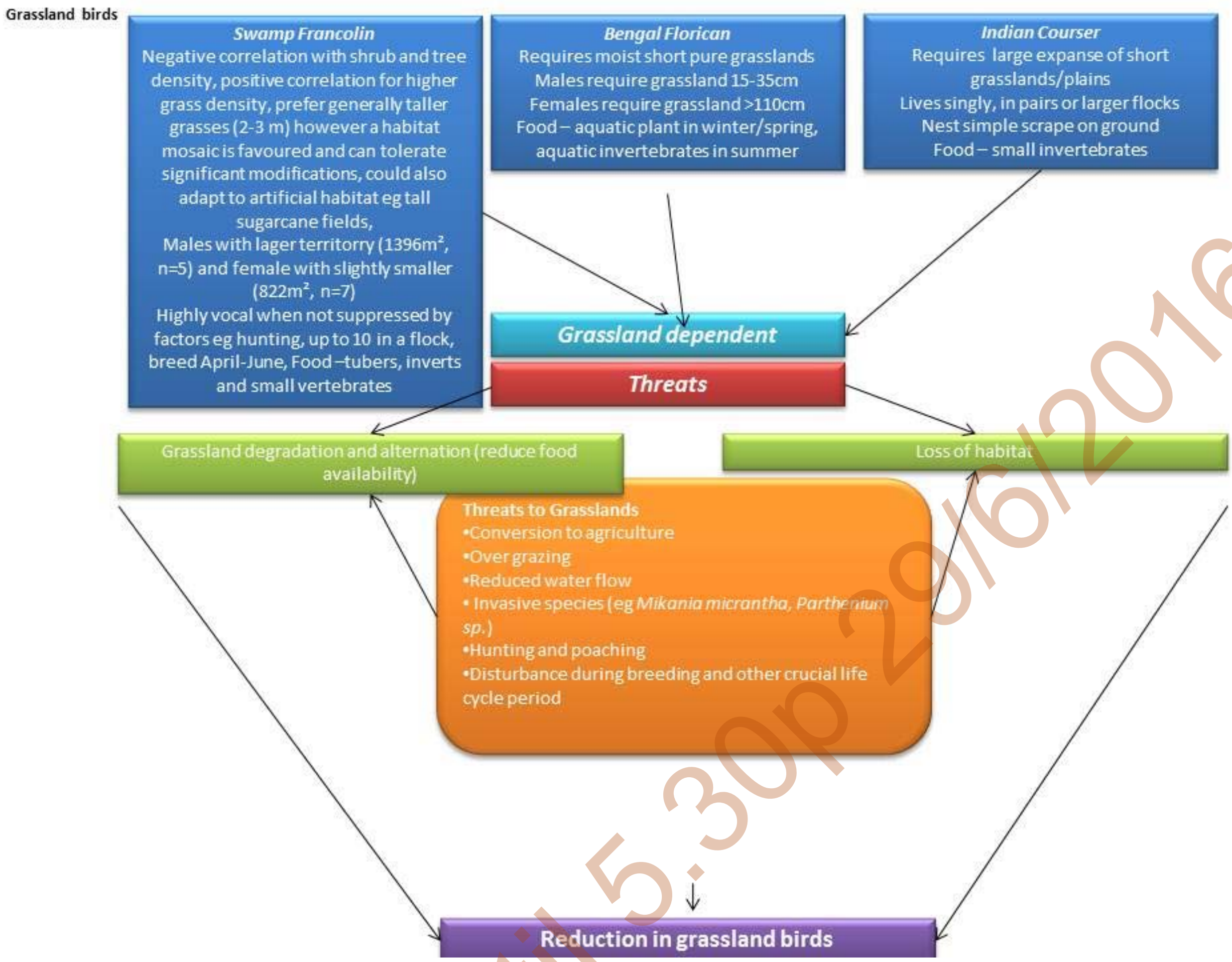


Figure 8-3 Conceptual model showing representative bird species (Swamp Francolin, Bengal Florican and Indian Courser) of the grassland habitat with their characteristics and possible threats



Swamp Francolin prefers tall and moist grasslands although it has been shown to readily adapt to man-modified habitats such as sugarcane fields (Figure 8-3). Males are known to cover a larger territorial area than females. In areas where disturbance is minimal, they tend to be very vocal and in these areas their calls can be heard year round, with a peak during the early morning and another smaller peak during late afternoon. Altered river flow may mean drying up of grasslands and loss of its suitable habitat. This species would be impacted in a medium term.

Bengal Florican is known to prefer shorter grasslands compared to the Swamp Francolin (Figure 8-3). This species is especially observed in short *Imperata-Saccharum* patches. It is said that males prefer shorter grasslands than females. This may be because males require a slightly open area for displaying. Altered flow regimes may mean loss of this species even as an immediate knock-on effect, as grassland ceases to grow in the event of reduced flows, reducing habitat suitability. The availability of aquatic plant and animals for consumption is also likely to be impacted with flow reductions, making it difficult for birds to survive in once suitable locations. Obviously all other threats mentioned in Figure 8-3 are operating simultaneously, impacting the future of this species. It is one of the most critically threatened birds in the world.

The Indian Courser prefers large expanses of short grasslands or heavily grazed large-sized open fields on a relatively flat ground. It is found singly or in pairs, and sometimes in loose flocks (Figure 8-3). The bird is now confined to floodplains of large rivers like the Koshi, although it is also found in open habitats far away from water. The impact of altered river flow to this species may be seen in a medium to long term time scale, as reduced flows prevent grass growth and therefore reduce habitat suitability. Flow change may also change invertebrate availability, also leading to the demise of this species.

### Forest birds

A forest bird conceptual model was created using current knowledge about Woodpeckers (Figure 8-4). These are a cavity nesting species within riverine areas and thus rely on natural flow regimes to maintain woody vegetation health. The trees not only provide cavities to nest in but also fruit, nuts and sap of live trees. As such, altered flow regimes will have a significant impact on these bird species, should forest degradation occur. Additional food sources, such as arthropods are also likely to be water dependent and hence their abundance will be affected by flow alteration.

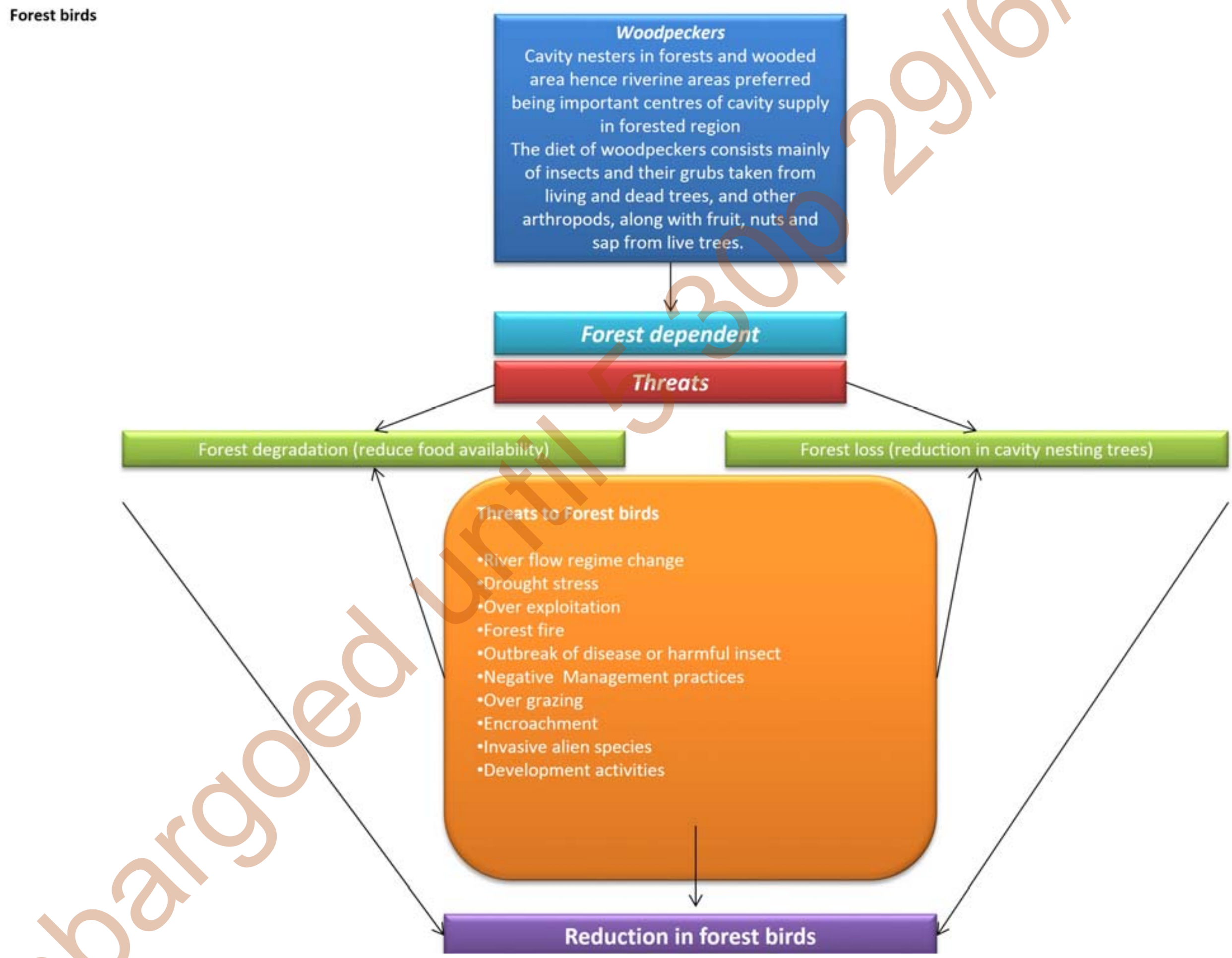


Figure 8-4 Conceptual model showing representative bird species (woodpecker) of the forest habitat with their characteristics and possible threats



## 8.6 Potential metrics for monitoring to inform environmental flows for river, water, forest and grassland birds

There are many variables that could be useful to aid the determination of environmental flows required to sustain bird populations and communities in the event of flow regime changes. Spatio-temporal monitoring of these variables should be designed. We therefore suggest monitoring of broader environmental variables including systematic bird/habitat monitoring. All of these linked variables will be able to reflect community composition of birds and other wildlife and their relationship with environmental flow requirements (see Table 8-5).

Table 8-5 Suggested metrics for monitoring abiotic and biotic components to link changes in bird populations with environmental flow requirements

| Nature-induced events | Physical parameters | Chemical parameters | Botanical parameters | Zoological parameters |
|---|---|---|---|---|
| Rainfall intensity, coverage and frequency | River hydrology | Dissolved minerals | Habitat types and their extent | Bird species, populations in different habitats and seasons |
| Fire intensity, coverage and frequency | Watershed condition | Turbidity | Invasive alien weeds | Indicator species |
| Flooding intensity, coverage and frequency | Water release | Dissolved oxygen | Vegetation changes | |
| | River depth | Temperature | | |
| | Effective floodplain area | pH value | | |
| | | Conductivity | | |
| | | Pollutants at various stretches | | |

## 8.7 New research required to address knowledge gaps

Birds are perhaps the easiest of animals to census and undoubtedly the most frequently censused of all taxa in the world (Gibbons et al. 1996). Bird studies are ever increasing in the country, although they are highly biased towards threatened species (Baral et al. 2012b). The most comprehensive faunal document in this country, belongs to birds, with many publications such as site-based conservation documents (BCN and DNPWC in prep) and species' status assessments (Inskipp et al. 2016). Although various direct threats to birds that have been identified (BCN & DNPWC 2011, Inskipp et al. 2016), the underlying causes of many of these threats, especially in relation to changes in hydrological cycles and environmental flows, have not been discussed. In this regard, anthropogenic changes such as altered flow regimes which can affect species and ecosystems have not been studied for birds (as well as several other major taxa). Such changes could pose threats not only to one species but entire communities and ecosystems that exist in the affected Basin area. As determination of environment flows are dependent on various factors, it is increasingly felt that holistic environmental studies are required to detect subtle changes in communities. Research should also include studies on glacial lake outburst floods and the possible effects from these on the lower river basin. Water use in all its manifestations (industrial scale to subsistence), various infrastructure that halts or alters river flow to make sections of river static, and changes from lotic to lentic ecosystems mainly brought about by dams, reservoirs and barrages, should also be studied.

## 8.8 Livelihoods

River flow and water are first and foremost the most important factors for sustenance of life for all communities. Water is also the only medium used in all households for washing and cleaning. Water is vital for agriculture for irrigation purposes, for river fishing communities and commercial fish farmers, for tourism and recreation and last but not least, for ecosystem integrity and sustenance of biodiversity. Birds are also vitally linked to the livelihoods of local people. They are one of the best animal pollinators of plants. They help reduce invasive pest populations (such as insects and snails).

Bird-watching tourism has been gradually increasing in the country. More than 500 individuals in the country are directly engaged in bird-watching tourism supporting nearly the same number of families. There are several thousands of families and businesses supported indirectly and by a chain value effects. In the Koshi Tappu area alone, there are three large investment lodges catering for high end bird watching tourism. Each of these supports around 10 families. In addition to these, other small lodges and home-stay programmes as well as riverside restaurants are plentiful in the area, which again are supporting a large number of families. Most of the lodges/accommodation and eating places are marketing the area based on the unique and threatened birdlife of the Koshi Basin. Population decline or absence of birds will mean a direct impact to the livelihood of these people.

## 8.9 Summary

The Koshi Basin is one of the largest river basins in Nepal. Because of its strategic location in the eastern part of central Himalaya and the western part of eastern Himalaya, it forms one of the most biodiverse river basins of the Himalaya region. The Basin is criss-crossed with many large snow-fed rivers as well as innumerable small rivers, streams, waterfalls and brooks. Water in all essence gives its true character; its watersheds and Himalayan snow peaks as water-towers are the source of this water.


Small Pratincole (*Glareola lactea*) (Photo: Darren Clark)

Watersheds and rivers in the form of wetland resources provide habitat to many bird species. Because of their sheer diversity and representation in all altitudinal and horizontal gradients alike, there are a few key specialist species that will act as indicators of ecosystem change, like ‘the canaries in the coal mines’. Current research knowledge can guide us to a path of balanced conservation and development. Future research could be more focused as to how and what to monitor, how best we can be informed regarding changes of flow regimes. There is a clear need of conducting environmental flow assessment in depth within the Koshi Basin. More specific and focused knowledge could help highlight the middle path and present a win-win situation.

## Acknowledgements

We thank Susheel Shrestha, Darren Clark and Himalayan Nature for the use of their photographs. We also take this opportunity to thank our reviewers – Dr Bhagawan Raj Dahal (Zoological Society of London - Nepal Office) and Carol Inskipp (Nepal bird expert) – for their insightful and constructive comments.

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# 9 Determining flow requirements for the Wild Water Buffalo (*Bubalis arnee*)

*Authors: Khadga Basnet[1], Sagar Dahal[1]*

## 9.1 Introduction

An environmental flow or water regime of a river is critical to maintain ecosystems and ecosystem services in a river basin (see Dyson et al. 2003, Tharme 2003) and has been widely considered in integrated river basin management (Poff et al. 2003). This is important for Nepal for several reasons. Major rivers such as the Koshi, Gandaki, and Karnali originate in the Himalaya and flow down the plain lowlands forming large river basins. These rivers have huge potential for hydropower generation, irrigation, and other multiple uses of water resources required for economic development. Similarly, they are important for biological diversity, socio-culture, and political stability within Nepal.

In the Koshi Basin, the focus area of our study, historical records suggest that the Koshi River is known for disastrous floods. Similarly, water of the river has been diverted for multiple uses including hydropower and irrigation causing low flow particularly during dry season. Both high (flood) and low flows may affect terrestrial animals (mainly mammals) in general and the Wild Water Buffalo (*Bubalis arnee*) in particular.

A Water Buffalo in Koshi Tappu Wildlife Reserve (Photo: Y Uprety)

According to the Brisbane Declaration 2007 (Brisbane Declaration 2007),

*"environmental flows describe the quantity, timing and quality of water flows required to sustain freshwater and estuarine ecosystems and the human livelihoods and well-being that are dependent upon these ecosystems".*

The main objective of this chapter is to explore this relationship in the Koshi Tappu Wildlife Reserve of the Koshi River Basin via literature review and a case study of the Wild Water Buffalo using a conceptual model approach.

### Koshi Tappu Wildlife Reserve

The Koshi Tappu Wildlife Reserve (the Reserve) (Chapter 2, §2.5) is located on the floodplain of the Koshi River at the south eastern part of Nepal. The Reserve is the site of the last remaining population of the Water Buffalo.

[1]Central Department of Zoology, Tribhuvan University, Kirtipur, Kathmandu

## Diversity of terrestrial animals in the Koshi Basin

Broadly, Koshi Tappu Wildlife Reserve has five types of ecosystems: Khair-Sisoo riverian forest, grassland (steppe graminae), cultivated land, water bodies, and floodplain and sandy area. It has subtropical vegetation with lower tropical sal (*Shorea robusta*) and mixed broadleaf forest. More than 514 species of flora, 32 species of mammals, 485 birds, 17 species of herpeto fauna, and 105 fish species have been recorded from the Reserve (DNPWC 2002, Bhuju et al. 2007, Basnet 2011).

Several published sources (e.g. Baral & Shah 2008, Taylor et al. 2016) have shown the number of terrestrial mammals in the Reserve to be as high as 35 (Table 9-1). The main species of the Reserve include the Water Buffalo, Gaur (*Bos gaurus*), and Blue Bull (*Boselaphus tragocamelus*), Wild Elephant (*Elephas maximus*), Hog Deer (*Axis porcinus*), Spotted Deer (*Axis axis*), Wildboar (*Sus scrofa*), Smooth-coated Otter (*Lutra perspicillata*), Fishing Cat (*Prionailurus viverrinus*), Golden Jackal (*Canis aureus*) (see Bhuju et al. 2007). However, a steady decline in the number of large mammals such as the Gaur and Blue Bull has been observed in the reserve. The current study focuses on the Water Buffalo as a potential indicator of flow regime change.

Table 9-1 List of terrestrial mammals and their status in Koshi Tappu Wildlife Reserve

| Family | Scientific name | Common name | Nepal Red book status* | IUCN status* | CITES |
|---|---|---|---|---|---|
| BOVIDAE | *Bos gaurus* | Gaur | P,VU | VU | I |
| | *Boselaphus tragocamelus* | Blue Bull (Nilgai) | VU | LC | |
| | *Bubalus arnee* | Wild Water Buffalo | P,EN | EN | III |
| CANIDAE | *Canis aureus* | Golden Jackal | LC | LC | III |
| | *Vulpes bengalensis* | Bengal Fox | P, VU | LC | III |
| CERCOPITHECIDAE | *Macaca mulatta* | Rhesus Macaque | LC | LC | II |
| | *Semnopithecus hector* | Tarai Gray Langur | LC | NT | I |
| CERVIDAE | *Axis axis* | Spotted Deer (Chital) | VU | LC | |
| | *Axis porcinus* | Hog Deer | EN | EN | |
| | *Muntiacus muntjak* | Barking Deer | VU | LC | |
| ELEPHANTIDAE | *Elephas maximus* | Asiatic Elephant | P,EN | EN | I |
| FELIDAE | *Felis chaus* | Jungle Cat | LC | LC | II |
| | *Panthera pardus* | Common Leopard | NT | VU | I |
| | *Prionailurus viverrinus* | Fishing Cat | EN | EN | II |
| HERPESTIDAE | *Herpestes edwardsii* | Indian Grey Mongoose | LC | LC | III |
| | *Herpestes javanicus* | Small Asian Mongoose | LC | LC | III |
| HYSTRICIDAE | *Hystrix indica* | Indian Crested Porcupine | DD | LC | |
| LEPORIDAE | *Lepus nigricollis* | Large Hare | LC | LC | |
| LUTRANAE | *Lutra lutra* | Common Otter | NT | NT | I |
| | *Lutrogale perspicillata* | Smooth-coated Otter | EN | VU | II |
| MURIDAE | *Mus musculus* | House Mouse | LC | LC | |
| | *Mus sp.* | Field Mouse | | | |
| | *Rattus rattus* | House Rat | LC | LC | |
| MUSTELIDAE | *Martes flavigula* | Yellow-throated Marten | LC | LC | III |
| PTEROPODIDAE | *Pteropus giganteus* | Flying Fox | LC | LC | II |

| Family | Scientific name | Common name | Nepal Red book status* | IUCN status* | CITES |
|---|---|---|---|---|---|
| PTEROPODIDAE | *Cynopterus sphinx* | Greater Short-nosed Fruit Bat | LC | LC | |
| SCIURIDAE | *Funambulus pennantii* | Five-stripped Palm Squirrel | LC | LC | |
| | *Ratufa bicolour* | Black Giant Squirrel | EN | NT | II |
| | *Callosciurus pygerythrus* | Hoary-bellied Squirrel | LC | LC | |
| SUIDAE | *Sus scrofa* | Wild Boar | LC | LC | |
| VESPERTILIONIDAE | *Pipistrellus coromandra* | Coromoandel Pipistrelle | LC | LC | |
| | *Pipistrellus tenuis* | Least Pipistrelle | LC | LC | |
| | *Scotozous dormer* | Dormer's Pipistrelle | - | LC | |
| VIVERRIDAE | *Viverra zibetha* | Large Indian Civet | NT | NT | III |
| | *Viverricula indica* | Small Indian Civet | LC | LC | III |

(*) Status: DD= Data Deficient; EN=Endangered; LC = Least Concern; NT=Near Threatened; VU=Vulnerable). A status of 'P' indicates that the mammal is protected by the NPWC Act 1973.
The CITES (the Convention on International Trade in Endangered Species of Wild Fauna and Flora) column indicates whether the mammal is listed in one of its appendices (I, II or III): I lists species that are threatened with extinction; II lists species that are not necessarily threatened with extinction, but may become so if trade is not regulated; III are species listed by one member country to request other countries to assist in controlling their trade.

## 9.2 The Wild Water Buffalo

The Wild Water Buffalo (hereafter `Water Buffalo') are found in south Asia and south-east Asia, particularly in Bhutan, India, Indonesia, Malaysia, Nepal, and Thailand. In Nepal, there were Water Buffaloes in Chitwan area, which is now known as Chitwan National Park. However, they were extirpated after 1960s due to human encroachment causing deforestation, habitat loss, and also diseases transferred by domestic buffaloes and cattle (Seidensticker 1975). A critically endangered species with a small population in the Koshi River Basin, the Water Buffalo prefers the habitat of low lying alluvial grasslands and their surroundings though it will also utilise riverine forests and woodlands, and cultivated lands (Hedges et al. 2008).

Water Buffalo are highly dependent on water resources. Although the changes in the Koshi River course and regular flooding highly disturb the habitats of the Reserve, the consequences can be very beneficial – floods create waterholes and also deposit fertile alluvial mud for new grasses, both of which make habitats suitable for Water Buffaloes. More than 87% of their time is spent grazing on sprouting thatch grass (*Saccharum spontaneum*), resting, and wallowing around these habitats (Rai 2013). Indeed, waterholes are often used for undertaking Water Buffalo census. Ram and Sharma (2011) estimated the population in the Reserve using waterholes and block count method, and recorded 237 individuals (Table 9-2). With small year-to-year fluctuations without any particular pattern, the population of the species is rising slowly in the Reserve in spite of a decrease in the calf/cow ratio (Table 9-2).The most recent census of the species in 2014 counted 227 individuals.

Table 9-2 Population and age-sex category of the Water Buffalo in the Koshi Tappu area (Source: DNPWC 2011 (Arna Census Report 2068)

| Year | Male adults | Female adults | 2nd year calves | 1st year calves | Total | Ratio calves:cows |
|---|---|---|---|---|---|---|
| 1976 | 12 | 18 | 22 | 11 | 63 | 0.61 |
| 1987 | 32 | 29 | 14 | 16 | 91 | 0.55 |
| 1988 | 37 | 33 | 8 | 15 | 93 | 0.45 |
| 2000 | 56 | 53 | 17 | 19 | 145 | 0.36 |
| 2004 | 54 | 63 | 24 | 18 | 159 | 0.29 |
| 2009 | 55 | 119 | 22 | 23 | 219 | 0.19 |
| 2010 | 57 | 108 | 24 | 26 | 215 | 0.24 |
| 2011 | 66 | 117 | 15 | 39 | 237 | 0.33 |

## 9.3 Current research knowledge and gaps

Koshi Tappu Wildlife Reserve is one of the well-studied protected areas of Nepal (Basnet 2000, 2011, Sah 1997, DNPWC 1995). Studies ranging from general surveys and population census (Ram 2010, Mishra et al. 2009, Heinen & Kandel 2006, Heinen & Singh 2001, Heinen & Srikosamatara 1996, Hedges 1995, Dahmer 1978) to genetic and behavioural research and their management implications, conservation policies, Buffer Zone and park-people relations (Aryal et al. 2011, Flamand et al. 2003, Heinen 2002, Heinen 1993a,b), and even the outcome of a particular conservation project (Khatri et al. 2012) have been published locally and internationally. Moreover, a large number of student theses and dissertations on the Reserve are produced every year. Thus, there exists a vast body of information on the Reserve, its biodiversity, and wildlife conservation.

However, long-term studies linking species-ecosystem and landscape and cause and effect relationship between environmental flow and wildlife species including Water Buffalo are lacking.

## 9.4 Environmental flow in the Koshi River: change and impacts

The Koshi River of Nepal is one of the major snow-fed river systems receiving flows from numerous tributaries that originate in the high mountain areas covered by snow and glaciers. More than 68% of the total drainage area of the Saptakoshi lies below 3000m (Gupta 1997). Like in other rivers of Nepal, groundwater is the primary source for maintenance of base flow of the Koshi River. The monsoon rainfall, snow-melt water, and various human activities (e.g. hydropower) change the discharge of the river with high monthly variation (Sharma 1993). High flow (flood) brings deposition of large amounts of silt and sedimentation (Table 9-3) that can result in changes to the course of the river. With 118 $Mm^3$ $year^{-1}$ sediment due to extensive soil erosion and landslides in its upper catchment areas (Regmi 2013), the Koshi River is counted as one of the highest silt-yielding rivers in the world (Wakode et al. 2013).

Seasonal rainfall variation, river flow discharge (Figure 9-1 to Figure 9-3), deposition of sediment (Table 9-3) and associated disturbances must have affected the Reserve and Water Buffalo but no quantitative data are available to assess the impact. Hence, it is difficult to determine whether the Koshi River flow has affected occurrence, abundance and distribution of terrestrial mammals including Water Buffalo.

Table 9-3 Contribution of sediment of different tributaries of the Saptakoshi River (Source: Thapa 2003)

| River | Catchment area $km^2$ | Annual sediment load million tonnes | Sediment load tonne/ha/yr | Erosion rate tonne/ha/yr |
|---|---|---|---|---|
| Tamur at Tribeni | 5,900 | 47.20 | 80.00 | 240.0 |
| Arun at Tribeni | 36,533 | 54.80 | 15.00 | 45.0 |
| Sunkoshi at Tribeni | 19,230 | 86.53 | 45.00 | 135.0 |
| Koshi at Barahchhetra | 31,773 | 177.00 | 55.71 | 169.0 |

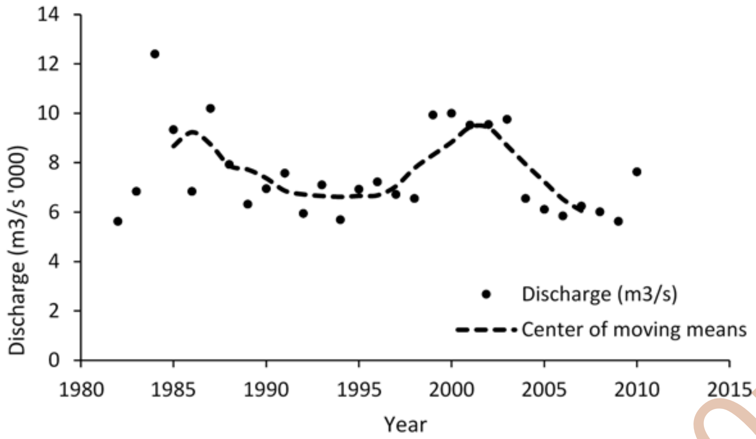


Figure 9-1 Trend of discharge ($m^3$/sec thousands) in Chatara (1982–2015)

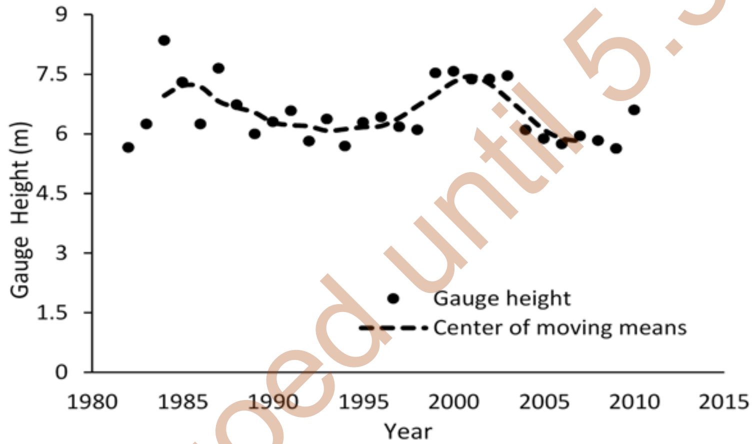


Figure 9-2 Extreme gauge height at Chatara (1982–2010)


Figure 9-3 Trend of extreme rainfall in Chatara, Sunsari (1985–2015)

## 9.5 Conceptual model: the relationship between floods and the Water Buffalo

A schematic conceptual model (Figure 9-4) has been generated to explain the possible relationship between the Water Buffalo and flow change in the Koshi River. Since the information related to water requirements of the Wild Buffalo is limited, it could be assumed that the information contained in the conceptual model is sufficient to understand the flow requirements to protect Water Buffalo, however, this may not the case. The model considers:

- depth of waterholes required for wallowing – adult and young
- size of waterhole needed – especially minimum size for adult and young
- wallowing nature of the water buffalo
- river bank characteristics to allow buffalo to get in and out of the waterhole
- water quality and quantity of the waterhole (how important are they?)
- water requirements to grow tall grasslands and forests of the area.

The model incorporates three wetland habitats favoured by the Water Buffalo, namely alluvial tall grassland, mixed riverine forest and waterholes, all of which need to be present in combination. These provide grazing, shade and wallows. As described in the previous section, changes in flow that adversely affect the condition and/or extent of these habitats may be a threat to the Water Buffalo. The model does not contain any temporal information as to how long the Water Buffalo will reside in areas where their preferred habitat is degraded; nor does it contain knowledge as to the threshold of tolerance before the Water Buffalo will abandon a site, hence, these are knowledge gaps.

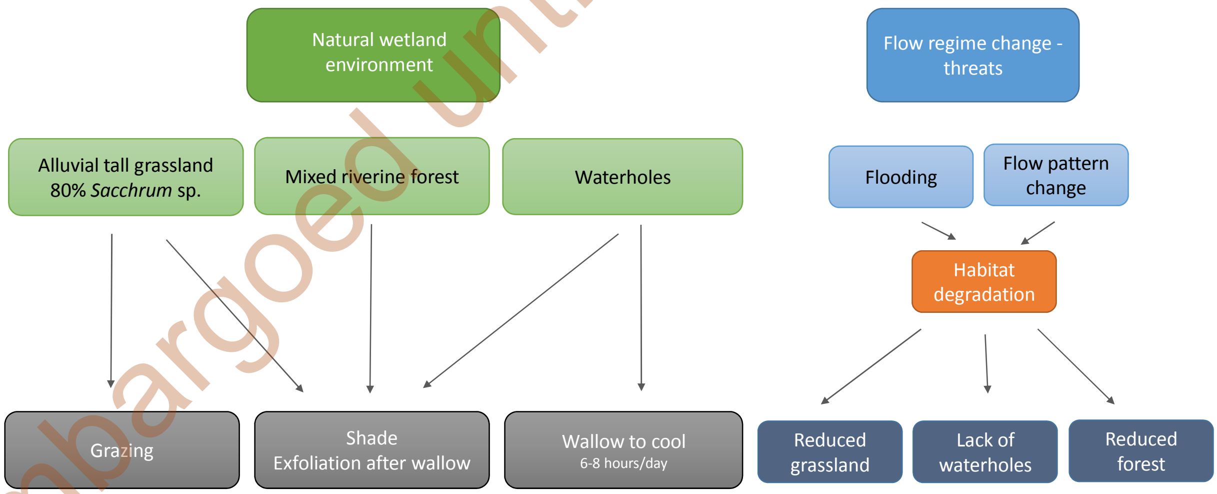


Figure 9-4 Water Buffalo conceptual model



## 9.6 Challenges and opportunities

Despite government's water conservation interventions, the Water Buffalo of the Reserve is under constant pressure from anthropogenic activities and natural disturbances (Aryal et al. 2011, Ram & Sharma 2011). The most serious threat is in-breeding of Water Buffaloes with domestic buffaloes left by nearby villagers for grazing. Other potential threats include habitat fragmentation and habitat loss due to high flow and flood, transmission of diseases from domestic animals, poaching, and other human-wildlife conflicts (Rai 2013). Outbreaks of invasive plant species like *Mikenia* are also emerging threats to the wild animals of the Reserve (Hedges et al. 2008).

The Reserve was severely affected during the insurgency period because most of the security posts were removed (Ram and Sharma 2011), leading to habitat destruction. The severe Koshi flood in 2008 caused the river to change its main course and inundated local settlements by breaking the eastern Koshi Dam. This flood devastated wildlife and their habitats besides killing people and destroying their properties, and damaging tourism (Khatri et al. 2010). Impacts of both of these incidents will last long because of the destruction of habitats and potential loss of wildlife species affecting their population structure.

New research would lead to working toward long-term ecological research addressing flow regimes and the effects of changes on biodiversity in general, and on the Water Buffalo in particular. Since research data for the Reserve are available, the data should be consolidated and analysed to unfold many of the questions raised above. Proposing just a list of possible research is naïve; therefore, a broad research framework that accommodates a wide range of research objectives and long-term monitoring may fetch desirable results. This includes understanding of:

- the state of natural disturbances (e.g. status, frequency, intensity) together with anthropogenic disasters
- physical (e.g. habitats), biological (e.g. populations of the Water Buffalo), and socioeconomic (e.g. local communities) changes brought by natural and anthropogenic disasters
- responses (e.g. recovery process) of species, ecosystem, and landscape including human communities to such disasters.

Natural history and historical data are always important, therefore, a proper analysis of the existing data should be the gateway to this complex research process. Other problems for immediate action include investigating the possibility of reintroducing Water Buffaloes to suitable habitats in the Narayani floodplain and potential diseases that are transmitted from domestic livestock. The issue of transmittable diseases is important because Water Buffaloes were wiped out from Chitwan due to disease in the 1960s.

## 9.7 Livelihoods relationship

Wildlife has direct and indirect impacts on local livelihoods. Crop depredation, predation of domestic animals, transmission of diseases to domestic animals, and attack on people by wildlife are the main negative impacts of wildlife on livelihoods of local people. However, Protected Areas (BPP 1995), biodiversity conservation projects (Khatri et al. 2010, 2012), and wildlife contribute positively to local livelihoods and livelihood diversification. The main potential direct economic opportunities for Buffer Zone communities of the Reserve include:

- community development programs and income generation schemes of the reserve
- 35–50% of the revenue earned by the Reserve (e.g. tourism) for community development
- employment opportunity in the Reserve
- wildlife tourism and income generation (wildlife sighting); the Water Buffalo is an attraction for many.

## 9.8 Summary

The Koshi Basin is one of the most flood-prone areas, with a reputation of being the highest siltation carrying river, in the world. The river has changed its course regularly within the last 200 years due to the tectonic movement and deposition of silt. However, the flow regime is critical to maintain the dynamic ecosystems that have adapted to these changes. Koshi Tappu Wildlife Reserve is located in the Koshi Basin within Sunsari, Saptari and Udaypur districts. The Reserve was established particularly for the conservation of the last remaining population of the Water Buffalo in 1976. Floodplains consisting of young sprouting grass, wallowing ground, and waterholes are essential for the survival of these endangered species with a decreasing population trend worldwide in general. However, the population of the Water Buffalo in the Reserve, is showing an increasing trend in spite of a low calf/cow ratio. This increase may be due to continuous flooding and inundation of the Koshi River that maintains the grassland ecosystem as a depositional fertile siltation ground, forming plenty of water holes for wallowing. The main threats to the population are from inbreeding with domestic buffaloes, habitat fragmentation and loss, and conflict with humans.

A broad framework of long-term ecological research is essential to understand the dynamics of the Koshi River flow and terrestrial animals, particularly the Water Buffalo of the Koshi Tappu Wildlife Reserve on which livelihoods of Buffer Zone communities depend.

### Acknowledgements

This paper is the outcome of a series of discussions and workshops in 2015 and 2016 in Kathmandu, for which CSIRO provided funding. We would like to acknowledge Tanya Doody and Susan Cuddy of CSIRO, Laxmi Bhatta of ICIMOD, Narendra B. Pradhan and Ishana Thapa of Bird Conservation Nepal for their support, Department of Hydrology and Meteorology for 30-year rainfall data, Prakash Aryal for data analysis and discussion, and Yadav Uprety for a photograph.

# 10 Connecting flows, fish diversity and ecology in the Koshi Basin

*Authors: Tek Bahadur Gurung[1,] Anandeeta Gurung[2], Tanya Doody[3]*

## 10.1 Introduction

The Koshi Basin is a major river basin located in Nepal and experiencing stress in its aquatic ecosystems.This chapter presents a review of freshwater fish diversity of the Koshi Basin and attempts to elucidate the interplay between river flow and fish biodiversity, economy and livelihoods as a part of integrated water resource management. The Koshi River system is rich in fish species diversity, whilst the Ramsar protected Koshi Tappu Wildlife Reserve and its surroundings are known to represent the largest small scale inland capture fishery of Nepal in terms of fish species abundance, fish haul and the number of fishers dependent on fish for their livelihood. Through review, we have determined for the first time that 141 fish species (134 indigenous and 7 exotic) are located along the gradient from the upper Sunkoshi to the Koshi Barrage (8,000 – 75 m asl) in the Koshi Basin.

## 10.2 Threats to fish biodiversity

Environmental and anthropogenic changes over past decades have imposed great threats to the natural flow regime of the Koshi River, with likely significant impacts on fish based ecological services and fisheries which represent one of the most important options of food, nutritional security and livelihood among marginalised communities. Damming across rivers for hydropower and irrigation extraction has altered flow regimes in the past and is likely to continue due to increasing power requirements. It is known that over harvesting has severely depleted fishery resources, depriving local fishermen of their major source of subsistence throughout Nepal (Gurung 2013). In addition, other anthropogenic, natural hazards and climate changes have altered the flow regime of the Koshi River (Gosain et al. 2010) which is also likely to impact fisheries and overall biodiversity of global significance. Climate change, erratic rainfall, temperature rise, melting of snow, glacier burst, flash flood, deforestation, damming, barrages, embankments for hydropower, and agricultural irrigation have all substantially impacted river flow and discharge.

A concrete dam (the Koshi High Dam) has recently been proposed for construction in Barahkshetra (near Chatara). The dam is proposed to be 269 m high with a live storage capacity of 4420 $Mm^3$ and

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1 Principal Scientist and Director, National Animal Science Research Institute (NASRI) of Nepal Agricultural Research Council (NARC)

2 PhD Scholar, Graduate School of Life Sciences, Dept of Environmental Life Sciences, Division of Ecology and Evolutionary Sciences, Biological Institute, Tohoku University, Japan

3 CSIRO Land and Water, Adelaide, Australia

gross storage capacity of 8500 $Mm^3$ (Dixit 2009, Oza 2014, Khatri et al. 2012, Devkota & Gyawali 2015). The purpose of the dam is threefold: to irrigate 66,450 ha of land in Nepal and millions of hectares in India, flood control and produce 3489 MW of hydropower (DoED 2013). Recently, a Joint Ministerial Commission of India-Nepal Water Resources (JCWR) has agreed to complete a detailed project report for the Koshi High Dam Multipurpose Project (Devkota & Gyawali 2015). Construction of this dam is very likely to impact aquatic ecology and in particular fish number and biodiversity, as water is regulated by the dam wall. Hydropower dams in general have been accused of altering aquatic thermodynamics, flows and many other aspects of aquatic life (WCD 2000). Thus, impacting poor and marginalised communities depending on capture fisheries for livelihood. The ecological services offered by river flow connectivity are also likely to be irreparably impacted.


(Photo: Ram P Chaudhary)

Worldwide, environmental flows have been determined as a key factor to aid major hydrological decision making within an integrated river basin management framework (Poff et al. 2003). Matthews et al. (2014) express that the flow regime or environmental flows, are the 'master variables' for maintaining the integrity of aquatic ecosystems. Environmental flows are the quantity, timing, and quality of water flows required to sustain freshwater and estuary ecosystem and the human livelihood, and wellbeing that depend on these ecosystems (Matthews et al. 2014). Nepal is unique globally as the home of the Himalayas, with large snow reserves which discharge water downstream. As such, the concept and knowledge of environmental flows is becoming an indispensable part of research and government policy in the country, as the potential of Himalayan water resources are continuously recognised as a means to support anthropogenic development in Nepal. It is urged that Himalayan Rivers should be managed and regulated in such a way that they become the place of 'more fish, more power and more prosperity' which has been achieved in many other parts of the world (Forseth & Harby et al. 2014).

## 10.3 Fish species, fisheries and fish ecology in Koshi River system

### Fish classification

The Koshi River and its tributaries represent cold, cool and warm water habitats from the Mountains, Mid Hills and warm water climatic zones, respectively. There has been a classification of streams, rivers and other water bodies according to their temporal and spatial changes in surface water temperature as cold, cool and warm water, with some overlapping in temperature regimes (Hillman et al. 1999, Bouchard & Genet 2014). Such a classification could be useful to categorise fish species as cold, cool or warm water dwellers. However, in the present study we simply categorise cool water fish as those which neither inhabit permanently in cold or warm waters, however their life history strategies rely on a temperature range of 12 to 29°C (Figure 10-1). We classify cold water species are those which mostly complete their life cycle in temperatures ranging from 7-20°C (Figure 10-1). Warm water fishes require temperatures from 15 to 32°C to complete their life history strategies (Figure 10-1). Fish may exist outside these temperature ranges but to reproduce they must remain in water temperatures which suit their life history strategy. There are some exceptions with species having an ability to exist in extreme cold and warm waters. *Cyprinus carpio* and

*Ctenopharyngodon idella* for example, survive in both cold and warm water temperature ranges but require water temperature between 18°C and 25°C for reproduction.

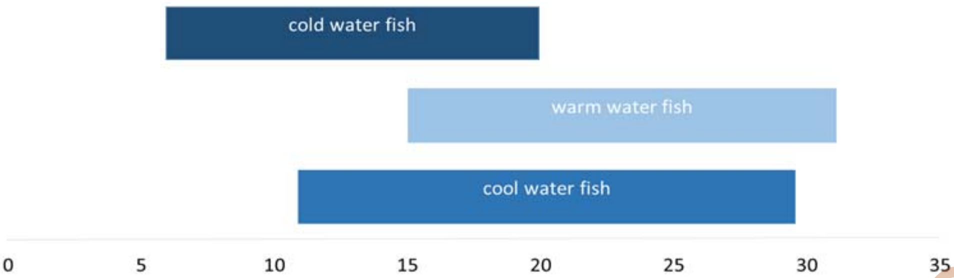


Figure 10-1 Temperature (degrees Celsius °C) ranges required to support life history strategies of cool, cold and warm water fish

## Fishes and fisheries

Five species appear on the International Union for Conservation of Nature (IUCN) red list and include: *Bagarius yarrelli* (gonch), *Tor putitora* (Himalayan mahseer), *Tor tor* (tor mahseer), *Schizothorax richardsoni* (ray-finned fish) and *Neolissochielus hexagonolepis* (Katle) in Nepal. *Tor putitora* is listed as endangered; *Schizothorax richardsoni* is vulnerable while the rest are reported as near threatened. There are nine species belonging to the Genus *Glyptothorax*, which are locally known as Tilkabhre. These are the most important endemic fishes to riparian communities in terms of the importance for food, nutrition security, sports, cultural and religious purposes (KHP 2013). Rare and endemic species are critical components of community structure, as their loss can result in faunal homogenization (Burlakova et al. 2011), which can compromise ecosystem functioning (Smith & Knapp 2003).

The commercially important *Schizothorax* Genus is represented by seven species. Both the *Schizothorax* spp. and *Psilorhynchus pseudochenius* (Stone carp) are known to be worshipped by hill tribes and ethnic communities (KHP 2013) during their upward and downward migration relating to seasonality and rhythmic natural courses in streams and rivers.

(Photo: Ram P Chaudhary)

There have been many surveys and estimates of fish species in the river system, however, until now, these estimates have not been collated. Payne and Temple (1996) for example, estimate that the Koshi River system has 110 fish species. A further estimate suggests 92 fish species are reported to persist in the lower reaches of the river (Thapa 2008). Shrestha (2007) suggested that the Koshi River harbours 108 fish species while Rajbanshi (2002) listed many fish species, of which 46 are cold water fish from the Koshi River system. An inventory by Limbu and Subba (2011) listed 81 fish species from the Koshi River, with a further estimate by Ranjit (2002) of 22 fish species which were cold and cool water species from the upper Sunkoshi River, one of the main tributaries. In addition, Shrestha et al. (2009) documents 30 fish species from the Tamurkoshi tributaries, and Edds and Ng (2007) added seven more species from the Koshi River and its tributaries in the east (Table 10-1).

Compilation of the total fish species for the first time indicates that there are 141 fish species which consist of 134 native species (Table 10-1) and seven exotic species (Table 10-2). The most dominant family of the Koshi fishes is Cyprinidae, represented by 63 species, with only one species belonging to *Balitoridae, Anguillidae, Erethistidae, Clariidae, Engraulidae, Nandidae, Notopteridae, Tetrodontidae, Amblycipitidae, Saccrobranchidae, Gobidae, Sitoridae, Chacidae* and two species belonging to *Siluridae, Clupidae, Mastacembelidae, Centropomidae, Anabantidae*. The family *Bagridae* has seven species, *Sisoridae* has 17 species, *Ophiocephalidae* has five, *Cobitidae* has 13 species and *Schilbeidae* has five species.

The number of fish species reported in the country has seemingly increased, as a result of an increase in recent ichthyological activities (Edds & Ng 2007). While there is likely to be some duplication in species due to synonyms and mistakes in identification, we are optimistic that more fishes are yet to be discovered, not only in the Koshi Basin but worldwide. It is likely that more fish species are yet to be discovered from different tributaries such as Tamakoshi, Likhu, Bhotekoshi, Dudhkoshi, Arun and Indrawati (Chapter 2, Figure 2-2). Among these, the Indrawati and tributaries of Arun are known to be the hub of mountain capture fisheries. The presence of Majhi and Bote ethnic communities entirely depend on fishing as an occupation along the tributaries and have done so since ancient times, indicating that capture fisheries flourished in the past in these rivers.

To date, the number of fish species are yet to be quantified globally (Lierman et al. 2012). The Koshi Basin in particular, has been poorly studied for fish species diversity, thus, an inventory of fish species of the Koshi River system is therefore a high priority.

## Fish ecology

The ecology of fishes of Nepal is poorly understood. Detail studies have yet to be carried out to improve our understanding of the ecological interactions of fishes, especially in high altitude areas (Edds & Ng 2007). In general, the fishes in cold water areas in the Himalayas have been found to be predominantly represented by cyprinid of the genus *Schizothorax* spp (Snow trout). The snow trout migrates upstream and is reported to spawn in March to June at water temperatures ranging from 14°C to 21°C by laying eggs in the gravels along the banks of streams in clear water of moderate current between depths of 30-60 cm (Negi 1994). The fishes of this genus are found in cold waters even at an altitude of about 3000 msl. Observations suggest that the “cold water” zone tends to end where water the temperature exceeds 21°C (Payne & Temple 1996). Beyond this point, the cool water fishes emerge as the dominant fishes in the lower reaches of Mid Hills, with Mahseers, Katle and *Bagarias* spp seemingly frequent in water bodies in this region, but not in warmer parts, except for accidental occurrence probably due to sweeping floods. Mahseers (*Tor putitora* and *Tor tor*) and Katle (*Neolissocheilus hexagonolepis*) are often closely alike in ecological needs, thus both are found in cool water, clean river pools and lakes with oxygenated water interconnected with Mid Hill river streams and often in upper reaches of floodplains (Shrestha 2007; ESSA Technologies Ltd 2014).

(Photo: SK Wagle)

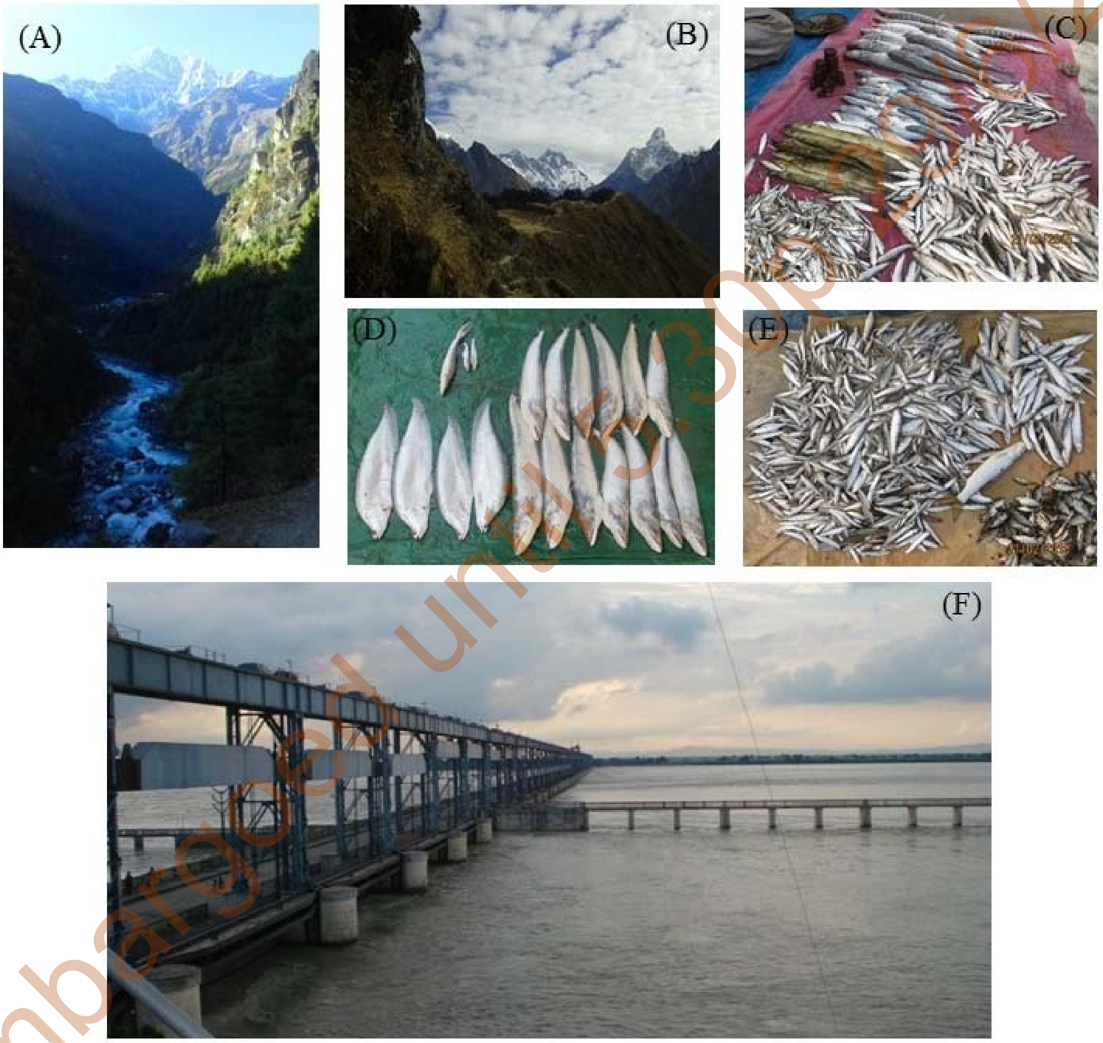


Figure 10-2 (a) Dudhkoshi, a tributary of the Koshi River (Photo: TB Gurung); (b) Mt Everest (Photo: TB Gurung); (c) Captured fish – Koshi River (Photo: SK Wagle); (d) Featherbacks – Koshi River (Photo: SK Wagle); (e) Minnows and forage species – Koshi Basin (Photo: SK Wagle); (f) Koshi barrage near Nepal-India border (Photo: TB Gurung)

According to Fu et al. (2004) the maximum elevation distribution of *Herzensteinia microcephalus* and *Triplophysa stewarti* (Cypriniformes: Cyprinidae) was 5200 m asl, which is likely to be the highest point among freshwater fish occurrence around the globe, however to date, fish in these zones are little studied in the Koshi Basin. In contrast, at a river elevation of about 2900 m in the DudhKoshi, close to the Namche bazzar area, it is understood that no fish exist in the river, probably due to geographical isolation of the river by water falls.

## 10.4 The flow regime: key driver of change

### Threats and impacts

The flow regime is the key 'driver' of ecology and biodiversity of rivers and their associated floodplains (Junk et al. 1989, Richter et al. 1997, Hart & Finelli 1999, Kattel et al. 2015). Modification of flow regimes is the most serious and continuing threat to ecological sustainability of rivers, associated wetlands and freshwater fish biota (Naiman et al. 1995, Matthews et al. 2014, Opperman et al. 2015).

There are several hydropower dams within the Koshi River system however; how they have impacted fish ecology has yet to be evaluated. It is agreed worldwide, that permanent modification of the natural flow regime is likely to have widespread, long term ecological impacts (WCD 2000). Hence, the construction of hydropower dams and in many instances, multiple 'cascades' of hydropower along a river which will create disruption to natural flow regimes and renders significant ecological risks. The construction and operation of a cross dam across the Koshi River is likely to substantially degrade the natural habitat, causing several hill stream fishes to disappear due to conversion from lotic to lentic habitats. For example, in the Kulekhani River, once the highly predominant *Schizothorax* fishery collapsed following the creation of lentic water by inundating into a large reservoir; another fish *Neolissocheilus hexagonolepis* which thrives well in pools became dominant in the reservoir (Swar 1992). Other implications include the loss of native fish species and disruption to the natural upstream-downstream connectivity by the dam, not only in terms of flows but also numerous abiotic - biotic characteristics and ecological services. Downstream of dams, it is likely that floodplain commercial fisheries might be significantly impacted by reduced flows or alterations to water temperature caused from damming. As a result, thousands of fishers might become unemployed due to reduced fish yield and drastic shift in species composition within the floodplain.


(Photo: SK Wagle)

### Flow change impacts and mitigation options

It is well known, that in comparison to terrestrial or marine biota, more freshwater fish have become extinct in the past due to anthropogenic impacts (Dudgeon et al. 2006, Arthington et al. 2010, Lierman et al. 2012) and in particular, the impacts of river flow regulation and diversion for various purposes. In Nepal, anthropogenic activities present the biggest threat to the conservation of fish species (Gurung 2013). Realising this fact, there has been an initiation of projects to mitigate the impact of damming within the Kali Gandaki River to preserve fish biodiversity and resilience to ethnic communities which depend on fishing for their livelihood (Gurung & Baidya 2012). According to the Aquatic Animal Protection Act of Nepal, it is the law to construct fish ladders or fish hatcheries if a dam has to be commissioned, either for hydropower or irrigation. Accordingly, a medium sized hatchery has also been constructed close to the Kali Gandaki Hydropower Station in Beltari by Nepal Electricity Authority, operated in joint collaboration with the Nepal Agricultural Research Council (NARC) to produce about 1 million fry of native fish per year. The purpose of this is to compensate the stock up and down stream of the river. The hatchery has expertise to breed at least 10 native river species (Gurung & Baidya 2012).

## 10.5 Methods to investigate river flow characteristics and to determine environmental flow metrics

The flow regime of a river is the key to provide a healthy functioning river and floodplain ecosystem. Based on this premise, Bunn and Arthington (2002) have drawn four basic principles which link flow and ecology. According to the $1^{st}$ principle, flow is a major determinant of both physical habitat and biotic composition. The $2^{nd}$ principle supports the idea that all aquatic species have evolved life history strategies primarily based on direct responses to natural flow regimes. According to $3^{rd}$ principle, maintenance of natural patterns of longitudinal and lateral connectivity is essential to the viability of populations of many riverine species. Principle 4 states that invasion and success of exotic and introduced species in rivers is facilitated by the alteration of natural flow regimes.

To monitor the relationship between river flows and fish ecology, several methods which have been proposed in the literature are briefly discussed below. Fish are a useful indicator of anthropogenic stresses in the aquatic environment when compared to phytoplankton, macrophytes, macroinvertebrates, water quality, flow regimes, dissolved oxygen, water temperature, seasonal flow, minimum flow parameters and magnitude etc. (Karr & Chu 1999). The Index of biotic integrity (IBI), first proposed and developed by Karr (1981), is the most widely accepted and extensively used assessment method (Jha 2006), where the fish and their attributes are the focus of investigations. The IBI is based on the hypothesis that there are predictable relationships between fish assemblage structure and the physical, chemical and biological condition of stream systems. Based on Karr's (1981) work, the IBI methods evolved further (Meador et al. 2008, Ganasan & Hughes 1998, Qadir & Malik 2009, Liu et al. 2010, Jia & Chen 2013, Mostafavi et al. 2014). In general, the metrics that were determined as important were used to assess impact by (1) quantifying human pressures at different spatial scales, (2) identifying applicable fish metrics which indicate a response to human pressures, and (3) integrating these metrics into a multi-metric fish index (Mostafavi et al. 2014).

(Photo: Ram P Chaudhary)

To understand the potential flow metrics that might appraise environmental flow requirements, requires detailed investigation of fish assemblages, structure and interaction among fishes. It would be important to understand what parameters of the flow regime are important to specific organisms or ecological process requirements. Islam (2008) described Environmental Flow Requirements (EFRs) of riverine ecosystems, where the ecological water needs of fishes were assessed as well as the local demands of human communities' social requirements along the river. He preferred that the livelihood of the people living close to the river should be associated and included as a metric of river ecological function. The practice of EFR's began as a commitment to ensuring a 'minimum flow' in the river, often arbitrarily fixed at 10% of the mean annual runoff (WCD 2000), even in Nepal. According to the Hydropower Development Policy of Nepal 2001, "Provision shall be made to release such quantum of water which is higher of either at least 10% of the minimum monthly average discharge of the river /stream or the minimum required quantum as identified in the environmental impact assessment study report".

Arthington et al. (2003) proposed the DRIFT (Downstream Response to Imposed Flow Transformations) method of environmental flow assessment, which is a structured process for predicting the biophysical, social and economic consequences of altering a river's flow regime. The fish component of DRIFT is a ten-step protocol designed to make such predictions using field data on a river's fish fauna, flow-related aspects of fish biology, knowledge base and professional experience of fish ecologists.

Substantial alteration of river flow from natural causes, can also substantially impact fish ecology (Liermann et al. 2012). Knowledge of how natural and altered flow regimes can affect fish assemblages and species in streams can be assessed using ELOHA (Environmental Limitation of Hydrologic Alterations) approaches (Arthington & Sternberg 2009), which describe the above mentioned four principles that articulate the influence of flow regimes on aquatic biodiversity (Bunn & Arthington 2002). Both the DRIFT and ELOHA approaches are useful to understand the impacts of flow modifications and aid in setting the modification limits after which substantial decline in fish stock for example, might occur.

## 10.6 Fish-flow ecology relationships

In general, it is known that invasive fishes can adapt successfully in river ecosystems with regulated flows (Malmqvist & Rundle 2002; Dudgeon et al. 2006). According to Malmqvist and Rundle (2002) water pollution, fragmentation, destruction or degradation of habitat, and invasion by non-native species all are linked and exacerbated by the modification of river flows and wetland inundation regimes. These are also important components which affect livelihoods by altering fishery viability by reducing edible native species and increasing invasive, less palatable species.

Conceptual linkages are demonstrated in Figure 10-3 to highlight the relationship between the natural or altered flow regimes and fish, by the level of fishery viability in subtropical floodplains. Under natural flow conditions, where longitudinal and lateral connectivity between river reaches and wetlands is suitable and where dissolved oxygen remains optimal to support native fish which are ideal for human consumption. As sufficient river flow is maintained, the area of macrophytes remains small and nutrient loads remain ideal for species such as featherbacks, catfish and murrels (Figure 10-3). However, as a result of significant flow regime change, poor water body connectivity and poor water quality eventuates and invasive fish then dominate and outcompete natural species due to their ability to survive in altered conditions. Alterations to fish species composition due to flow regime shifts can have devastating impacts on the local livelihoods which rely on native fish for food and income. A shift from indigenous major carp and featherbacks to forage species as a result of changes to flow regimes, transforms a viable livelihood option to a livelihood which has poor economic returns (Figure 10-3).

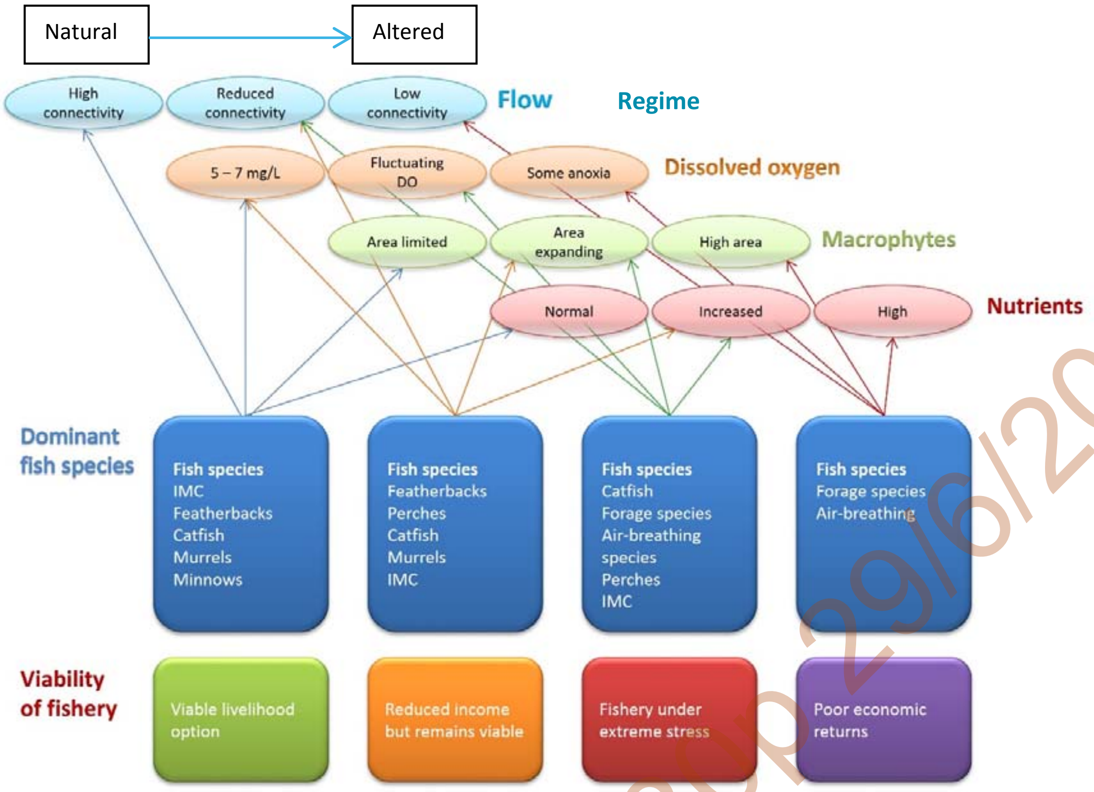


Figure 10-3 Conceptual model highlighting the interrelationship between river flow alteration, environmental factors, fish species and fishery viability. IMC – Indigenous major carp

Under ideal river conditions in Nepal, the expected fishes include indigenous carp dominated by *Labeo rohita*, *Cirrhinus mrigala*, *Catla catla*, Mahseers (*Tor tor*, *Tor putitora*, *Neolissocheilus hexagonolepis*), featherback (*Notopterus notopterus*, *N. chitala*), Minnows (minor cyprinid : *Puntius spp*, *Barilius spp*, *Labeo spp*), lower abundance of catfishes (*Mystus spp*; *Wallago attu*, *Bagarius bagarius*, *Bagarius yarelli*, *Clarias batrachus* etc), Murrels (*Channa punctatus*, *Channa striatus*, *Channa gachua*, *Channa marulius*) and Perches (*Anabas spp*). Among these, *L. rohita*, *C. mrigala*, *C. catla* are known to decline in capture fisheries (Payne & Temple 1996, Sarkar et al. 2013). The fish stock in Sapta Koshi might be considered as a 'natural gene pool' of commercial stocks. *Labeo rohita* (Dahanukar 2010), *Catla catla* and *Cirrhinus mrigala* thrive well in all fresh waters below an altitude of approximately 549 m. Since these are all indigenous major carp present in the Koshi Basin, Sapta Koshi thus contains ideal habitats for conservation.

In floodplains streams, rivers and lakes with reduced flow and low dissolved oxygen (DO), the fish composition might be dominated by featherbacks (*Notopterus chitala*, *N. notopterus*), cat fishes (*Wallago attu, Clarias spp, Heteropneustis fossilis, Mystus spp*), Perches (*Anabas testudineus*), Colisa (*Colisa spp*), Murrels (*Channa spp*) (Sarkar et al. 2013) with a poor representation of indigenous major carp, Mahseers, Minor carp or Minnows. Among the dominant species, most are known to be hardy and air breathing or can tolerate low levels of DO (Sarker et al. 2013). In streams and rivers with poor flow, increased levels of nutrients, fluctuating DO, and abundant macrophytes, a predominance of catfishes occur with an appearance of forage species (minor carp or minnows, Colisa, *Chanda ranga*, *Chanda nama* and *Chanda chanda*). Generally, small fishes like minnows, Colisa and Chanda may be used as insectivore or as ornamental or aquarium fish (Chandra et al. 2008; Shrestha & Edds 2012). Many of them might also be contributing as forage fishes for larger predators including fish, birds, aquatic mammals and reptiles.

(Photo: SK Wagle)

Water temperature, DO and nutrients were found to be the most important environmental variables influencing fish species richness, abundance and assemblage structure (Kundu et al. 2014). Higher DO and alkalinity of water offer higher abundance of *Aspidoparia morar*, *Tetraodon cutcutia*, *Gudusia chapra* and *Clupisoma garua* (Kundu et al. 2014, Thiel et al. 1995, Pegg & Taylor 2007). Maximum summer temperature of water (28.16 ± 0.19 ºC) and minimum water depth (3.0-3.6 m) could be unfavourable for most of the fishes except for silurids like *Mystus vittatus* and *Wallago attu*. Abundance of some species viz., *Esomus danricus*, *Chanda nama* and *T. cutcutia* can be correlated with environmental factors such as nitrate; while pH, salinity, hardness, nitrite and phosphate can be minor determinants of fish assemblage in freshwater systems (Kundu et al. 2014).

In areas with intermittent river flow, there are likely to be anoxic episodes as a result high macrophytes abundance and nutrient load. Under such conditions, it is likely that the fish stock would be dominated by forage and air breathing species with a higher majority of murrels, perches (*Anabas testudineas*) and poor presence of indigenous major carp.

## 10.7 Livelihoods

Water supports the livelihood of all (Cook et al. 2009) and is a major primer of global biodiversity. Water remains central to the global development agenda, as social and economic development continues to be held back by insecure food and clean water (Matthews et al. 2014), leading to conflict in demand and use of water resources. These conflicting demands, are exacerbated by increasing population numbers, increases the risks of food insecurity, poverty and environmental damage in major river systems (Cook et al. 2009).

According to Devkota and Gyawali (2015), the livelihood of millions of people of Nepal and India depend on water availability in the Koshi Basin. However, during the rainy season, frequent floods and drought have rendered millions vulnerable to their impacts. With the changing developmental trajectories of these countries, rapid development that includes urbanization, road and building construction and industrial have taken place in recent years in the lower part of the Basin, increasing the need the extract water resources. These activities are going to persist into the future. As in other parts of the world, long term water resource management is thus becoming a key driver for sustainable development of this region, in order to meet the growing water demand for domestic, irrigation, fisheries and industrial uses, and to mitigate the distressing impact of water induced disasters (floods and landslides).

The livelihood of fishers and their income from capture fisheries are interlinked with river flow (Figure 10-3), as discharge is the key driver of fish distribution (Fu et al. 2004; Bhatt et al. 2012, Pandit and Grumbine 2012). In general, fish species richness and abundance is higher in warm water floodplains, moderate in cool water and lowest in cold water zones. Of the 134 indigenous species identified, the majority are representative of warm water floodplain zones. Factors contributing to species richness are complex and associated with abiotic, biotic and physiological components such as food, oxygen, predation, water velocity, depth, productivity, recruitment success, diversity of micro habitats, water temperature, and flows dynamics etc. As such, higher endemism may also occur in the cool water zones in the Nepali Mid Hills at elevations between 700 to 1500 m (Fu et al. 2004, Bhatt et al. 2012). Such a finding has yet to be proven in the Koshi Basin.

As demonstrated in Figure 10-3, alteration to the natural flow regime impacts fisheries viability and livelihoods in regulated regions where quality fish catch would otherwise be high, with high market demand. Under natural conditions fish would be flourishing in rivers with a natural flow regime, and where IMC, Mahaseers and Asala fishes would be in abundance. In rivers where natural flows have been greatly interrupted and with poor DO, an abundance of air breathing and forage fish stocks are anticipated. As stocks of air-breathing fish increase, fisheries and livelihoods dwindle, resulting in poor economic returns (Figure 10-3), unemployment, malnourished families, higher gaps between poor and rich, wider gaps between the rural and urban population, unbalanced use of natural resources, and ultimately, more social conflict.

## 10.8 Challenges

Fish resource conservation is a great challenge especially in the context of climate change and the energy crisis in Nepal for an ever increasing population. There are many hydropower stations in the country, with more power stations planned. Currently, some hydropower stations maintain the regulation of the minimum flow requirement for aquatic life downstream (10% of mean monthly flow), however, the majority of the stations do not release water from the dam. Under such conditions, a single river can be fragmented into several disconnected reaches by hydropower stations.

Fish ladders and hatchery construction is required under Aquatic Animal Protection Act 2017 (BS)-with amendments 2057 (BS) (AAPA 2000) in rivers where flow obstructions are created by damming, either for hydropower or irrigation. Despite of such pre-requisite either there are no fish ladders or any other optional management in favour of aquatic life, or if present, the fish ladders do not function properly to meet the objectives of their construction, due to poor design and installation, among other problems (KHP 2013). It is often reported that the fish ladders that should to support fish conservation, actually become the fishing sites during times when fish aggregate to move up and down the ladders. This suggests that the volumes of water supplied are not adequate to facilitate and protect fish during the movement up ladders. Therefore, fish ladder redesign and suitable water allocations should be considered. As fish ladders are open to the public, lid or mesh over the top might to prevent access by humans and therefore reduction of fish stock.

Until now, only a single hydropower station has constructed a functioning fish hatchery in the country (Gurung & Baidya 2012), the value of this restoration approach has yet to be examined. In general, the status of fish conservation in run-of-river dams or reservoir system is not encouraging despite continued efforts (Rijal & Alfresen 2015). Therefore, opportunities exist in the future to create more fish hatcheries that are associated with damming for hydropower and irrigation development, as well as capture fisheries. Regulated fisheries can help reduce over exploitation, improve income and support consumption requires by locals.

(Photo: AK Baidya)

Several hydropower projects are functioning without any provision for aquatic animal protection facilities or environmental flows. This is despite the existing legal provision in the Hydropower Development Policy 2001 (MoWR 2001) which states that minimum water flow downstream must be provided to maintain ecosystem diversity. Unfortunately, this legal provision is not being met due to lack of formal enforcement and monitoring by government bodies. For example, the Marsyangdi Hydropower Project (69 MW) have not provided the compensatory flow release as required (Rijal & Alfredsen 2015) and did not construct a fish hatchery or fish ladder as mentioned in AAPA 2057. In addition, several other hydropower stations have not abided by the rules and regulations (KHP 2013; Rijal & Alfredsen 2015). Therefore, the challenges that lie ahead are serious and consideration must be given to protection of aquatic life in Nepali rivers. Legal provisions of sustainable flows are required and enforcement is needed to ensure ecosystem sustainability, socio-economical welfare, ecosystem services and sustainable livelihoods into the future. As Matthews et al. (2014) explained, the concept environmental flows is a not a mere ecological science and environmental advocacy and neither should it promote a 'people verses fish mentality'. Instead, it is a term interrelated to good policy, governance, poverty alleviation, climate change and economic development, more than the fish, recognising 'people' as the main beneficiaries.

## 10.9 Summary

The Koshi Basin is of utmost economic importance to Nepal in terms of irrigation, hydropower, fisheries, biodiversity, drinking water, water ways, scientific and socio-economic dimensions. The Koshi River System has one of the richest fish species diversity with at least 134 native species and seven exotic species. However, growing numbers of hydropower stations and population growth are threatening this unique diversity and impacting capture fisheries and therefore the livelihoods of thousands of poor fisher's families. Several endemic species are under threat due to habitat fragmentation and deterioration of water quality in these rivers.

(Photo: TK Shrestha)

Substantial work is required to characterise flows and understand flow related ecology in the Koshi Basin (and other riverine areas of Nepal) to protect aquatic habitats. Particularly given the possibility of larger future water extraction which might modify flows from their natural state, in order to meet economic and social growth requirements. The current rule of environmental flows (10% of mean monthly flow) requires quantitative assessment across all rivers in Nepal, in order to understand its adequacy and the impact of flow change on fish species, and fisheries. The present legal provisions in relation to hydropower developments are not effective to protect the fish diversity of the Koshi River due to lack of regulation and monitoring of operation. Unless legal provision of sustainable river flows are constituted for fish diversity protection, the risks of species loss will be ongoing in rivers with power generation and irrigation water diversion activities. Thus, good policy and governance emphasizing environmental flows for biodiversity conservation, poverty alleviation, climate change mitigation and economic development recognising 'people' as the main beneficiaries is required.

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## Annex: Tables

Table 10-1 List of native fishes reported to occur (indicated by ●) in the Koshi River System

| No. | Species | Family | Rajbanshi (2002) | Ranjit (2002) | Edds & Ng (2007 | Shrestha et al (2009) | Limbu & Subba (2011) |
|---|---|---|---|---|---|---|---|
| 1 | *Amblyphorygnodon mola* | Cyprinidae | | | | | ● |
| 2 | *Aspidoparia jaya* | Cyprinidae | | | | | ● |
| 3 | *Aspidoparia morar* | Cyprinidae | | | | | ● |
| 4 | *Barilius barna* | Cyprinidae | ● | | | ● | ● |
| 5 | *Barilius bendelisis* | Cyprinidae | ● | ● | | ● | ● |
| 6 | *Barilius jalkapoorie* | Cyprinidae | | | | | ● |
| 7 | *Barilius barila* | Cyprinidae | ● | ● | | ● | |
| 8 | *Barilius bola* | Cyprinidae | ● | | | | |
| 9 | *Barilius guttatus* | Cyprinidae | ● | | | | |
| 10 | *Barilius radiolatus* | Cyprinidae | ● | | | | |
| 11 | *Barilius tileo* | Cyprinidae | ● | | | | |
| 12 | *Barilius vagra vagra* | Cyprinidae | ● | ● | | ● | |
| 13 | *Barilius shacra* | Cyprinidae | ● | ● | | ● | |
| 14 | *Chagunius chagunio* | Cyprinidae | ● | | | | ● |
| 15 | *Chela laubuca* | Cyprinidae | ● | | | | ● |
| 16 | *Cirrhinus mrigala* | Cyprinidae | | | | | ● |
| 17 | *Cirrhinus reba* | Cyprinidae | | | | | ● |
| 18 | *Danio devario* | Cyprinidae | ● | | | | ● |
| 19 | *Danio acquipinnatus* | Cyprinidae | ● | | | | |
| 20 | *Danio dangila* | Cyprinidae | ● | | | | |
| 21 | *Danio rerio* | Cyprinidae | | | | | ● |
| 22 | *Securicula gora* | Cyprinidae | ● | | | | |
| 23 | *Salmostoma acinaces* | Cyprinidae | ● | | | | |
| 24 | *Salmostoma bacaila* | Cyprinidae | ● | | | | |
| 25 | *Garra lamta* | Cyprinidae | ● | | | | ● |
| 26 | *Garra annandalei* | Cyprinidae | ● | ● | | ● | |
| 27 | *Garra gotyla gotyla* | Cyprinidae | ● | ● | | ● | |
| 28 | *Garra rupecola* | Cyprinidae | ● | ● | | | |
| 29 | *Garra nasuta* | Cyprinidae | | | | ● | |
| 30 | *Labeo rohita* | Cyprinidae | | | | | ● |
| 31 | *Labeo calbasu* | Cyprinidae | | | | | ● |
| 32 | *Labeo angra* | Cyprinidae | ● | ● | | | |
| 33 | *Labeo dero* | Cyprinidae | ● | ● | | ● | |
| 34 | *Labeo dyocheilus* | Cyprinidae | ● | ● | | | |
| 35 | *Labeo gonius* | Cyprinidae | ● | | | | |
| 36 | *Labeo boga* | Cyprinidae | | ● | | | |
| 37 | *Neolissocheilus hexagonolepis* | Cyprinidae | ● | ● | | ● | |

| No. | Species | Family | Rajbanshi (2002) | Ranjit (2002) | Edds & Ng (2007 | Shrestha et al (2009) | Limbu & Subba (2011) |
|---|---|---|---|---|---|---|---|
| 38 | *Puntius sophore* | Cyprinidae | | | | | ● |
| 39 | *Puntius sarana* | Cyprinidae | | | | | ● |
| 40 | *Puntius ticto* | Cyprinidae | | | | | ● |
| 41 | *Puntius conchonius* | Cyprinidae | ● | | | | ● |
| 42 | *Puntius phutunis* | Cyprinidae | | | | | ● |
| v | *Puntius chola* | Cyprinidae | | | | | ● |
| 44 | *Puntius gelius* | Cyprinidae | | | | | ● |
| 45 | *Puntius terio** | Cyprinidae | | | ● | | |
| 46 | *Shizothorax richardsonii* | Cyprinidae | ● | ● | | ● | |
| 47 | *Shizothorax esocinus* | Cyprinidae | ● | | | | |
| 48 | *Shizothorax sinuatus* | Cyprinidae | | | | ● | |
| 49 | *Shizothoraichthys macropthalmus* | Cyprinidae | | ● | | | |
| 50 | *Shizothorax curvifrons* | Cyprinidae | | | | ● | |
| 51 | *Shizothorax labiatus* | Cyprinidae | | | | ● | |
| 52 | *Shizothorax progastus* | Cyprinidae | ● | ● | | ● | |
| 53 | *Tor putitora* | Cyprinidae | ● | ● | | ● | ● |
| 54 | *Tor tor* | Cyprinidae | ● | | | | |
| 55 | *Crossocheilus latius* | Cyprinidae | ● | ● | | ● | ● |
| 56 | *Oxygaster bacaila* | Cyprinidae | | | | | ● |
| 57 | *Psilorhyncus sucatio* | Cyprinidae | ● | | | | |
| 58 | *Psilorhynchus gracilis** | Cyprinidae | | | ● | | |
| 59 | *Psilorhynchoides pseudechenes* | Cyprinidae | ● | ● | | ● | |
| 60 | *Psilorhynchoides homaloptera* | Cyprinidae | ● | | | | |
| 61 | *Naziritor chelynoides* | Cyprinidae | | | | ● | |
| 62 | *Schistura rupecola inglisi* | Cyprinidae | | | | ● | |
| 63 | *Schistura multifaciatus* | Cyprinidae | | | | ● | |
| 64 | *Balitora brucei* | Balitoridae | ● | | | | |
| 65 | *Colisa fasciatus* | Anabantidae | | | | | ● |
| 66 | *Anabas testudinius* | Anabantidae | | | | | ● |
| 67 | *Anguilla bengalensis* | Anguillidae | | ● | | | ● |
| 68 | *Mystus aor* | Bagridae | | | | | ● |
| 69 | *Mystus cavasius* | Bagridae | | | | | ● |
| 70 | *Mystus tengra* | Bagridae | | | | | ● |
| 71 | *Mystus bheekerie* | Bagridae | | | | | ● |
| 72 | *Mystus vittatus* | Bagridae | | | | | ● |
| 73 | *Rita rita* | Bagridae | | | | | ● |
| 74 | *Batasio batasio* | Bagridae | | | | | ● |
| 75 | *Bagarius bagarius* | Sisoridae | ● | | | | ● |

| No. | Species | Family | Rajbanshi (2002) | Ranjit (2002) | Edds & Ng (2007 | Shrestha et al (2009) | Limbu & Subba (2011) |
|---|---|---|---|---|---|---|---|
| 76 | *Gagata cenia* | Sisoridae | | | | | ● |
| 77 | *Gagata viridescens* | Sisoridae | | | | | ● |
| 78 | *Glypothorax cavia* | Sisoridae | ● | ● | | | ● |
| 79 | *Glyptothorax annandalei* | Sisoridae | ● | ● | | | - |
| 80 | *Glyptothorax indicus* | Sisoridae | ● | | | ● | |
| 81 | *Glyptothorax sulcatus* | Sisoridae | | ● | | | |
| 82 | *Glyptothorax telchita telchitta* | Sisoridae | ● | ● | | ● | ● |
| 83 | *Glyptothorax botius** | Sisoridae | | | ● | | |
| 84 | *Glyptosternum blythi* | Sisoridae | | ● | | | |
| 85 | *Glyptothorax pectinopterus* | Sisoridae | ● | | | | ● |
| 86 | *Glyptothorax trilineatus* | Sisoridae | ● | | | | ● |
| 87 | *Pseudecheneis sulcatus* | Sisoridae | ● | | | | |
| 88 | *Pseudecheneis crassicauda* | Sisoridae | | | | ● | |
| 89 | *Nangre assamensis** | Sisoridae | | | ● | | |
| 90 | *Sisor rheophilus** | Sisoridae | | | ● | | |
| 91 | *Myersglanis blythi* | Sisoridae | | | | ● | |
| 92 | *Erethistes pussilus* | Erethistidae | | | | | ● |
| 93 | *Xenentodon cancila* | Belonidae | | | | | ● |
| 94 | *Chanda nama* | Centropomidae | | | | | ● |
| 95 | *Chanda ranga* | Centropomidae | | | | | ● |
| 96 | *Channa gachua* | Ophiocephalidae | | | | | ● |
| 97 | *Channa punctatus* | Ophiocephalidae | | | | | ● |
| 98 | *Channa striatus* | Ophiocephalidae | | | | | ● |
| 99 | *Channa morulius* | Ophiocephalidae | | | | | ● |
| 100 | *Channa stewartii* | Ophiocephalidae | | ● | | | |
| 101 | *Clarias batrachus* | Clariidae | | | | | ● |
| 102 | *Semiplotus gongota* | Cobitidae | | | | | ● |
| 103 | *Botia lohachata* | Cobitidae | ● | | | ● | ● |
| 104 | *Botia Dario* | Cobitidae | | | | ● | ● |
| 105 | *Botia almorhae* | Cobitidae | ● | ● | | ● | |
| 106 | *Botia histrionica* | Cobitidae | | | | ● | |
| 107 | *Lepidocephalichthys guntea* | Cobitidae | ● | | | | ● |
| 108 | *Lepidocephalichthys menomi** | Cobitidae | | | ● | | |
| 109 | *Neoeucirrchthys maydelli** | Cobitidae | | | ● | | |
| 110 | *Acanthocephala pangia* | Cobitidae | | | | | ● |
| 111 | *Nemacheilus beevani* | Cobitidae | ● | ● | | | |
| 112 | *Nemacheilus rupicola* | Cobitidae | ● | ● | | | |
| 113 | *Nemacheilus elongates* | Cobitidae | | | | ● | |
| 114 | *Semiloptes gongota* | Cobitidae | | | | | ● |
| 115 | *Setipina phasa* | Engraulidae | | | | | ● |

| No. | Species | Family | Rajbanshi (2002) | Ranjit (2002) | Edds & Ng (2007 | Shrestha et al (2009) | Limbu & Subba (2011) |
|---|---|---|---|---|---|---|---|
| 116 | *Nandus nandus* | Nandidae | | | | | ● |
| 117 | *Notopterus chitala* | Notopteridae | | | | | ● |
| 118 | *Tetrodon cutcutia* | Tetrodontidae | | | | | ● |
| 119 | *Amblyceps mangois* | Amblycipitidae | | | | | ● |
| 120 | *Clupisoma garua* | Schilbeidae | ● | | | | ● |
| 121 | *Pseudeutropius atherinoides* | Schilbeidae | ● | ● | | | ● |
| 122 | *Pseudeutropius murius batarensis* | Schilbeidae | | | | | ● |
| 123 | *Ailia coila* | Schilbeidae | | | | | ● |
| 124 | *Eutropiichthys vacha* | Schilbeidae | | | | | ● |
| 125 | *Heteropneustes fossilis* | Saccrobranchidae | | | | | ● |
| 126 | *Glossogobius giuris* | Gobidae | | | | | ● |
| 127 | *Macrognathus aculeatus* | Mastacembelidae | | | | | ● |
| 128 | *Mastacembelus armatus* | Mastacembelidae | | | | | ● |
| 129 | *Siror rhabdophorus* | Sitoridae | | | | | ● |
| 130 | *Chaca chaca* | Chacidae | | | | | ● |
| 131 | *Gudusia godanhiaii* | Clupidae | | | | | ● |
| 132 | *Gudusia chapra* | Clupidae | | | | | ● |
| 133 | *Ompok bimaculatus* | Siluridae | | | | | ● |
| 134 | *Wallago attu* | Siluridae | | | | | ● |

*New fish species reported by Edds & Ng (2007)

Table 10-2 List of exotic fishes in Koshi Basin

| No. | *Scientific name* | Common name | Family |
|---|---|---|---|
| 135 | *Aristichthys nobilis* | Bighead carp | Cyprinidae |
| 136 | *Ctenopharyngodon idella* | Grass carp | Cyprinidae |
| 137 | *Cyprinus carpio* | Common carp | Cyprinidae |
| 138 | *Hypophthalmichthys molitrix* | Silver carp | Cyprinidae |
| 139 | *Oreochromis niloticus* | Gift Tilapia | Cichlid |
| 140 | *Clarias gairipinus* | African catfish | Clariidae |
| 141 | *Pangasius sp* | Pangas | Pangasiidae |

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# 11 Ecology of crocodile and dolphin in the Koshi Basin

*Authors: Karan Bahadur Shah[1], Shambhu Paudel[2]*

## 11.1 Background

The Koshi River is one of the major tributaries of the Ganges and originates from the Tibetan plateau in the central Himalaya. It is also rich in biodiversity. Its flora and fauna are of very common to rare and endangered status. Two fauna which are under threat are the crocodiles and dolphin which are restricted to the Tarai region of the Koshi River (Goit & Basnet 2011, Baral & Shah 2013, Paudel et al. 2015). In fact, reptile and mammal species symbolic of Koshi Tappu Wildlife Reserve (Chapter 2, §2.5) are two species of crocodile i.e. Mugger crocodile (*Crocodylus palustris*), Gharial crocodile (*Gavialis gangeticus*) and two species of mammal i.e. Wild Water Buffalo (*Bubalis arnee*) and the Ganges River Dolphin (*Platanista gangetica ssp. gangetica*). Gharial however, no longer occur in the river (Maskey & Schleich 2002, Goit & Basnet 2011, Baral & Shah 2013).

The Mugger, Gharial and dolphin are listed as Vulnerable, Critically Endangered and Endangered respectively under the Red Data Book of the International Union for Conservation of Nature (IUCN) and all of them are included in the Convention on International Trade in Endangered Species of Wild Fauna and flora (CITES) Appendix I (IUCN 2015; CITES 2016). The Gharial and Dolphin are also included in the Nepal government's National Parks and Wildlife Conservation Act 1973. Nationally, the dolphin is declared as a Critically Endangered species (Jnawali et al. 2011).

## 11.2 Importance of crocodile and dolphin to the Koshi Basin and Nepal

Crocodiles and dolphin are the top predators of the aquatic ecosystem in Nepal and play a vital role in shaping wetlands. They have ecological, scientific, recreational, cultural, ethical and economic values. Management interventions targeted to save crocodiles and dolphins, also protects existing habitats and water quality to ensure the survival of plants and animals which are also present. By eating sick, injured and other economically inferior fish species, crocodiles maintain fish populations that have high economic value and maintain genetic quality (Shrestha 2001, Whitaker & Andrews 2003). Gharial and dolphin are nationally protected priority species i.e. they are included in National Parks and Wildlife Conservation Act 2029 BS (1973). The genera of Mugger, Gharial and Dolphin are each represented by a single species in Nepal. Gharial is considered to be 20 times more endangered than the tiger and seventh most Critically Endangered species among the crocodilians globally (Maskey 1989). Actually this is not only for Nepal but it is in the global context.

The Koshi River's populations of crocodiles and dolphin are the only populations existing in the eastern region of Nepal. Their national population is fairly low (Gharial<100, Mugger<200 and

[1] Professor of Zoology, Natural History Museum, Tribhuvan University, Swoyambhu, Kathmandu
[2] Senior Research Officer (Freshwater), The Himalaya, Kathmandul

dolphin<30) with declining trends and restricted distribution (Maskey & Schleich 2002, Baral & Shah 2008, Maskey 2008, Goit & Basnet 2011, Jnawali et al. 2011, Baral & Shah 2013, Paudel et al. 2015). Crocodiles and dolphin are charismatic species and considered to be very important tourist attractions, therefore, they are one of the most valuable wildlife treasures in Nepal.

Figure 11-1 Gharial crocodiles, noting that they have been reported as extinct in the Koshi River (Baral & Shah 2013) (Photo: http://king-animal.blogspot.com.au/2012/09/gharial.html#.V2jXVE1f2tM)

The occurrence of crocodiles and dolphin in the Koshi River has been mentioned in previous studies (Shrott 1928, Biswas 1970, Maskey 1984, Andrew & McEachern 1994, Sah 1997, Shah & Tiwar 2004, Bhuju et al. 2007, Baral & Shah 2008, Goit & Basnet 2012, Baral & Shah 2013 Paudel et al. 2015, 2016). Gharial was once abundant in the Koshi River (Shortt 1921) but the natural population has now been reported as extinct (Maskey 2008, Goit & Basnet 2011, Baral & Shah 2013).

It was thought wise to distribute the Gharial population among different river systems in Nepal in the event that a catastrophe occurs in the Narayani River, where the major population of the species occurred. Realizing this fact, Gharials were first reintroduced in the Koshi River in 1983 (Maskey 1984). Forty-two (42) individuals were reintroduced to the river in both 1983 and 1987 however Gharial again became extinct. The last Gharial was seen in the river in 1989 (Maskey 2008). Ten Gharials were reintroduced in the Koshi in 2010 (Dr Narendra B Pradhan, pers comm 2016), but they met with the same fate. Destruction of basking and nesting habitats, failure of eggs and hatchlings as a result of heavy flooding, accidental killing by trapping in gill nets, food shortage (due to illegal fishing and wildlife poaching), downstream migration and anthropogenic disturbances are believed to be responsible for the population decline (Mugger) and extinction (Gharial) of the species in the area.

Figure 11-2 Ganges River Dolphin (Photo: S Paudel)

There is a lack of knowledge in relation to the ecological functions of the flow regime and the ecology of river dolphins despite some general studies which consider population estimation and conservation threats (Shrestha 1989, Smith 1993, Jnawali & Bhuju 2000, Timilsina & Baral 2003, WWF Nepal 2006, Baral & Shah 2008). Habitat loss through river flow regulation can have negative effects on the distribution, gene flow, movement, migration patterns, and behaviour of freshwater species (Bunn & Arthington 2002; Lytle & Poff 2004). Therefore, it is explicitly assumed that altered flows could have negative impacts on endangered species such as the Ganges River Dolphin in Nepal. Management and maintenance of adequate and ecologically relevant river flows is thus one of the most important challenges for freshwater river dolphin conservation in general and in particular in Nepal where only questionable viable populations are remaining (Richter et al. 2003, Smakhtin et al. 2007, Paudel et al. 2015a).

## 11.3 Drivers of the flow change

There are a number of reasons that flow change occurs. The Koshi barrage is one of the major infrastructures responsible for significant river regime change. As a result of barrage construction, a large expanse of open water remains present throughout the year between the barrage and the Reserve and, in the absence of an effective fish ladder, it allows downstream movement but obstructs upstream movement of fish, and crocodiles. The construction of dams without adequate upstream and downstream fish pathways impedes seasonal migratory routes of fish and other aquatic species including crocodiles, turtles and dolphins (Shrestha 1989). Each year, crocodile juveniles and hatchlings are flushed below the barrage and cannot return during the post monsoon season and thus, usually perish (Whitaker & Andrews 2003). The barrage is also responsible for increased siltation and alteration of suitable basking and nesting habitats for the crocodiles.

Most parts of the river are subjected to rapid and intense flooding during the monsoon season, which brings with it erosion, siltation and topsoil degradation causing habitat disturbance and decline (Sah 1997). Erosion of topsoil and river sediment affects the availability of breeding habitats for reptiles such as crocodiles and turtles (Maskey 2008). The Koshi River changes its course every five to six years (WMI/IUCN-Nepal 1994) creating further habitat destruction.

The natural process of soil erosion and increased run-off have been augmented by human pursuit of more food, collection of more fibre, fodder, fuel and other consumptive needs in the hill regions (Maskey 2008). Habitat destruction due to such increasing human pressure on the environment (hydropower and irrigation abstraction) has threatened the survival of crocodiles in India and Nepal (Whitaker & Daniel 1978).

The embankments in the Koshi River are constructed parallel to the river to control flooding (Bhuju et al. 2007), but sometimes it actually intensifies meandering and channelization in the river (Sah 1997). Throughout the year, heavy traffic occurs along the river due to recreational rafting, bamboo rafting for commercial purposes as well as river crossings at different locations by locals using ferryboats. Shrestha (2001) mentioned that at the sound of motorised ferryboats and motorboats, crocodiles abandon their basking promontories and dive into the water. Illegal fishing, especially by nonconventional methods (use of pesticides, explosive and electric current i.e. electro-fishing), flooding and agricultural run-off are also responsible for water quality change.

## 11.4 Current ecological knowledge and threats

Out of 21 species and seven subspecies of extant crocodile on the earth, only two species the Mugger (*Crocodylus palustris*) and Gharial (*Gavialis gangeticus*) are found in Nepal (Andrew & McEachern 1994, Shah 1995, Shrestha 2001, Shah & Tiwari 2004, Maskey 2008). Similarly, out of seven species of fresh water dolphin worldwide only one species, the Ganges River Dolphin (*Platanista gangetica ssp. gangetica*), is found in Nepal (Shrestha 1997, WWF 2006). Crocodiles and dolphin were once common in the major river systems of Narayani, Koshi, Karnali and Mahakali of Nepal, but they have been extirpated from some rivers and are becoming rarer in those locations they do inhabit (Shrestha 1997, Shah and Tiwari 2004).

Maskey and Schleich (2002) mentioned the occurrence of 10-12 Muggers in the Koshi River, however, based on direct observation of the species, Goit and Basnet (2011) estimated 16 and Baral and Shah (2013) estimated 20-30 crocodiles in this river. Gharial does not currently occur in the Koshi River (Maskey & Schleich 1992, 2002, Maskey 2008, Goit & Basnet 2011). Paudel et al. (2015b and 2016) estimated 14 dolphins residing in the Koshi River, and only present below the barrage. Both natural (e.g. flood, change in river course, behaviour of the species) and anthropogenic (e.g. barrage construction, overfishing and illegal hunting) causes are responsible for low population numbers of Muggers, dolphins and extinction of Gharial in the river system. No hatchlings and juvenile Muggers smaller than 2m were observed in the Koshi River (Goit & Basnet 2011, Baral & Shah 2013), suggesting recruitment is probably not occurring in this area.

Several factors seem to be responsible for the reintroduced Gharial's extinction from the area. Gharials released in 1983, 1987 and 2010 were not fitted with radio transmitters for their monitoring and also were not kept in temporary enclosures for acclimatization (Andrew & McEachern 1994, Maskey 2008, Dr Narendra B Pradhan pers comm 2016).The released Gharials should be maintained in a temporary enclosure adjacent to the main river channel for 1 to 2 weeks prior to release. They have a tendency to gradually move downstream (Maskey 2008), hence, they might have migrated downstream below the barrage immediately after their release and could not return upstream due to the absence of fish pathways.

Out of 42 released Gharials in Narayani River, 81% (34) gradually moved downstream and only 19% (8) upstream from the release site (Maskey 2008).They might have also been swept below the barrage by monsoon flooding, killed either by poachers and/or Muggers as mentioned by Maskey (2008) or due to being trapped in gill nets. Absence of alternate habitats could be another reason for their decline, because Gharials usually move into small tributaries during periods of monsoon flood in the main river (Maskey 2008). However, except for the Trijuga River, there are no other tributaries in the Tarai section of the Koshi River. Additionally, there was a mistake identifying the sex of the released Gharials (Mr Bed Khadaka pers comm. 2016), thus a skewed sex ratio could be another reason for the lack of recruitment.

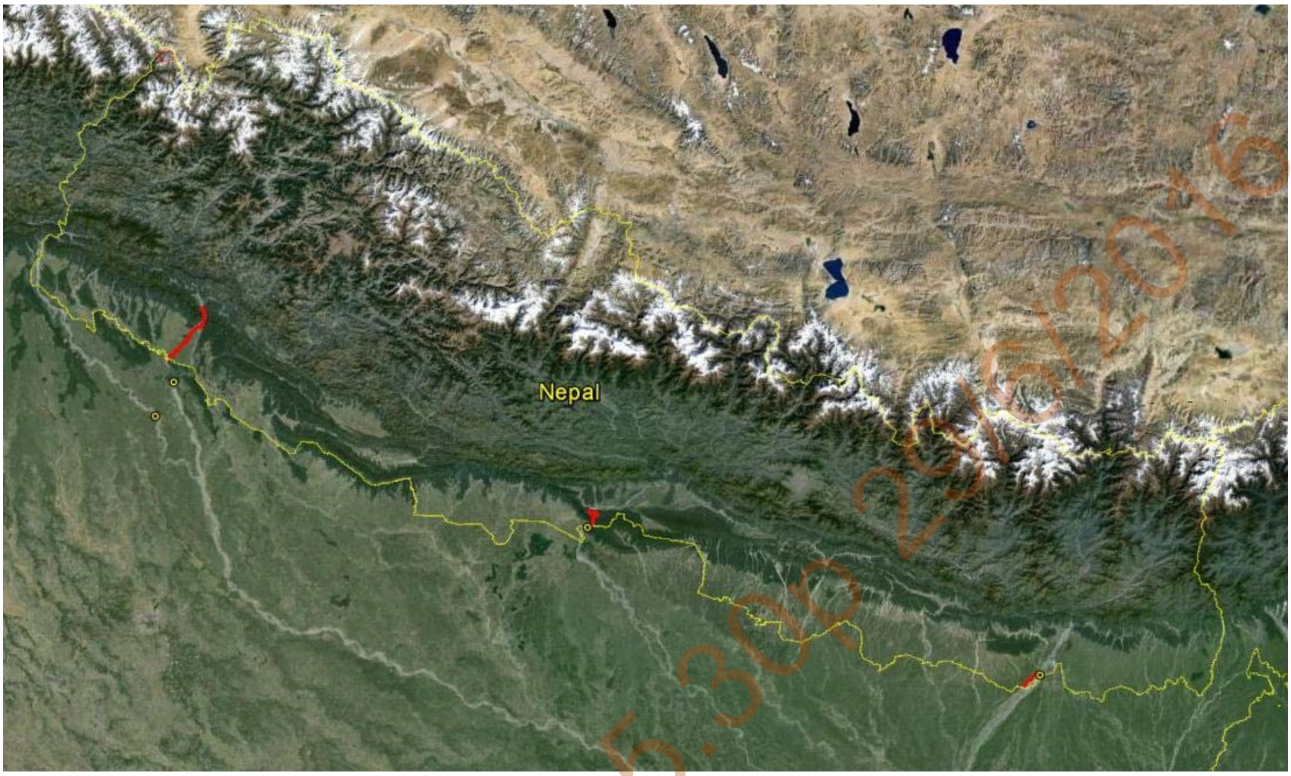


Figure 11-3 Isolated groups of river dolphin caused by dams (yellow place mark circle) in Nepal. Red stretch lines indicate current river dolphin distribution in Nepal. Dams below and at the border in Karnali and Narayani Rivers respectively prevent genetic connectivity with Indian population but still some hope remains in SaptaKoshi (Map prepared by S Paudel)

The Ganges River Dolphin is the only recorded cetacean species in Nepal and it is under threat from water abstraction. The population in Nepal currently has fewer than 30 individuals and has experienced a continuing decline since the 1980s. This dolphin species comes under increased pressure when its habitat is reduced and overlapped by fisheries during low flow seasons. Large structures like dams (Figure 11-3), flood-control structures, and embankments for irrigation projects, agriculture and hydroelectric power (Dudgeon 2000, Dudgeon et al. 2006, Collen et al. 2008) have influential impacts on freshwater river dolphins, which lead to the loss of longitudinal and lateral connectivity of habitats (Vannote et al. 1980, Ward 1998, Ward et al. 1999, Dudgeon 2000, Bunn & Arthington 2002, Nilsson et al. 2005). Current population trends and their range of distribution (i.e. 50 km in 1989 is now limited within 7 km in Sapta Koshi River) clearly indicates the effect of development structures and water abstraction on river dolphin ecology in Nepalese river systems (Shrestha 1989, Paudel et al. 2015b).



## 11.5 Conceptual relationship between river flow and crocodiles

### Maintain population

Crocodiles display many structural and functional adaptations to successfully live an amphibious life, therefore, the availability of suitable aquatic and terrestrial habitats are crucial for their survival

(Figure 11-4). Temperature selection (either heat seeking or heat avoidance) within available habitats is an important daily activity for crocodiles. They regularly bask each day in the cooler winter months (Zug 1993) and the selection of appropriate basking sites on river banks is crucial for thermoregulation, foraging and to escape predation (Shrestha 2001, Ballouard et al. 2010). Environmental factors play an important role in the growth rate of crocodiles and growth is (1) a product of food intake, which is in turn mediated by temperature and (2) bioenergetics needs, also mediated by temperature (Krishnamurthi & Bhaskaram 1980).

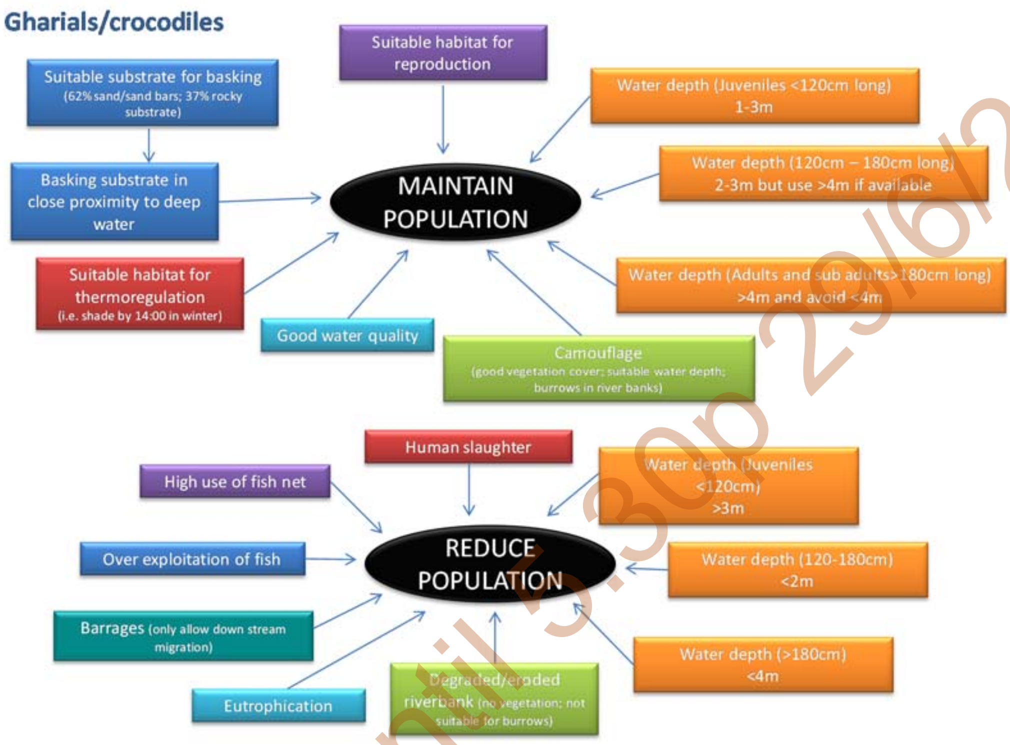


Figure 11-4 Flow-ecology conceptual model for crocodiles

Crocodiles use sand banks for both basking and nesting, thermoregulation. Dietary needs also appear to be an important factor in determining their use of sand banks (Maskey 2008). They bask on the sand banks for long periods during the winter when the water temperature and water level are low. Less time is spent feeding, presumably to avoid the coldness of the water at that time. In contrast, in summer, they spend most of their time in water to avoid the heat of the day (Maskey 2008, Goit & Basnet 2011). Larger Gharials (> 2.20 m length) bask close to water deeper than 1m, while smaller (< 2.20 m length) bask close to shallow water less than1m deep (Ballouard et al. 2010).

Gharials require optimum habitats such as deep, fast flowing and relatively clear water that adjoins high sand banks (Maskey 2008) to flourish. Evidence suggests that water pollution plays a role in habitat suitability (Ballouard et al. 2010). In Narayani River, Gharials were found to use five habitat types: sand banks, grass banks, sand and grass banks, rock banks and river channels (Maskey 2008). They were not observed on rock, grass or sand and grass banks in proportion to their occurrence, suggesting their habitat preference is sand banks and river channels. Their population in the Narayani River was found concentrated mostly in areas dissected by numerous river channels which provide high sand banks and deep pools exceeding 7m. Sand banks provide the most suitable habitat for basking, foraging and nesting (Maskey 2008, Ballouard et al. 2010, Goit & Basnet 2011). Further it is said that if basic habitat needs are not met, crocodiles do not breed (Shrestha, 2001).

In winter, Muggers move onto land and spend most of the time on sand banks (Whitaker 1979). Most Mugger sightings in the Koshi River during winter were on the sandbank as compared to other habitats and most of the animals were found basking and gaping (Goit & Basnet 2011). Gaping has possible significance in thermos-regulation and it is perhaps a device to rid the oral cavity of infection, algae, bacteria, fungus and other pathogens and parasites (Whitaker & Basu 1979). Crocodiles seek shade near their basking spot as a cooling mechanism (Shrestha 2001). Shade seeking begins at about 14:00hrs when the sand gets very hot (25°–30°C).

Riverine plant communities provide protection and shelter for the crocodiles. Trees and their drooping branches, fallen logs and other vegetation offer resting and holding, as well as hiding platforms for crocodiles, while burrows are used for winter hibernation and summer aestivation (Shrestha 2001). Goit and Basnet (2011) observed sub-adult Muggers hiding behind grasses or fallen trees in the Koshi area. Some species aestivate by remaining quiescent for days buried in mud, leaf litter or in underground burrows excavated as water levels fall (Whitaker & Whitaker 1984). In the dry season, Muggers use their burrows to avoid heat during the day time but at night they came out and wander the area in search of food (Mobaraki 1999). Burrows are primarily retreats in which the animals spend the hottest part of the day. Burrow size varies from 2.5 to 6m deep under the supportive deep root systems of trees (Maskey & Schleich 2002).

Gharials prefer deep fast flowing rivers, where adults congregate in the deep holes at river bends and at the confluence of smaller streams, while juveniles select smaller side streams or river backwaters (Zug 1993). Muggers prefer still water with a depth of 3-5m (Whitaker & Whitaker 1979). Crocodiles chose fine sand banks as nesting sites in preference to alluvial sand banks. About 90% of the 73 nests located in the Narayani and Rapti River were found on fine sand banks and only 10% of the nests were located on lower quality alluvial banks (Maskey 2008). Numerous reports on different species of crocodiles suggest a possible correlation between breeding time and changing water levels (Ferguson 1985). Gharials' egg laying and incubation synchronizes with high temperature and humidity, and hatching with high water levels. At the same time, nest temperature and humidity are important factors for embryonic survival, development and growth (Maskey 2008).

Crocodiles' nesting area should be high enough to avoid monsoon flooding. In the vicinity of dams they might select higher areas as flooding occurs earlier and with larger magnitude than the upstream areas. The Tribeni dam on the Narayani River causes water levels to rise earlier and higher than normal, jeopardizing natural nesting success (Maskey 2008). Thus, natural nesting success of crocodiles is also dependent upon the type and location of nesting sites in relation to water level.

## Reduce population

The most common predator of crocodiles is man. Crocodile meat is used as food and body parts are used in the preparation of traditional medicines in Nepal which has threatened their survival (Shah 1997). Tribal hunters have been collecting eggs and slaughtering crocodiles for food, skin and other body parts for medicinal purposes (Whitaker & Daniel 1978, Andrew & McEachern 1994, Schleich & Maskey 1992) causing their population decline and disparate sex ratio (Maskey 2008).

There is a predominant belief that crocodile eggs, dried penis and snout (ghara) of male Gharials have aphrodisiac properties. The eggs are also considered as a delicacy (Shah 1997, Shrestha 2001, Maskey 2008). Mystical beliefs have been attributed to the ghara of male Gharials in Nepal; the ghara is dried into incense and burnt in crop fields in the belief that it controls insects and other pests (Maskey & Schleich 2002). Local tribesmen believe that a ghara placed under the pillow of an expecting woman relieves and speeds up labour (Mishra & Maskey 1981).

The major cause of critically depleted crocodile populations is largely attributable to the construction of dams. These create abnormally high water levels during the monsoon season which flood practically all nests near the dam (Maskey 2008). Dams such as the Koshi barrage allow only one way movement of crocodiles and during the monsoon season, strong currents of water sweep most of the juveniles downstream into the Indian River system. Goit and Basnet (2011) observed one adult Gharial at Bhimnagar, India, where the species was not previously recorded while a Koshi River Gharial was observed in the Ganges River in India (Biswas 1970).

The Koshi barrage is not equipped with devices to facilitate upstream movement of fish, causing food depletion for crocodiles. High use of fish nets and overexploitation of fish is also detrimental to crocodiles as they become entangled in nets and are either drowned or killed by fishermen (Maskey 2008, Goit & Basnet 2011, Baral & Shah 2013). Local fishermen use both conventional and nonconventional techniques such as nets, hook, traps, electro-fishing and biological and chemical poisons for fish capture. Fishing activity reduces the number of fish on which Gharial feed, disturbs basking activity, and leads to mortality caused by drift nets (Ballouard et al. 2010). Fishermen kill the crocodiles to protect their expensive nets from being extensively damaged (Maskey 2008).

Survival of Gharials in Nepal is threatened primarily by continuous habitat destruction, which is related to increasing human pressure on the environment from extensive agriculture, firewood collection, cattle grazing, grass cutting and heavy traffic in the river course (Whitaker & Daniel 1978). Overgrazing and movement of livestock along shorelines, contributes to soil erosion which leads to loss of suitable habitats for crocodiles (Goit & Basnet 2011). Gharials were not located on the eroded banks of the Narayani River (Maskey 2008). Eutrophication of wetlands (especially many oxbows of the area and Kamaltal) is also detrimental to crocodiles, as it stimulates unwanted vegetation growth and subsequent algal blooms which could cause oxygen depletion and fish kills (WMI/IUCN-Nepal 1994).

## 11.6 Conceptual relationship between river flow and dolphins

Distribution and habitat use of river dolphins is guided by the hydraulic characteristics of rivers. During the high water level in the monsoon season (July-October), dolphins generally move to tributaries or distributaries of the river, but congregate at deeper pools where a greater water depth remains during low flow months (November-May). Deep pool habitat, confluence with eddy encounters and meandering were the prime habitats of dolphin presence during low flow season (Biswas et al. 1997, Bashir 2010, Kelkar et al. 2010, Choudhary et al. 2012, Paudel et al. 2015b, Paudel et al. 2016). Mean (±SD) depth and width of the river where dolphins were sighted in Nepal was 4.24 ± 1.98 m and 225.93 ± 96.63 m, respectively (Figure 11-5, Paudel et al. 2015). While measuring river depth and width at 300m intervals along a 60 km stretch in Sapta Koshi (upstream and downstream from Sapta Koshi barrage), a mean depth 1.40 ± 1.10 m was recorded during the low flow season. This is below the threshold required for dolphin survival. There was only a small proportion of deep pools (> 3 m) available below the barrage in the Sapta Koshi within a 7 km stretch and this is where the dolphin population was concentrated. The highest proportion (41%) of sightings occurred where deep pool habitats exist, followed by river confluence (28%) and meanders(13%) within Nepal’s river systems, including Sapta Koshi. It is important to understand the minimum natural flow that can maintain suitable habitat characteristics (Figure 11-5) for higher abundance and habitat use.

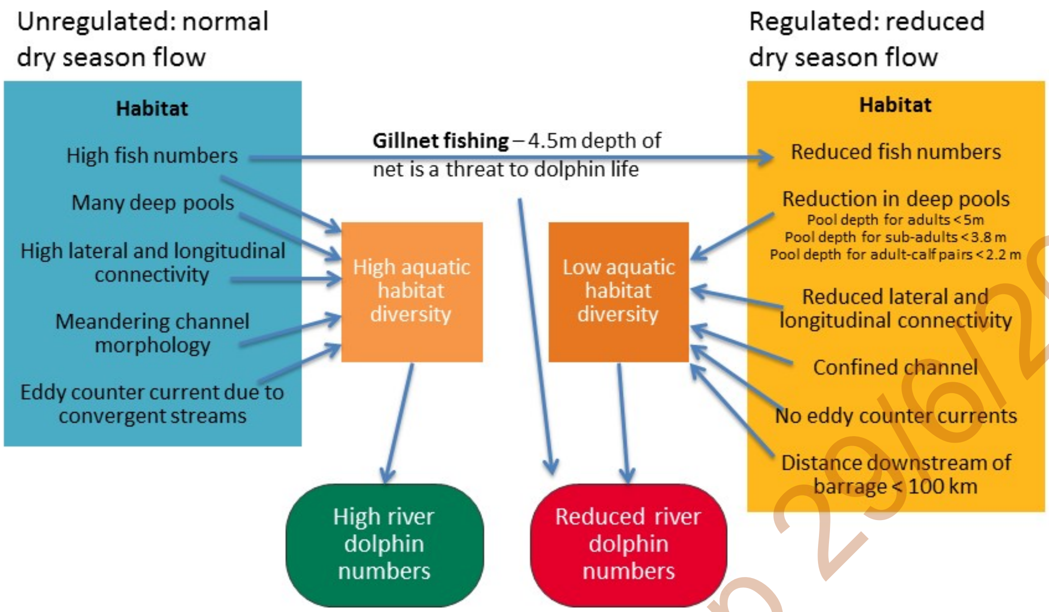


Figure 11-5 Flow-ecology conceptual model for dolphin

In the Ganga River in India, dolphins generally prefer the deeper waters and 50% of dolphin sightings were recorded at river confluences (Bashir et al. 2010). Minimum mid-channel depth requirements were estimated to be 5.2m for dolphin adults and between 2.2 and 2.4 m for mother–calf pairs (Choudhary et al. 2012). To maintain the required depth along a river, channel geometry (channel cross-sectional area) in conjunction with river flow, plays a key role for the survival of river dolphins during low flow season when habitats are limited (Braulik et al. 2012). It is clearly understood that channel geometry is a more important factor affecting dolphin presence and abundance than river geomorphology, with depth greater than 1m exerting the greatest influence (Braulik et al. 2012). A study from Pakistan reveals that Indus dolphins (*Platanista gangetica ssp minor*) avoided channels which have a small cross-sectional area (<700m$^2$) due to reduce foraging opportunities. These studies revealed that geometry had a greater influence on explaining dolphin habitat utilization, but there is still lack of detailed studies relating dolphin ecology with flow and river geometry in Nepal.

Water abstraction systems for human use may create rare hydro physical characteristics or less suitable dolphin habitats. This may result in a clustering of small groups of dolphins and create a shift towards Nepal-India borders in Nepal's rivers in the future. This scenario has been documented in the Sapta Koshi (in Nepal) and the Gandak River in India, where extreme clustering at small spatial scales, and positive association with river depth and meandering habitats were recorded (Choudhary et al. 2012). If flow during the low flow season reduced further due to increased abstraction, the number of deeper habitats are likely to decline. This may form insufficient patches of suitable habitat to support the dolphin population through the low flow season, and dolphins may become isolated within deeper river sections or leave the affected parts of the river completely. As a consequence, dolphins will be unable or unwilling to traverse through shallows between favourable patches of habitat. This provides clear evidence for a reduction in the availability of continuous primary habitats for river dolphins with disruption of longitudinal and lateral connectivity as flow regulation increases. It is important to consider low dry-season river discharge which is the principal factor explaining the dolphin's decline in Nepal.

Based on recent findings, (e.g. Sinha et al. 2010, Sasaki-Yamamoto et al. 2013) it is suggested that river dolphins are more active in the early-morning (08:00-11:00 hrs) and late-afternoon (13:30-16:00 hrs). Fishermen from the Sapta Koshi River prefer to fish daily in the morning rather than in the afternoon, for a total of 9±0.4 hours per day, which likely increases the risks to the neonate, new born, or dependent calves. Fishing activities during the low flow season therefore pose a greater risk to the river dolphin when more gear is set in deep pools. It is thus probable that dolphins are depredating and interacting with gillnets which is a common behaviour for many cetaceans around the world (Read et al. 2003, Mathias 2012, Waples et al. 2013).Though relative abundance of dolphins is generally lower (Kelkar et al. 2010, Paudel et al. 2015b) in the post-monsoon (October-December) than the pre-monsoon (March-May) period (Paudel et al. 2015b), fishing in the dry season could also make it more difficult for the river dolphin to avoid being entangled in gillnets. Paudel et al. (2016) revealed that the average net depth used by fishermen was 4.5 m in the river systems of Nepal, which also corresponds to the average water depth (4.4 m) where river dolphins are usually spotted (Paudel et al. 2015b). The effective number of months when fisher communities catch fish is 5.1±0.2 months using a net depth of 3.0±0.1m in Sapta Koshi. This poses a major risk for the river dolphin as the nets touch the river bottom in regulated river systems during the dry season. The dolphin conceptual model (Figure **11-5**) thus seems more applicable to regulated flow systems in Nepal. If we are able to ensure some alternative livelihood options for fisher communities, we can maximize the abundance of river dolphins during the dry water season by retaining minimum required discharge.

(Photo: S Paudel)

## 11.7 Impacts of river flow change

Nepal's river systems and their biological diversity are under threat from river flow regulation for multipurpose human use. Identified as one of the global threats, this is creating serious risks to freshwater biodiversity and their ecosystem processes by making freshwater indicator species more threatened, particularly in the low-flow dry season(McAllister et al. 2001, Bunn and Arthington 2002, Robinson et al. 2002, Nilsson et al. 2005). Serious impediments to river flow, continued degradation of riverine habitats and unsustainable use of riverine resources threatens not only Gharial but every other aquatic organism in the area as well as the people who rely on these resources (Stevenson 2015).

There are only a few pros and more cons to altered flow regimes. The Koshi barrage has exerted a serious impact on the aquatic and semi-aquatic fauna such as fish, crocodiles and dolphins as they are affected in their movement. Species extinction is possible due to the barrier to their movement (Shrestha 2001). Fish are the principal food item for crocodiles and dolphin and low abundance of their prey species in the river ultimately leads to their population decline. Inundation due to the barrage causes soil erosion, sedimentation and reduction in sandbanks ultimately leading to habitat degradation and loss. Inundation and change in the river course may also cause high loss of crocodile eggs and hatchlings. The Koshi barrage may cause water levels to rise earlier and higher than normal, impacting natural nesting success. The release of monsoon over flow water washes crocodiles out of the protected area. Heavy monsoon flooding may bring depletion of fish and other riverine resources, change in water quality and temperature fluctuation may invite unbalanced sex ratio in the crocodiles (Maskey 2008). Many of the wetlands of the Koshi Basin have changed from mesotrophic to eutrophic due to the accumulation of nutrients from natural and human activities (Goit & Basnet 2011).

Pros include increase in vegetation coverage due to altered flow (Sah 1997) which can sometime offer alternative habitats, hunting grounds and access to other ponds for crocodiles (Whitaker & Whitaker 1979). Monsoon flooding which connects the still water bodies (e.g. oxbows) to the main river, also flushes unwanted plant species (WMI/IUCN-Nepal 1994). The barrage also provides an excellent irrigation facility, downstream flood control and road access.

## 11.8 Monitoring recommendations and knowledge gaps

Regular monitoring of an area's significant biotic and abiotic factors is necessary to assess the requirement of environmental flows. These include number of crocodiles, dolphin, diversity and abundance of fish, amphibian, turtle and wetland dependant birds and mammals in the area. Likewise, availability and quality of basking and nesting habitats of crocodiles, adverse impacts of anthropogenic activities, seasonal change in the river course and water quality should also be monitored in regular basis.

Information gaps occur for different aspects of the Koshi River's crocodiles and dolphin. Studies are lacking on the upstream distribution of Mugger, its breeding success, sex ratio and food requirements of both Mugger and dolphins in the area. Gharials were reintroduced in 1983, 1987 and 2010 (Maskey 2008, Goit & Basnet 2011, Dr Narendra B Pradhan pers comm. 2016), but information on their released sites and exact causes of extinction are not available. The survival of crocodiles and dolphins in the area depends on water requirements such as water quality, depth and availability of basking and nesting habitats for crocodiles, however information on these parameters is lacking.

A combination of protection, public education, and proper management of the species and their habitats is required to ensure the continued survival of crocodiles and dolphin in the Koshi River. The problems associated with flow regime change and conservation of crocodiles and dolphins are varied and complex and they must be addressed by conducting appropriate studies in the future.

A standard crocodile and dolphin survey methodology should be developed for the area giving emphasis to visual, acoustic and community interviews. In cases where strict protection and the removal of deleterious influences appear inadequate to save the surviving population of crocodilians, reintroduction or restocking may be an appropriate method to improve the distribution of a species (Sale 1986). Hence, a good understanding of water requirements is needed.

New appropriate sites for Gharial release should be explored and after their release, the animals should be properly monitored for at least the next 2-3 years to monitor their survival rate in the future to increase understanding. The release sites should receive moderate monsoon floods, should be free from detrimental anthropogenic activities, and habitats with good provision for food, basking, nesting, water depth, quality and flow. The released Gharials should be of suitable age, size, and sex ratio, as larger animals (> 1.2 m in length) showed a higher probability of survival than smaller ones (Maskey 2008).

Dolphin's sparse sightings and shifting distribution towards the southern sections of Nepalese rivers clearly indicates the reduction in suitable habitats and disconnected lateral and longitudinal connectivity (Limbu & Subba 2011, Paudel et al. 2015a,b). Therefore, it can be assumed that development of structures for controlling flow or extraction of water resources is a key threatening process for river dolphin survival in Nepal during the dry season when habitat is critical. No considerable improvements on population status has been seen in more than two conservation decades and their range of distribution has been reduced significantly (Shrestha 1989, Paudel et al. 2015b). The Government of Nepal, with the aid of different development agencies, has identified (and proposed) 11 hydropower and water storage projects in the Koshi Basin (Figure 11-6; Chinnasamy et al. 2015) where already all the sightings of river dolphins have only been made below the Koshi barrage (Paudel et al. 2015b). Furthermore, river flow below the Koshi barrage is completely guided by the barrage management authorities (Indian government) who have a poor understanding of river flow interaction with the ecology of river dolphins. Whilst this problem has been raised, it has so far been ignored by the concerned authorities in Nepal, in relation to dolphin conservation in the Koshi River.

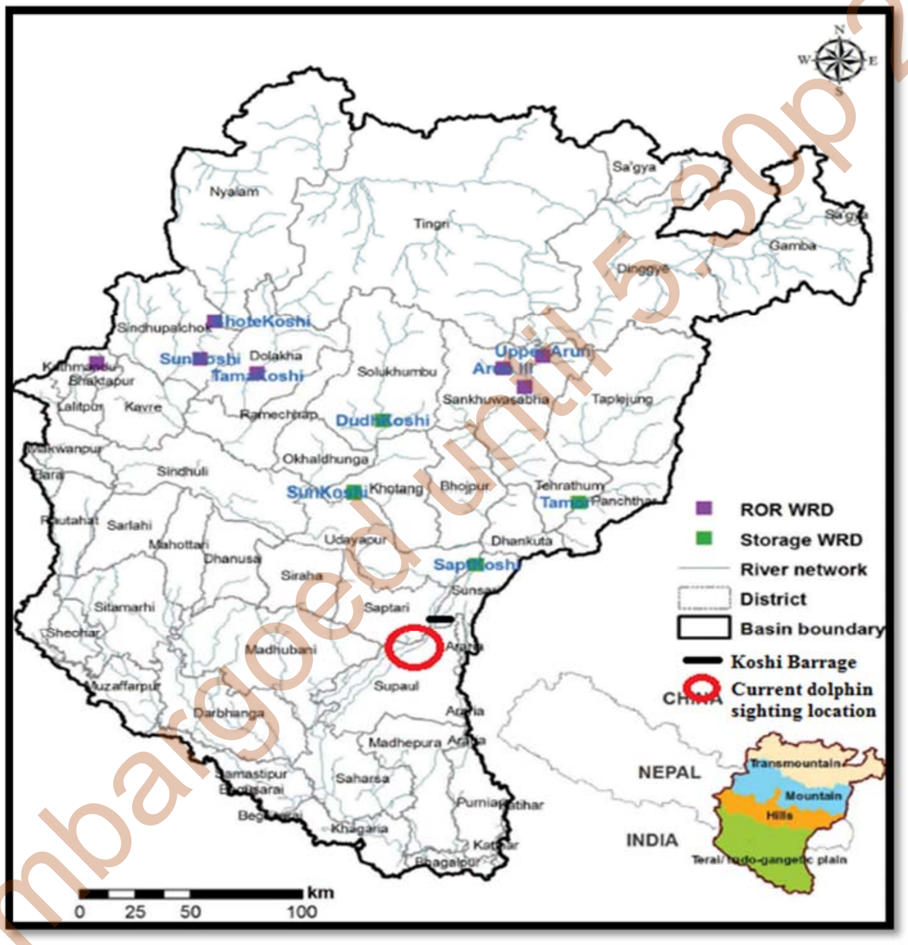


Figure 11-6 Distribution of water based projects upstream of the SaptaKoshi in Nepal (adapted from Chinnasamy et al. 2015)

Without understanding the ecological functions of river flow and the ecology of river dolphins, there is no strong evidence that can be used to inform regulators of the river systems. The minimum discharge required to sustain the present population and their natural habitats when habitat is reduced, is far from clear. Quantitative data on minimum river flow requirement should be determined to create numbers of suitable habitats and to minimize the possible effects from proposed dams and other human structures during low flow seasons. Clear effects of structures (built barrages) have already been shown to affect distribution, gene flow, movement, migration patterns, and behaviour of many freshwater species in Nepalese waterways. Efforts are required from international and national conservation authorities (e.g. like Koshi Tappu Wildlife Reserve and District Forest Offices) to synchronize development goals with conservation of river dolphins if we are to be responsible for maintaining this creature for the next generation. If we fail to do so, the species will likely be extirpated from Nepal due to human activities as was seen recently for the Yangtze River dolphin in China (Turvey et al. 2007).

Tourism has a great impact on the livelihoods of local people but some activities may exert negative impacts on crocodiles, dolphins and other aquatic species. Therefore, we suggest that the impact of tourism on these species should be studied. Additionally, species hotspots should be identified so that impacts of flow change and anthropogenic activities might be mitigated. Research should be conducted on the Koshi River's water quality, depth and availability of basking and nesting habitats for crocodiles. Mitigation measures should be developed for different threats, especially due to natural calamities, anthropogenic activities and the impacts of climate change. A guideline should be prepared to impose a strict ban on anthropogenic activities that have negative impacts on the species. Strict protection of preferred basking sites and prohibition of fishing in the main settling zones are the principal conservation measures (Stevenson 2015). To develop a trans-boundary mechanism to tackle these threats is also important.

The Gharial Conservation Action Plan (2012-2021) for Nepal has been prepared and there is an urgent need to prepare a Conservation Action Plan for Mugger crocodile and dolphin. Proper implementation of the plans will provide proper safeguards to the future of these species.


(Photo: S Paudel)

Local participation is necessary in the conservation of crocodiles and dolphins. The constraints for crocodiles and dolphin conservation can be solved to some extent by joint efforts such as sharing conservation and management responsibility and economic incentives to the local community (Goit & Basnet 2010, Whitaker & Andrews 2003, Stevenson 2015). Singh (1987) and Whitaker (1987) also suggested that the future Indian crocodilian conservation effort should include public education and management of crocodilians as a sustainable economic resource for the local people living around crocodilian habitat. The idea of value-added conservation (Hines & Percival 1987) has been expressed for the American alligators as well as for other species of crocodile. Therefore, encouraging local people to participate in the protection of not only crocodiles and dolphin but also the entire biodiversity of the area by launching biodiversity related education and awareness programmes and linking crocodile and dolphin conservation with income generation (tourism and recreation) for local people is necessary.

Crocodile farming has done wonders for crocodilians in many developing countries (Whitaker & Andrews 2003). Nepal also initiated this activity at Chitwan and Bardia. The government should also establish a crocodile breeding centre within the Koshi Basin, to enhance conservation strategies and to provide education and livelihood support to local people. Education materials in Nepali language should be prepared and distributed among locals to teach them the value of the river ecosystem with crocodiles and dolphin being the charismatic species of the area. Crocodiles are portrayed as a harmful animal among the local people (Baral & Shah 2013), therefore awareness creation is important to ward off this and other wrong beliefs like crocodile eggs, Ghara and dolphin oil possessing medicinal value.

## 11.9 Livelihoods

Subsistence fishing and rice cultivation which is usually supplemented by the use of wetland resources, are the major sources of livelihood of people living near the the Reserve (Sah 1997, Bhuju et al. 2007). The majority of the fish collectors were the Ghongi tribesmen (including Majhi, Malaha, Sardar, Goti and Musahar) because their poverty and limited land had driven them to fish for subsistence living (Goit & Basnet 2011). Despite several limitations, there is great prospect for eco-tourism in the area and this can provide economic incentives to the local community. In addition to aquatic birds and water buffalo, the presence of crocodiles and dolphin are popular attraction for tourists in the area.

Ecotourism generates direct or indirect income through the consumption of local products and creating employment opportunities for the local community. Ecotourism can uplift the socio-economic conditions of local people as when people have a good living standard they depend less on the natural resources. Local biodiversity will therefore be conserved (Goit & Basnet 2011).

The occurrence of crocodiles in the Koshi River is beneficial to local communities whose livelihoods are dependent on fishing. Their presence actually helps to increase yields of edible fish for man (Whitaker & Andrews 2003). According to Shrestha (2001), crocodiles eat sedentary bottom dwelling predatory fish species such as gounch (*Bagarious bagarius*), tenger (*Mystus seenghala*) and murrel (*Channa marulius*) and other fish predators such as otters, water birds, water snakes, turtles and wild pigs and influence the excessive multiplication of number of other game fish population. The more crocodiles there are, the better the fishing. They also play a vital role in nutrient cycle in a nutrient and electrolyte poor environment. Faeces and scraps of crocodiles form an allochthonous basis for primary production and serve as the foundation for the food chain which in turn benefits fish production.

Ecologically, the number of deep pools (preferred habitats for dolphin and fisheries) and their connectivity rely upon the amount of discharge available within a river stretch. When water is limited during the low water season, highly fragmented deep pools spatially overlap with fisheries and river dolphins (Kelkar et al. 2010, Paudel et al. 2016). Large numbers of deep pools below the Koshi barrage are heavily encroached by fisheries, where the last remaining population stock of river dolphins is surviving. When utilization of deep pools by fisheries increases, the risk of susceptibility to entanglement in fishing gear also increases. We have evidence of two dolphins (*pers. obser*), which died after being entangled in the Sapta Koshi (in 2016) and Karnali (in 2015), respectively. This also changes the underwater behaviours of river dolphins due to the reduction of suitable habitats which may increase the level of stress which impacts on their survival. When river flow is reduced, the magnitude and extent of conflicts between fisheries and the river dolphin increases, which poses a threat for the whole ecosystem. It is important to strengthen co-existence of fisheries and river dolphins by highlighting the importance of maintaining adequate dry season river flows in the main stream to sustain dolphin populations and reduce competition for prey. This requires management plans for fish-stock restoration, securing of tenure rights and the provision of alternative livelihoods

(Photo: S Paudel)

for fishers which may help to reconcile conservation and local needs in overexploited river systems in the future.

Thus, river regime change is directly related to the livelihoods of local people, because it is related to the survival of crocodiles, dolphin, fish and many other natural resources. In addition to this, it is also related to irrigation facilities, inundation of the agriculture lands and flood control.

## Acknowledgements

Prof KB Shah conceived, developed and analysed the gharial ecological model in relation to changing environment; and S Paudel conceived, developed and analysed the river dolphin ecological model in relation to changing environment.

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# 12 Macroinvertebrates as indicators of river health

*Authors: Subodh Sharma[1], Deep Narayan Shah[2], Ram Devi Tachamo Shah[3]*



## 12.1 Introduction

Macroinvertebrates are bottom dwelling organisms without a backbone and can be seen without the aid of a microscope. They live in a variety of habitats from vegetation and woody debris to rocks and sediments. They are widely distributed in all continents and occur from small streams to large rivers and from marshy lands to lakes. The large number and varying topology of rivers in the Koshi River Basin in Nepal (Chapter 2) provides a substantial number of habitats for macroinvertebrates. They are highly specific to substrate distribution, therefore, with an increase in habitat diversity, their diversity and richness increases (Allan & Castillo 2007). In general, streams and rivers have higher substrate diversity than lakes and wetlands, thus supporting a greater diversity and richness of macroinvertebrates (Johnson et al. 2004).

Baetidae (Copyright: RDT Shah)

Most macroinvertebrates are highly sensitive to water pollution, physical changes to river condition such as flow alteration, sedimentation, channelisation and changes in water quality due to climate change. As they live in water with short life spans as compared to fishes, they integrate the disturbances over a short period of time and reflect overall ecological health of streams, rivers, ponds and lakes (sensu Hynes 1970). Therefore, they have been extensively used in monitoring of ecological status of water bodies worldwide. Their change in abundance, diversity and richness indicates the presence of pollution and deviation from a reference condition (Rosenberg & Resh 1993).

Caenidae (Copyright: RDT Shah)

Heavy doses of fertiliser in agricultural land in the headwaters has been identified as a major activity causing water quality degradation. Much of the applied fertiliser by farmers is washed into the river system of the watershed mainly during the monsoon. Hydro-morphological degradation, such as, channel embankment, river-bed excavation, bank cutting, impoundment, and water abstraction are major drivers observed causing water pollution in the Koshi Basin. Other drivers include wastes, siltation from deforestation and conversion of forest into agricultural land, and soil erosion.

[1] Aquatic Ecology Centre, School of Science, Kathmandu University

[2] International Union for Conservation of Nature (IUCN), Kathmandu, Nepall

[3] Central Department of Environmental Science, Tribhuvan University, Kathmanu, Nepal

## 12.2 Importance of macroinvertebrates

Macroinvertebrates comprise multiple phyla such as arthropods, annelids, and molluscs. They are the central component of the aquatic food chain. According to functional feeding types, they are described as shredders, grazers, predators and collectors. Shredders breakdown coarse organic materials such as leaves and twigs while collectors feed on fine organic materials replenishing nutrients and translocating organic materials (Wallace & Webster 1996). Some macroinvertebrates graze upon aquatic vegetation and weeds controlling the widespread distribution of weeds and algae. They are major food sources for fishes, frogs and birds.

Macroinvertebrates are highly diverse communities. They all have a different ability to tolerate pollution (Rosenberg & Resh 1993). According to their tolerance to pollution, hundreds of biotic methods have been developed worldwide to assess water quality of water bodies (Bunn & Davies 2000; De Pauw & Hawkes 1993). Nepal can be considered as rich in terms of macroinvertebrates diversity. The country also hosts large populations of endemic macroinvertebrate species (*sensu* Nesemann et al. 2007).

A study performed in two river basins, the Bagmati in Kathmandu Valley and Seti in Pokhara Valley, indicated the relative importance of effluent factors, such as agricultural, industrial, household, and cremation as the most detrimental. In the case of the other three major stressing groups, the relative importance is not the same between the two river basins. Shrestha et al. (2008a) indicated a total of 22 stressing factors identified along river stretches in the Hindu Kush-Himalaya, which have been grouped into four broad groups (Table 12-1).

Table 12-1 Classification of the drivers causing water pollution in Bagmati River basin contributing about 45.3% from Effluents, 20.4% from Activities and Facilities, 19.4% from Hydro-morphological disturbances, and 14.9% from Personal Hygiene and Sanitation (modified from: Shrestha et al. 2008a)

| Effluents | Activities and facilities | Hydro-morphological degradation and ecological disturbances | Personal hygiene and sanitation |
|---|---|---|---|
| • Waste dumping<br>• Sewerage<br>• Cremation site<br>• Industrial effluent<br>• Agricultural effluent | • Squatter settlements<br>• Military camp upstream<br>• Picnic spots<br>• Vehicle crossing<br>• Open defecation<br>• Littering<br>• Fishing and boating | • Channel, embankment and weir<br>• Flood<br>• Bank cutting<br>• Reservoir, dam and impoundment<br>• Irrigation<br>• Landfill leachate<br>• Stone quarrying and crushing<br>• Sand quarrying | • Bathing<br>• Washing |

In Nepal, six biotic methods exist; NEPBIOS (Sharma 1996), NEPBIOS-BRS (Pradhan 1998), GRSBIOS (Nesemann 2006), NEPBIOS-Extended (Sharma et al. 2009), HKHBIOS (Ofenback et al. 2010), and NLBI (Tachamo-Shah et al. 2011). They have all been developed for assessing ecological status of rivers and stagnant water bodies (Table 12-2).

Table 12-2 Evolutionary history of biological assessment methods of water quality in Nepal and the Hindu Kush-Himalayan region

| Biotic methods used in Nepal | Reference | Descriptions |
|---|---|---|
| NEPBIOS | Sharma (1996) | NEPBIOS- Nepalese Biotic Score |
| NEPBIOS-BRS | Pradhan (1998) | NEPBIOS- Bagmati River System |
| GRSBIOS | Nesemann (2006) | Ganga River System Biotic Score |
| NEPBIOS- Extended | Sharma et al. (2009) | Nepalese Biotic Score-Extended |
| HKHBIOS | Ofenboeck et al. (2010) | Hindu Kush-Himalayas Biotic Score |
| NLBI | Tachamo Shah et al. (2011) | Nepal Lake Biotic Index |

Width, depth, and current velocity of rivers varies. The change in taxa richness and abundance with these three physical attributes, change in natural (seasonal) and manmade conditions and need to be observed in environmental flow studies to understand the response of macroinvertebrates to environmental flow (Figure 12-1).

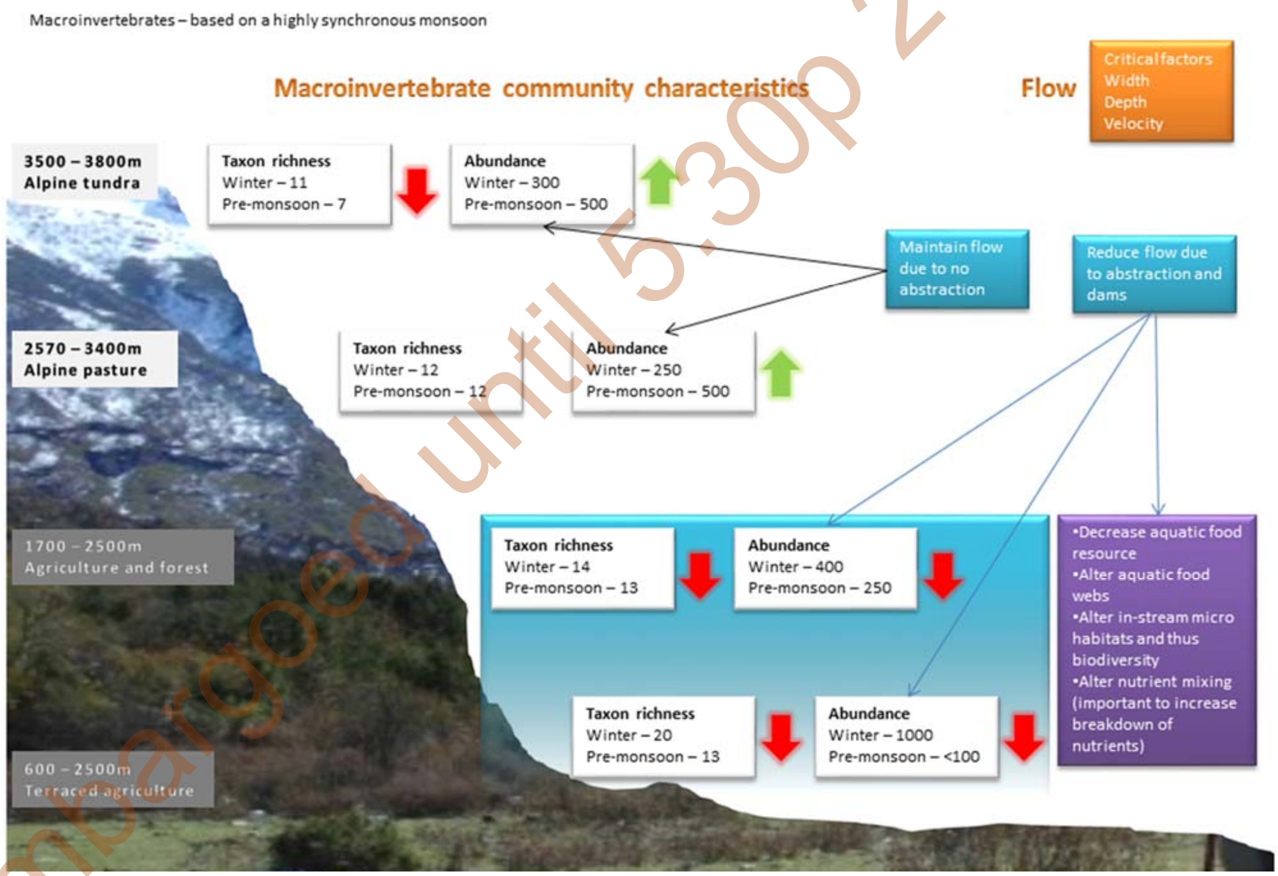



Figure 12-1 Simplified conceptual diagram showing physical attributes and response of aquatic invertebrates in varying e-flow conditions along an altitudinal gradients in different ecological zones

Macroinvertebrates belonging to the Orders Ephemeroptera, Plecoptera, and Trichoptera are proven to be climatically vulnerable taxa (Hering et al. 2010, Tachamo Shah et al. 2015). Species of these orders are sensitive to changing physical and chemical characteristics of river. Tachamo-Shah et al. (2015) listed 33 potentially climate sensitive taxa for Central Himalaya streams, including the upper catchment of the Koshi Basin. Several studies have predicted shifting of cold adopted species to favourable temperatures at higher elevation and latitude (Tachamo Shah et al. 2012, Domisch et al. 2011) with warmer habitats colonised by lower altitude species (Finn et al. 2010). Natural flows in streams and rivers play a significant role in maintaining the ecological integrity of rivers (Poff et al. 1997). Macroinvertebrates are also adapted to varying water regimes. River flow quantity and timing are determining factors for the structure of macroinvertebrate communities. Studies show that changes in river flows have a dramatic impact on freshwater communities such as macroinvertebrates (Horsák et al. 2009).

## Macroinvertebrates diversity and distribution

Biological diversity is a scientifically acceptable and objectively measurable parameter (Cook 2004). It is frequently used and considered an important gauge to decide the value of a particular habitat. Changes in diversity and taxa richness are used as an indication of how a habitat is responding to any human impact and chosen kind of management (Chapman 1992, Welch & Lindell 1992).

The macroinvertebrates population of running waters in the Himalayan region and Ganga watershed include more than 200 families and above 7000 species (Nesemann 2009) (Table 12-3).

Table 12-3 Species Inventory of macroinvertebrates reported from Bhutan, Bangladesh, Nepal, Northern India, and Northern Pakistan. Source: Sharma, 2008 (Database managed as HKHdipsoftware)

| Insecta | Total taxa | Non-Insecta | Total taxa |
|---|---|---|---|
| Coleoptera | 2420 | Bivalvia | 63 |
| Diptera | 2144 | Gastropoda | 115 |
| Ephemeroptera | 295 | Hirudinea | 63 |
| Heteroptera | 109 | Nematoda | 2 |
| Megaloptera | 1 | | |
| Odonata | 282 | | |
| Plecoptera | 182 | | |
| Trichoptera | 1159 | | |
| Others | 1265 | | |

According to their origin and zoogeographical distribution, Nesemann et al. (2007; Table 12-4) identified five groups of macroinvertebrate species in the Ganga River Basin viz., Palaearctic and Holarctic fauna, Endemic Himalayan fauna, Oriental fauna, Cosmopolitan fauna, and Neozoa.

Palaeartic and Holartic fauna originate from Eurasia and are mainly distributed in temperate and cold water bodies (cold-sternotherm fauna). The Trans Himalayan zones of Nepal and India (Kashmir) have Palaearctic freshwater fauna distributed between 1700-2700 m above sea level.

Similarly, Endemic Himalayan fauna which represent transitional fauna between Palaearctic and Oriental regions originate from invasion since the Pliocene period, within an altitudinal range between 800 to 2000 m above sea level. They have originated from 'inner valleys' of the Himalayas which were seasonal lakes and wetlands during Pleistocene glaciations.

Table 12-4 Major groups of macroinvertebrates in the Koshi River Basin in Nepal (Nesemann et al. 2007)

| Group | *Species* |
|---|---|
| Palaearctic and Holarctic Fauna | *Dendrodrilus rubidus, Tubifex, Bothrioneurum vejdovskianum, Aulodrilus limnobius, Spirosperma nagarkotensis, Gammarus lacustris, Galba truncaluta, Pisidium casertanum, Radix auricularia, Helobdella stagnalis, Nais alpina, Nais elinguis, Lumbriculus variegatus* etc. |
| Endemic Himalayan Fauna | *Epiophebia laidlawi, Himalayanpotamon atkinsonianum, H. emphysetum, H. sunkoshiense, Potamiscus sikkemensis, Erhaia sp., Tricula spp., Myxobdella nepalica, Haemadipsida zeylanica agilis, Haemadipsida zeylanica monivindicis, Perionyx fluviatilis, Pisidium (Ohdneripisidium) annandalei, P. (O.) kuiperi, Pisidium (Afropisidium) clarkeanum dhulikhelensis, P. (A.) ellisi, Musculium goshaitanensis, Musculium cashmiriensis, Asiaticobdella punyamatensis, Lymnaea andersoniana simulans, Dero phewatalensis* |
| Oriental Fauna | *Aulophorous indicus, A. hymanae, A. tonkinensis, A. flabelliger, Dero sawayai, Branchiodrilus semperi, B. hortensis, Allonais paraguyaensis, A. gwaliorensis, Gyraulus euphraticus, Indoplanorbis exustus, Camptoceras lineatum, Radix persica, Radix ovalis, Radiatula* spp., *Lamellidens* spp., *Musculium indicum, Neoniphargus indicus, Sartoriana spinigera, Barythephusa lugubris, Parathelphusa panningi, P. martensi, Bothrioneurum iris, Perionyx excavatus.* |
| Cosmopolitan Fauna | *Limnodrilus hoffmeisteri, Aulodrilus pluriseta, Branchiura sowerbyi* |
| Neozoan Fauna | *Physella (Haitia) mexicana, Physella acuta, Eisenia fetida* |

Oriental fauna (including Palaeotropical and Pantropical) originated from South East Asia and in particular from India, and are distributed widely in the Gangetic plains up to 800-1700 m above sea level. A large number of these fauna are endemic to the river system or the sub-continent.

Cosmopolitan fauna are limited to a few species only, with true cosmopolitan distribution and with no clearly visible habitat preferences.

Neozoa species are those which are distributed due to androgenic dispersal by transportation or by active expansion through channels.

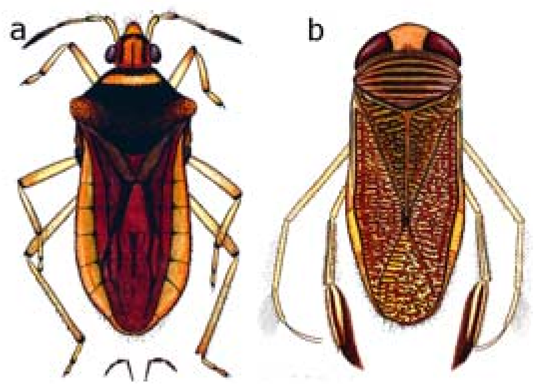
## Flow regime change

Change in flow regimes disrupts aquatic ecosystems by changing water quality, sediment transport and substrate composition, channel morphology and habitat diversity (Agostinho et al. 2008, Lauters et al. 1996, Petts 1984, Richter et al. 2003). Among others, these abiotic changes alter the composition and structure of macroinvertebrate and fish communities significantly. For instance, the abundance and diversity of macroinvertebrates decrease due to the reduction of available habitats as a result of reduced substrate heterogeneity (Patterson & Smokorowski 2011).

Globally, most major rivers are altered by dams and flow regulations (Nilsson et. al. 2005) and Nepal is no exception. In recent years, several dams have been planned in different rivers including the Koshi Basin. In the context of altered natural ecological processes, the conservation and management of freshwater ecosystems remains a major challenge. In spite of this, only a few studies have been conducted on stream habitat condition, particularly flow regimes and biota in different rivers of Koshi Basin (Rijal & Alfredsen 2015).

## 12.3 Contribution to the taxonomic knowledge of macroinvertebrates

For several groups of non-insect macroinvertebrates (Mollusca, Annelida, and Crustacea), illustrated keys have been compiled and applied within the international group of taxonomists. Furthermore, these materials were frequently used for training of students in India, Pakistan, Bangladesh, Nepal and Bhutan. A revised and updated version with descriptions of new species was published by Nesemann et al. (2007), which included most of the taxonomically and zoo-geographically important new records of Sharma (1996), Pradhan (1998), Nesemann (2006), Shah (2007), Tachamo (2007, 2011), Sinha and Sharma (2001, 2003), Oheimb et al. (2011), Clewing et al. (2013), and Glöer and Bößneck (2013). Aquatic insects of the Himalayan region have been recently incorporated into identification keys such as: Ephemeroptera by Soldán and Bauernfeind (2006), Plecoptera by Graf et al. (2006), Odonata by Hartmann (2006) and Nesemann et al. (2011), Coleoptera by Huber et al. (2006), Heteroptera by Huber et al. (2006), Trichoptera by Graf et al. (2006), and Diptera by Janeček (2006), Rozkosny and Brabec (2006), Bouchard (2004).



Heteropetra (a) Veliidae, (b) Corixidae)
(Copyright: H Nesemann)

In many of the available identification books for aquatic invertebrates (Dudgeon 1999), only the larger and more popular groups are covered, whereas the often frequently sampled smaller ones are missing e.g. Nematoda, Nemertini, Hydrocarina, Hydrozoa, sessile invertebrates etc.

For Asian benthic fauna, two publications are very useful, which give a detailed overview about the families, genera and species. Dudegon (1999) describes the macroinvertebrates of the tropical part of Asia for the more common orders, but he includes only a selection of the more popular invertebrates used for biomonitoring.

Additionally, publications from other continents have also been found useful to gather general knowledge about ecology and distribution for (genus-) family- and order-level. The works of Bouchard (2004): North America: Minnesota, Hutchinson (1993): North America, Needham and Needham (1984): USA, Pennak (1978a,b): USA, Kawai (2001): Japan, Kawai and Kazumi (2005): Japan, Gerber and Gabriel (2002): South Africa, provide highly valuable information of family characters and family definitions. They are helpful in identification to the family level, when the same families are present in Asian fauna.

## 12.4 Existing knowledge on macroinvertebrates for Koshi River Basin

Macroinvertebrates research is rapidly evolving in Nepal though little systematic information is available to date. For the Koshi Basin, some significant knowledge exists in relationship to altitudinal variation (Ormerod et al. 1994), water quality (Sharma 1996), organic pollution (Tachamo 2007, Feld et al. 2010), river classification strategies (Tachamo 2011) and impacts of climate change (Tachamo Shah et al. 2012, 2015).

Ormerod et al. (1994) studied macroinvertebrate distribution in the headwaters of the Koshi River along the trekking routes in Sagarmatha National park and found changes in community assemblages along altitudinal gradients. Sharma (1999) studied water quality in the Saptakoshi and its major tributaries. Tachamo (2007) and Feld et al. (2010) studied the effects of organic pollution on macroinvertebrates on Mid Hill streams and tributaries of the Koshi River. These studies classified stream and river sections into different water quality classes based on biotic indices. A complete list of macroinvertebrates identified mostly at genera and species were also presented in the annex (Tachamo 2007).


Leptoceridae (Copyright: RDT Shah)

Tachamo (2011) applied the Strahler stream order classification based on macroinvertebrate diversity and composition for the Indrawati River basin. The study depicted three distinct clusters of sites of stream order – 1, 2 and 3 were grouped together indicating headwater streams; stream orders 4, 5 and 6 were grouped together indicating medium rivers; and stream orders 7 and 8 formed one cluster indicating large rivers – revealing that stream macroinvertebrate communities were similar within headwater streams, medium stream and large streams rather than between stream types.

Tachamo Shah et al. (2012) simulated climatically suitable habitat distribution of endemic Himalayan Dragonfly (*Epiophlebia laidlawi*) at the present, and under extreme (A2) and moderate (B2) scenarios of climate change for 2050 and 2080. The study predicted that most of the headwater streams of the Koshi River are potential habitats for this species and would shrink by 80-90% under A2 scenarios by the year 2080. Tachamo-Shah et al. (2015) for the first time applied a freshwater macroinvertebrate based climate sensitive zone concept for the streams of the Central Himalaya where sampling was carried out along altitudinal gradients from 1500 m asl to 4100 m asl, mainly in the headwater streams of the Koshi Basin. The study identified an altitudinal band between 2900 m asl and 3500 m asl as a climate sensitive zone. This is a zone where climate change impacts will likely be observed earlier compared to other altitudinal bands. The study further identified 33 macroinvertebrates taxa as climate sensitive taxa.

## 12.5 Biomonitoring and river water quality

Biomonitoring is the use of biological responses to assess changes in the environment brought about by human interventions. Rivers in Nepal are used for different purposes by humans, ranging across household (bathing, swimming and washing), livelihoods (fishing and boating), irrigation, industries, transportation and waste dumping. Studies show that the major environmental stress factors are waste dumping, bathing and washing, open defecation and sewerage (Shrestha et al. 2008a, b).

There exists a relationship between the number and types of stressing factors and biomonitoring methods, which can be assessed through the macroinvertebrate based Nepalese Biotic Score (NEPBIOS) method (Sharma 1996) in different rivers of Nepal including the Indrawati, Tamakoshi, Likhu, Dudhkosi, and Arun rivers of the Koshi River Basin. A similar method is also proposed for the assessment of river water quality of the Ganga River System (GRSBIOS- Ganga River System Biotic Score; Nesemann 2009). A Lotic Invertebrate Index for Flow Evaluation (LIFE) assesses the response of invertebrate taxa at the level of families or species to flow velocity, developed in the UK by

Extence et al. (1999). A variety of hydrological indices methods are also in use, to analyse the change in flow regimes globally (Richter et al. 1997, Tharme 2003, Snelder & Booker 2013). Richter et al. (1997) listed 33 individual and 33 associated measures of variation for the characterisation of flow regimes altered by humans, and Snelder and Booker (2013) discussed the flow regimes of Huai River Basin in China, categorised into six classes based on 27 years of data and application of 80 hydrologic metrics. Tharme (2003) mentioned the use of various methods like Hydrological Index Method, Hydraulic Rating Methods, Habitat Simulation Methods and the Holistic Methods in environmental flow assessments. However, in Nepal, the use of hydrological models is limited to simple hydrological indices based on historical flow data.

## 12.6 Livelihoods and water

Hydro-morphological degradation and ecological disturbances are the major drivers regulating river flows in Koshi Basin. People use running water for domestic, agriculture and industrial activities. Demand has increased with increased population density. Water extraction from rivers has been increased to maximum levels in recent decades causing flow depletion in rivers. This has immense negative consequences on poor and marginalised people who spend most of their time fetching water for daily consumption. Therefore, changes in river flows have severe impacts on livelihoods. In terms of freshwater ecosystem services rendered by the Koshi Basin, 85.3% is contributed in Provisioning services (livestock fodder, floodplain agriculture, fish, energy, domestic water supply, other), 7.2% in Regulating services (flood control/prevention, carbon sequestration), and 7.5% in Cultural services (only for tourism). A negligible contribution is recorded in the Koshi River Basin from Supporting services (Fleiner 2013).

## 12.7 Knowledge gaps and opportunities

The analysis of river flow regimes has received much attention in Nepal with the introduction of Hydropower Development Policy in 2001. The Policy specifically mentions the amount of minimum flow that must be released. It states that *"Downstream release shall be maintained, either 10% of minimum mean monthly discharge or the quantity identified in the EIA study whichever is higher"*. This has led planners to the direction of raising awareness for conservation of fishes remarkably, however macro-invertebrates role in understanding environmental health and water quality assessment remains less understood.

Leipdostomatidae (Copyright: RDT Shah)

Considerable attention is now given to fisheries by the conservationist – however the diversity of other groups of aquatic biota such as macroinvertebrates and planktonic organisms and their role for the sustenance of fisheries and ecological integrity of aquatic habitats is largely overlooked. A serious effort must be undertaken to remedy this situation. There is an urgent need for extensive training and public awareness about the conservation of invertebrate biodiversity. Currently, species biodiversity of fishes, birds, and other larger fauna is comparatively better known compared to that of invertebrates.

The value and importance of wetlands has been described time and again within the framework of the Ramsar Convention. Wetlands, besides being a storehouse of biodiversity, also contribute remarkably to maintaining water quality. All aquatic biota are excellent indicators of environmental quality. Species diversity is related to habitat diversity. Thus, loss and degradation of habitats are the greatest threat in Nepal and require research to aid conservation of overall aquatic biodiversity.

Poisoning of water bodies and other fishing practices have increased in recent years in Nepal, which have not only threatened the aquatic life but also the lives of the people associated with it. These practices also result in over-exploitation of water bodies and fish stocks with the use of vicious fishing methods such as the use of explosives and poisoning. Vast network of rivers and streams in Nepal offer significant opportunities for fishing businesses but there is lack of awareness among people about the long-term effects of destructive fishing techniques currently in use and impacts to aquatic ecology.

The knowledge of freshwater macroinvertebrates of the Himalayan region and the northern Indian subcontinent is still very poor, with only a few popular groups like molluscs, some terrestrial insects or zooplankton crustaceans are attractive to scientific interest. Taxonomical studies are largely missing and the published results simply summarise and list already known geographical records. Except for a few scientists who are experienced in describing new species, the literature on aquatic macroinvertebrates of the last two decades is dominated by 'review articles' rather than by 'research papers'. Although numerous proceedings and regular journals are released, the amount of new results is very limited; misidentifications are frequently published and/or presented in conferences, seminars and workshops. Many authors are using older nomenclature, although more updated identification keys with corrected genus and species name are available. Even when appropriate literature exists, it is often not available to those working in the field and in laboratories. A more serious problem is that today very few people are trained to use the existing literature (Cook 1996).

The young scientific community in the Indian subcontinent must now emphasise conducting research on macroinvertebrate taxonomy through genetic diversity of aquatic biota and prepare identification keys for all groups and investment must not only be in taxonomy but also in understanding the ecology and biology of macroinvertebrates within these systems. Rare, endangered and threatened species must be well documented and policy must be created for the conservation of such species by protecting their habitat.

## Lack of regular and long term research

The country largely lacks regular and long term monitoring data in any field of research and this is particularly true for freshwater biodiversity. In order to determine long term change in macroinvertebrate communities due to local stressors (listed in Table 12-1) or regional stressor such as land use changes and global stressor such as climate change, regular interval research for long term periods are imperative to enable estimation of temporal and spatial biodiversity.

## Long term river monitoring

The relationship between macroinvertebrate assemblages and river flow is poorly understood. Changes in physical condition of rivers such as alteration in flow discharge might have significant effects on macroinvertebrates physiological activities and community composition however this is much understudied to date. Hence, research focusing on macroinvertebrate response to alteration in flow regimes should be the next priority.

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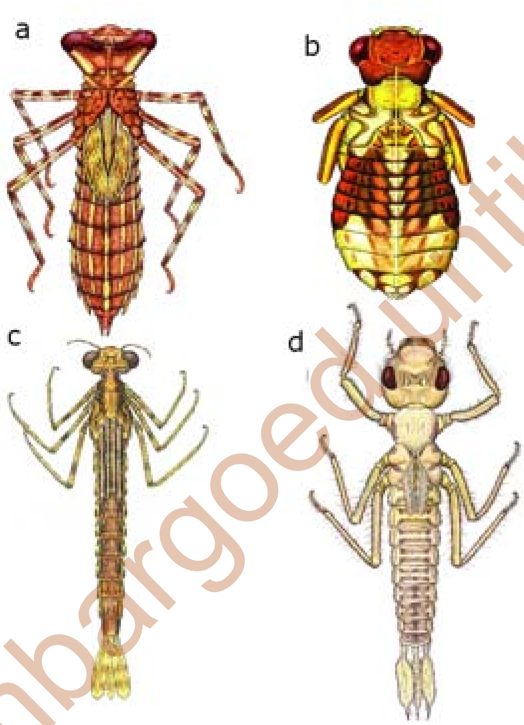


Odonata (a) Aeshnidae, (b Epiophlebiidae, (c) Synlestidae, (d) Platystictidae
(Copyright: H Nesemann)

# 13 Summary

*Authors: Tanya M Doody, Susan M Cuddy, Laxmi D Bhatta (editors)*

Water is critical for every living organism around the globe. This applies more so in less affluent countries whose basic livelihood needs may often solely rely on water from rivers, rainfall and groundwater to exist. In Nepal and similar developing countries, water is also vital to run hydropower stations in order to generate much needed power. Access to power considerably improves living standards of poorer communities. Similarly, water is required to support many agricultural livelihoods.

It has been noted regularly within, that Nepal and the Koshi Basin region encompass incredible biodiversity driven from a combination of high elevation variability and rainfall gradients to create diverse habitats for many flora and fauna species. Many of the habitats that exist within the landscape are related to the presence of water, either permanently or intermittently. The most productive provisioning services are provided by wet ecosystems such as rivers, wetlands, lakes, swamps and marshes within the Koshi Basin. These environments support forests for wood, fish for consumption and water for drinking, to name a few. They also support livelihoods, as plants are used for medicinal purposes and also for making mats and baskets to provide income. However, many of the habitats within Nepal and the Koshi Basin are under threat from humans and changes to flow regimes. Chaudhary and Sah (2016) provide a substantive list of threats in Chapter 6 that include unsustainable harvesting, land use change, climate change and infrastructure development often underpinned by unclear policy. Loss of habitat is one of the major causes of biodiversity loss. In riverine systems, changes in upstream flows can have devastating effects on downstream ecosystems.

Within these chapters, we sought to improve the understanding of the relationships between river flow and key ecological components in Nepal. Additionally, we sought to identify knowledge gaps that can be addressed in the future in order to aid with integrated water resource management in Nepal, with a specific focus on the maintenance of the ecological integrity of its ecosystems. Conceptual models were used as a way to visualise the quantitative and qualitative data that was available and to also identify some important knowledge gaps.

## 13.1 Knowledge gaps

For the first time in Nepal, the quantitative relationships of ecological components to flow (or the known thresholds to flow after which ecological components decline) in the Koshi Basin, have been summarised in Table 13-1. This is by no means an exhaustive list given time and resource constraints however, we believe it is a major step forward in understanding the type of information that is required to determine the water requirements for ecological components in the Basin and more broadly across Nepal and neighbouring countries. Four known thresholds to flow for fish were identified, three for grassland birds, crocodile and dolphins, one for water birds and two for buffalo (16 in total). It is almost certain that many other thresholds are known of but are unlikely to be reported in scientific journals. Rather, these relationships and studies remain locked away in inaccessible literature, environmental impact assessments and within the heads of the many experts in Nepal.

Table 13-1 Quantitative relationships that have been identified through scientific studies in Nepal

| Ecological component | Threshold to flow (quantitative relationships) |
|---|---|
| Fish | Snow Trout (*Schizothorax* spp) require ability to migrate upstream to spawn in March to June at water temperatures between 14–21°C<br>Require clear water of depths 30–60 cm to lay eggs in gravel along stream bank |
| Fish | Require (in general) a dissolved oxygen of between 5–7 mg $L^{-1}$ |
| Fish | Maximum water temperature of 28.16 (±0.19) °C and minimum water depth of 3.0–3.6 m, is unfavourable for most fishes |
| Fish | Common carp *(Cyprinus carpio)* and grass carp (*Ctenopharyngodon idella)* require a water temperature between 10–25°C for reproduction |
| Grassland bird | Swamp francolin (*Francolinus gularis*) prefers high density grass 2–3 m tall |
| Grassland bird | Bengal florican (*Houbaropsis bengalensis*) males prefer moist, short, pure grassland 15–35 cm tall |
| Grassland bird | Bengal florican (*Houbaropsis bengalensis*) females prefer moist grassland >110 cm tall |
| Water bird | Lesser Adjutant Stork (*Leptoptilos javanicus*) nests in tall trees generally > 30m high |
| Buffalo | Requires alluvial tall grassland composed of 80% *Sacchrum* spp |
| Buffalo | Need to wallow 6–8 hours a day to cool themselves |
| Crocodile | Suitable substrate for basking – 62% sand/sand bar and 37% rocky substrate |
| Crocodile | Requires shade by 14:00 in winter to manage thermoregulation |
| Crocodile | Water depth – juveniles require 1–3 m depth, if 120–180 cm long, require 2–3 m but will use >4 m water depth if available, adults require water depth >4 m |
| Dolphin | Water depth – adult/calf pairs require less than 2.2–2.4 m depth, sub-adults require >3.8 m depth and adults require >5 m |
| Dolphin | Gillnets that go to 4.5 m depth are a threat to dolphin life |
| Dolphin | Require channels with a cross-sectional area of >700 $m^2$ to ensure forging opportunities |

It was evident from the process undertaken to elicit these flow-ecology relationships, that much more is known based on qualitative data or observations which have not yet been scientifically tested (Table 13-2). It is not surprising that the most information exists in relation to birds, since they are the most studied fauna in the Basin. Again, this is not an exhaustive list but it is interesting that the most water-dependent birds (river birds and water birds) have very little quantitative data (Table 13-1) indicating a significant knowledge gap in their research. Most bird studies focus on species and bird number surveys. Eight different qualitative relationships to flow were identified for water birds and river birds, three for grassland birds and dolphin, two for buffalo, crocodiles, forest birds and fish and one for macroinvertebrates (28 in total). This indicates that researchers are aware of flow-ecology relationships, but to date are unlikely to have the resources to study them in a quantitative fashion.

Table 13-2 Qualitative relationships identified between river flow and ecological components in the Koshi Basin

| Ecological component | Relationship between ecology and river flow (qualitative) |
|---|---|
| Fish | Mahseers (*Tor putitora* and *Tor tor*) and Katle (*Neolissocheilus hexagonolepis*) require cool, clean river pools and lakes with oxygenated water interconnected with mid hill river streams, often in upper floodplain reaches. Temperatures are often less than 21ºC |
| Fish | Reduction in longitudinal connectivity, increasing anoxia, increasing area of macrophyte biomass and increasing nutrients lead to alteration of fish community composition |
| Forest bird | Woodpeckers nest in tree cavities in forested riverine areas |
| Forest bird | Woodpeckers feed on water dependent arthropods and other insects |
| Grassland birds | Swamp Francolin (*Francolinus gularis*) feed on water-dependent tubers, invertebrates and small vertebrates |
| Grassland birds | Bengal Florican (*Houbaropsis bengalensis*) feed on aquatic plants (winter/spring) and invertebrates (summer) |
| Grassland birds | Indian Courser (*Cursorius coromandelicus*) requires a large expanse of water-dependent grassland |
| Water bird | Black-bellied Tern (*Sterna acuticauda*) require undisturbed fish rich wetlands |
| Water bird | Black-bellied Tern (*Sterna acuticauda*) breed along sandy river banks between March and June |
| Water bird | Black-bellied Tern (*Sterna acuticauda*) feed on fishes |
| Water bird | Lesser Adjutant Stork (*Leptoptilos javanicus*) nests in water dependent *Bombax ceiba* and Adina cordifolia |
| Water bird | Lesser Adjutant Stork (*Leptoptilos javanicus*) feeds on water dependent snails, fishes and reptiles |
| Water bird | Common Merganser (*Mergus merganser*) inhabits medium to larger rivers and lakes |
| Water bird | Common Merganser (*Mergus merganser*) is an excellent swimmer but not able to live outside of waterbodies |
| Water bird | Common Merganser (*Mergus merganser*) live exclusively on fish |
| River bird | Little Forktail (*Enicurus scouleri*) prefer small to large rivers with cascading water, wet boulders to forage on and exists on an aquatic diet |
| River bird | Brown Dipper (*Cinclus pallasii*) prefer the channel centre of small to large rivers with cascading water and forage underwater for aquatic organisms. They also live on terrestrial water dependent organisms |
| River birds | Black-back and Slaty-back Forktails (*Enicurus immaculatus* and *E. schistaceus*) feed on channel margins of rivers and lakes |
| River bird | Spotted Forktail (*Enicurus maculatus*) prefers to forage in small, shaded streams with lots of leaf litter, feeds on riparian margins |
| River bird | Plumbeous Water Redstart (*Rhyacornis fuliginosa*) prefers small to large rivers to forage on a mixed aquatic-terrestrial diet, often found feeding on wet boulders |
| River bird | White-capped Water Redstart (*Chaimarrornis leucocephalus*) prefers small to large rivers. Feeds on water dependent flying and ground prey, found on the outer rim of the riparian zone |
| River bird | Blue Whistling Thrush (*Myophonus caeruleus*) prefers small to large rivers. Feeds on water dependent flying and ground prey, found on the outer rim of the riparian zone |
| River bird | Kingfisher species are directly dependent on river fish stock |
| Buffalo | Require mixed riverine forest in order to have shade and to exfoliate after wallowing |

| Ecological component | Relationship between ecology and river flow (qualitative) |
|---|---|
| Buffalo | Require water dependent *Sacchrum* spp for grazing |
| Crocodile | Require basking substrate in close proximity to deep water |
| Crocodile | Require habitat for camouflage – good riparian vegetation, suitable water depth and river banks suitable for burrows |
| Dolphin | 50% of sightings occur at river confluences. Eddy counter currents are important for persistence |
| Dolphin | Require a high degree of lateral and longitudinal connectivity |
| Dolphin | Require high fish numbers for feeding |
| Macro invertebrate | Maintain taxon richness in areas with little or no flow alteration |

A large number of knowledge gaps were identified throughout that are related to ecology and hydrology in more general terms (Table 13-3). Some of the more important gaps are related to a lack of Basin scale inventory for most fauna and flora. To date, assessments have been undertaken at much finer scales. There is also a broad lack of information to improve our knowledge of the ecological flow requirements of most faunal and floral species although there is some understanding that the flora and fauna reported within are likely to be useful as indicator species of flow regime change. This means that as flow regimes change, population numbers as likely to decline in native species and increase in invasive species.

More information is required about flow characteristics and seasonality of rivers and wetland connectivity, both historically and currently (and also in the future) to understand why habitats and specific species occur where they do. A knowledge gap of particular note, is whether the environmental flows 10% 'rule of thumb' – where a quantum of water is released which is higher than 10% of the minimum monthly average discharge of the river or stream – is actually applicable to each major stream in the Basin of if it is even applicable at all. Many other knowledge gaps are shown in Table 13-3 including the low level of investment in ecological monitoring.

Table 13-3 A summary of the knowledge gaps identified across the chapters within this report

| Knowledge/lack of gaps – ecology and hydrology |
|---|
| Detailed information about rangeland ecosystems (limited information available) |
| Comprehensive floristic inventory at Basin scale |
| Comprehensive faunal inventory at Basin scale (include fish, macroinvertebrates, birds and herpitofauna) |
| Response to flow regime alteration of all ecological components |
| Detailed understanding of flow requirements of ecological components especially thresholds which once altered lead to community decline (currently limited understanding) |
| Identification of terrestrial, riparian and aquatic corridor linkages |
| Monitoring of fishes, buffalo, birds, crocodiles, dolphins, macroinvertebrates to determine important flow parameters |
| Parameters of the flow regime important to fishes, buffalo, birds, crocodiles, dolphin, macroinvertebrates |
| How to address lack of appropriate fish ladders |
| Mapping of upstream distribution of crocodiles and dolphins and their associated breeding success, sex ratio, and food requirements |

| Knowledge/lack of gaps – ecology and hydrology |
|---|
| Habitat information on water quality, depth and availability of basking and nesting for crocodiles and dolphin |
| A standard crocodile and dolphin survey method |
| Why did reintroduced gharials fail? Need to track animals to understand |
| Conservation plan for mugger crocodiles |
| How much water is needed, when and how should it be delivered? |
| Flow characterisation |
| Impacts of climate change on flow regime |
| Level of stream disconnection caused from hydropower infrastructure |
| Is the 10% rule of thumb applicable everywhere? |
| Quantitative data on minimum river flow requirement, especially during low flow season |
| Long-term monitoring plots across an altitudinal transect to monitor the impacts of climate change and human abstraction |
| Monitoring of climate change impacts on water resources |
| Studies on glacial lake outburst floods and effects downstream on ecosystems |

Regionally, some additional knowledge gaps were identified (Table 13-4) highlighting the importance of engaging local communities in ecological conservation education. This can help to reduce over exploitation and unfavourable harvesting techniques (for example) and to encourage their collaboration by undertaking monitoring. By encouraging the locals to participate in understanding and protecting the environment, it helps them to understand the importance of rivers and wetlands on a much deeper level, rather than just as a system that provides resources. A big step forward in collecting ecological knowledge can occur with the establishment of participatory monitoring protocols and schedules, which would provide large sources of important qualitative data. To manage aquatic ecosystems for the future, both qualitative and quantitative data are required, as the qualitative data often guides where to provide resources for quantification of important ecological flow thresholds.

Table 13-4 Regional knowledge gaps which would help with preservation of aquatic ecosystem ecological integrity

| Knowledge/lack of gaps - Regional |
|---|
| Updated conservation status for the four Koshi Basin Ecoregions |
| Public education of the importance of ecological components and their habitats |
| Community participation in monitoring |
| Measurement and monitoring of water use (industrial scale to subsistence) |
| Knowledge on upstream-downstream linkages – transboundary scale (limited knowledge available) |

Further knowledge gaps were identified which are related to governance in Nepal and the Koshi Basin (Table 13-5), whether it is related to changing policies which represent water and the environment (see Chapter 2) or improving the monitoring and governance of river flows after human development. It was agreed that a broader understanding was required to determine the impacts of infrastructure that impede, dam or remove water from rivers.

Table 13-5 Knowledge gaps identified which would require some commitment for government bodies to aid water resource management

| Knowledge/lack of gaps - Governance |
|---|
| Umbrella policy to manage river basins in a holistic way |
| Environmental impact assessment – monitoring is weak |
| Clear policy on incentivising upstream communities, such as payment for ecosystem services |
| Mention of environmental flows in Policies and Acts |
| Barrage providing only one way flow (downstream) |
| Understanding of dolphin and river flow relationship by Indian counterparts |
| Adequate development and implementation of Conservation Action Plans for ecological components |
| Establishment of a crocodile breeding centre in the Koshi Basin |
| Study of impacts of infrastructure that halts or alters river flow (dams, reservoirs, barrages) |
| Development of fish hatcheries and capture fisheries associated with damming that provides hydropower and irrigation development |

## 13.2 Livelihoods

A clean, safe functioning river basin is vital to protect the wellbeing of the people who rely on water resources for a subsistence living and for income generation. Further research around the importance of livelihoods is being undertaken within the broader Sustainable Development Investment Portfolio, so we have not identified any knowledge gaps within this current study. Rather, our intent was to clearly demonstrate how important well-functioning aquatic ecosystems are to the people of Nepal. Protecting these ecosystems for local communities is an important driver in improving our understanding of aquatic systems and ecological water requirements in the Koshi Basin, so that our children's children can enjoy fresh, abundant and reliable water resources.

## 13.3 Next steps

To progress upon the work presented within this report it will be necessary to engage with government bodies, to impress upon them the importance of healthy functioning river systems, and to obtain resources to undertake the fundamental science that is required to determine ecological water requirements of river systems and the environmental flows that may be required once a river is modified in the Koshi Basin (i.e. damming).

Some key next steps identified by the report team include:

- Present findings to key stakeholders and policy makers
- Identify other key ecological components not reported within and determine baseline understanding

- Obtain additional flow threshold relationships from grey literature to further improve the understanding of knowledge gaps for key ecological components
- Develop and instigate targeted research programs to determine water requirements of key ecological indicators of flow change, using the conceptual models within as a starting point to set hypotheses
- Develop and instigate long-term monitoring programs to support aquatic ecology research
- Characterise as best as possible, the flow regime across the key rivers in the Basin from the high altitude regions to the Terai
- Determine a single environmental flows assessment method to apply more broadly and develop a consistent framework for assessing environmental flow targets in modified rivers
- Undertake environmental flow assessments in key river systems in the Koshi Basin
- Test the 10% ‘rule of thumb’ in key river systems
- Influence integrated water resource management in the Koshi Basin with a particular emphasis on aquatic ecosystem conservation
- Assist the Government of Nepal, in particular the Ministry of Population and Environment (MoPE), to streamline environmental flow and aquatic ecosystem assessment in hydropower EIA guidelines, which is under preparation, and possible inclusion in Environment Protection Regulation.
- Undertake a pilot aquatic ecosystem assessment in one of the ongoing hydropower projects to generate knowledge for the future.

Koshi River (Photo: Jyotendra Jyu Thakuri, Bird Conservation Nepal)

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CONTACT US

**t** 1300 363 400
+61 3 9545 2176
**e** csiroenquiries@csiro.au
**w** www.csiro.au

FOR FURTHER INFORMATION

**Dr Tanya M Doody**
CSIRO Land and Water
t +61-8-83038716
e tanya.doody@csiro.au
w www.csiro.au/en/Research/LWF

**Ms Susan M Cuddy**
CSIRO Land and Water
t +61-2-62465705
e susan.cuddy@csiro.au
w www.csiro.au/en/Research/LWF

**Mr Laxmi D Bhatta**
ICIMOD
t +977-1-5003222
e laxmi.bhatta@icimod.org
w www.icimod.org

**Ms Ishana Thapa**
Bird Conservation Nepal
t +977-1-4417805 / 4420213
e ishana@birdlifenepal.org
w birdlifenepal.org