UNIVERSITY OF CENTRAL ASIA
GRADUATE SCHOOL OF DEVELOPMENT
Mountain Societies Research Institute

AGA KHAN FOUNDATION
(Kyrgyz Republic)

UKaid
from the British people

What is the Impact of Climate on Local Communities in the Isfara River Catchment?

Maksim Kulikov
Gulbara Omorova
Evgenii Shibkov

RESEARCH PAPER NO.5, JANUARY 2020

UNIVERSITY OF CENTRAL ASIA
GRADUATE SCHOOL OF DEVELOPMENT
Mountain Societies Research Institute

AGA KHAN FOUNDATION
(Kyrgyz Republic)

UKaid
from the British people

Research paper # 5, 2020

What is the Impact of Climate on Local Communities in the Isfara River Catchment?

Maksim Kulikov

Contributors:
Gulbara Omorova
Field Assistant, Mountain Societies Research Institute, UCA

Evgenii Shibkov
GIS Expert, Mountain Societies Research Institute, UCA

Abstract:

This research provides an insight into historical development of runoff of the Isfara River with evaluation of influence climatic factors have on it. It further analyzes modern data on vegetation, runoff, precipitation and temperature to quantify their interrelation. Then it analyzes the perception local communities have about natural resources and their dynamics. The research was conducted between February and November 2019 in Batken province of Kyrgyzstan within the framework of the project "Reducing conflict over water and pastures in Kyrgyzstan and Tajikistan".

This Research report was prepared with support from the British Embassy in Kyrgyzstan. The views expressed in this publication do not necessarily reflect the official views or opinions of the Embassy.

Acknowledgements

The author would like to thank the respondents as well as Roy Sidle, Asel Murzakulova and Katherine Hall for their valuable comments and ideas. We would also like to thank Small Basin Council of the Isfara River, NASA, U.S. Geological Survey, Deutsche Wetterdienst, Kyrgyz Hydromet, GRDC, NSIDC for providing the LANDSAT images, runoff and climatic data. We also thank the development teams of R, Python, Pandas, GDAL, SAGA GIS and QGIS for all their hard and very important work.

Keywords: Isfara, climate change, natural resources, runoff, local communities.

The Mountain Societies Research Institute (MSRI) was established in 2010 to conduct research for development with the goal to improve the well-being of mountain societies in Central Asia.

MSRI is part of the Graduate School of Development, University of Central Asia. The University of Central Asia (UCA) was founded in 2000. The Presidents of Kazakhstan, the Kyrgyz Republic, and Tajikistan, and His Highness the Aga Khan signed the International Treaty and Charter establishing this secular and private university, ratified by the respective parliaments, and registered with the United Nations.

The Mountain Societies Research Institute's Research Papers Series is a peer-reviewed trans-disciplinary research series conducted to help inform and contribute to the Sustainable Mountain Development agenda in Central Asia. MSRI's integrated approach to research with and for the benefit of mountain societies demands an understanding of both social and ecological factors operating at multiple spatial and temporal scales.

Comments on papers or questions about their content should be sent to msri@ucentralasia.org. 'Research Papers' may be cited without seeking prior permission.

About authors:

Dr. Maksim Kulikov is a Research Fellow with UCA's Mountain Societies Research Institute. He has extensive research experience in environmental and natural resources management as well as spatial analysis and modelling of natural phenomena. Her research area covers climate, vegetation, irrigation and mountain ecosystems. Currently he is engaged in climate and environment-related research, with a focus on their spatial and temporal interrelations and modelling in Kyrgyzstan.

University of Central Asia
138 Toktogul Street, Bishkek 720001, Kyrgyz Republic
Tel.: +996 (312) 910 822, E-mail: msri@ucentralasia.org
 Please cite this publication as: Kulikov, M., Omorova, G., and Shibkov, E. (2020) Agroforestry for Landscape Restoration and Livelihood Development in Central Asia, Mountain Societies Research Institute Research Paper No.3, 49p.

CONTENTS

INTRODUCTION

Central Asia, the largely dry region located in the middle of the continent with scarce water resources consists of five Asian countries: Kazakhstan, Kyrgyzstan, Tajikistan, Uzbekistan and Turkmenistan. Aridity is one of the main factors determining the landscapes and agricultural production in the region. Agriculture in Central Asia relies largely on irrigation, the water for which comes from mountain rivers. The Tian Shan and Pamir mountains are the main water towers in the region supplying runoff from snowmelt, glacial melt, and rainfall. Central Asia is host to diverse landscapes, including deserts, steppes, alpine meadows and mountain snowfields.

More than 60% of Kyrgyzstan's population (NatStatCom, 2018a) and about 73% of Tajikistan's population (TajStat, 2015) resides in rural areas. In Tajikistan around 50%-70% of family income come from agricultural sector (Lerman, 2012). About 27% of Kyrgyz population and about 60% of Tajik population of working age are employed in agricultural sector (Goibov et al., 2012; NatStatCom, 2018a, 2019a). The population in Kyrgyzstan's southern Batken province and in northern Sughd province of Tajikistan is growing, but its natural resources remain scarce – a factor that contributes to tensions. The rural economy is crucial for the wellbeing of residents who rely heavily on natural resources. They are a part of a living ecosystem that depends on other factors, such as soil, precipitation and temperature. Horticulture is one of the dominant sources of income, and depends heavily on the irrigation systems, of which the Isfara River is the main source.

Agriculture and animal husbandry are the main livelihoods for local people, with revenues from labor migrants comprising the second largest income source. Horticultural productivity is very much defined by the natural resources, which are very limited in the region. The growing population, overuse of croplands and pastures, deteriorating irrigation system constantly contribute to decrease of agricultural productivity. Thus, the redistribution of pasture, agricultural lands, and water resources, which occurs in very densely populated areas with people of different ethnical backgrounds and unclear state borders, is viewed as the main factor driving conflicts in the region.

The Isfara River belongs to the Syrdarya river basin and is formed by the confluence of two smaller mountain rivers, the Kishemish and Karavshin, which start from the glaciers of Turkestan ridge and flow to the north where they converge in the vicinity of Vorukh village, and from there flow northwards as the Isfara River. The Isfara River is very important for Batken province of Kyrgyzstan and the downstream agriculture in Sughd province of Tajikistan and Fergana province of Uzbekistan. It is one of the three rivers in Batken province and provides water for more than 40 villages in Batken district of Kyrgyzstan and Isfara district of Tajikistan. Furthermore, the Tortgul reservoir in Kyrgyzstan is fed from the Isfara River and used for the irrigation of other agricultural areas and provides water to Batken, Isfara cities. This clearly indicates the importance of the river for irrigation-based agriculture and water security of the downstream areas. Predominantly monocultural agriculture in the region, reduces soil fertility and relegates water distribution to a political realm with impacts on local economies (Pak et al., 2014; Soliev et al., 2017) and vulnerability to climate change (Ramesh et al., 2013) but also with a great potential for improvement (Dukhovny et al., 2018; Horst et al., 2005; Löw et al., 2017a; Reddy et al., 2013).

Climate change has been identified as one of the main threats to the agricultural economy in Central Asia in the near future. Even though our study shows that residents in the Isfara River catchment have different opinions on the long-term average of water discharge, these same people have noticed a decrease in winter precipitation and size of glaciers, which are the main sources of water for the Isfara River. Numerous older and recent studies have shown direct connection between climate change, glaciation and availability of irrigation water (Aizen et al., 1995; Gosling et al., 2011; Hagg et al., 2013; Kogutenko et al., 2019; Konovalov, 1985; Oberhänsli et al., 2011; Sorg et al., 2012; Xu and Liu, 2014; Zuo et al., 2015) and its impact on the downstream cropping systems (Conrad et al., 2016; Siegfried et al., 2012). Climate change is anticipated to increase temperature and the seasonal redistribution of precipitation in Central Asia (Hijioka et al., 2014). This will have an impact on natural resources including pasture vegetation communities (agricultural and garden varieties) as well as irrigation water availability during the vegetation season (Hoegh-Guldberg et al., 2018). The local impacts of climate change are also anticipated as a possible trigger of pests and diseases for fruit trees, which contribute to the bulk of agricultural production in the area (NatStatCom, 2018a).

This paper brings together existing knowledge on climate change, glaciation, and the impact of climate change on runoff, as well as our research on the impact of runoff and climatic factors on vegetation resources with implications for water management in the Isfara River basin. People's perception of the availability of natural resources and the connection between natural resources and climate change impacts, as well as local understanding of the reasons for these changes are also important and need to be informed by instrumental assessment and modelling of changing climatic and natural factors. Therefore, the format of this publication is a combination of review and research papers. The research consists of four thematic parts: a review of existing knowledge around natural resources and climate change-related topics; analysis of historical climatic and Isfara runoff data; an analysis of modern climatic, runoff and remote sensing data; and a social survey on the perception of climate change and its impact on natural resources.

RESEARCH AREA

The Isfara River is formed by the confluence of the Kishemish and Karavshin rivers, which both have their source in the Turkestan mountain range (Figure 1). The main water source for these rivers are snow fields and glaciers (Adyshev et al., 1987). The Kishemish and Karavshin rivers start from the glaciers of the Turkestan range in the Batken province of Kyrgyzstan, then, after they confluence they become the Isfara River, which flows through the Tajik exclave Vorukh, further to the Sughd province of northern Tajikistan, and then onto the Fergana province in Uzbekistan, where it joins the Big Fergana Channel, which flows to the Kairakkum water reservoir in Tajikistan. The area upstream of Ak-Sai village is the area of water accumulation, and the area below that is the area of water consumption. This river belongs to a greater basin of Syrdarya river, which together with Amudarya are the two largest rivers in Central Asia, and which finally flow into the Aral Sea. The Kishemish tributary is fed by glacial melt from the Kishemish glacier and several snow-fed tributaries, while the Karavshin is formed by many small rivers coming from Shurovskogo, Minteke, Kara-Tur, Tamyngen, Jaupaia, Ak-Suu, Asan-Usim, Dukenek, Ak-Tyubek, and several small unnamed glaciers. The amount of water in these rivers and tributaries depends considerably on the elevation of the water catchment. Dissolved minerals in water of the Isfara River reach 300-500 mg/l, mainly consisting of bicarbonates (HCO_3^{1-}), sulfates (SO_4^{2-}), calcium (Ca^{2+}), and magnesium (Mg^{2+}) (Adyshev et al., 1987).

The research area includes the Tortgul water reservoir, which is supplied by the Isfara River through a constructed channel. The reservoir was opened in 1971 and has a projected volume of 90 million m^3 and a surface area of 6.6 km^2. The reservoir provides water to 9000 hectares of agricultural lands around the city of Batken and Isfara. The area does not have any natural lakes.

The lower reaches of the Isfara River basin have artesian waters of intermittent and continuous distribution to the north from Oktyabr and Ak-Tatyr villages (Adyshev et al., 1987). Ground water in the entire area sits mainly in Paleozoic and Proterozoic sedimentary and metamorphic rocks. The geological formations mainly include carbon systems with intrusions of Silurian, Devonian and some Quaternary systems. The primary rocks include shale, sandstone, limestone and conglomerate. Seismically the area is not very active, with the mean earthquake depth at 20-40 km and the highest magnitude reaching 5-7, which is expected to repeat every 8 years. The relief types include highland denudational in Paleozoic and Precambrian rocks in the upper reaches of Isfara tributaries, then midland erosional in Prepaleozoic and Paleozoic rocks, lowland erosional in foothills on Prepaleozoic and Paleozoic rocks, large piedmont hill ranges on Mesozoic rocks, and steep alluvial-proluvial piedmont loops (Adyshev et al., 1987).

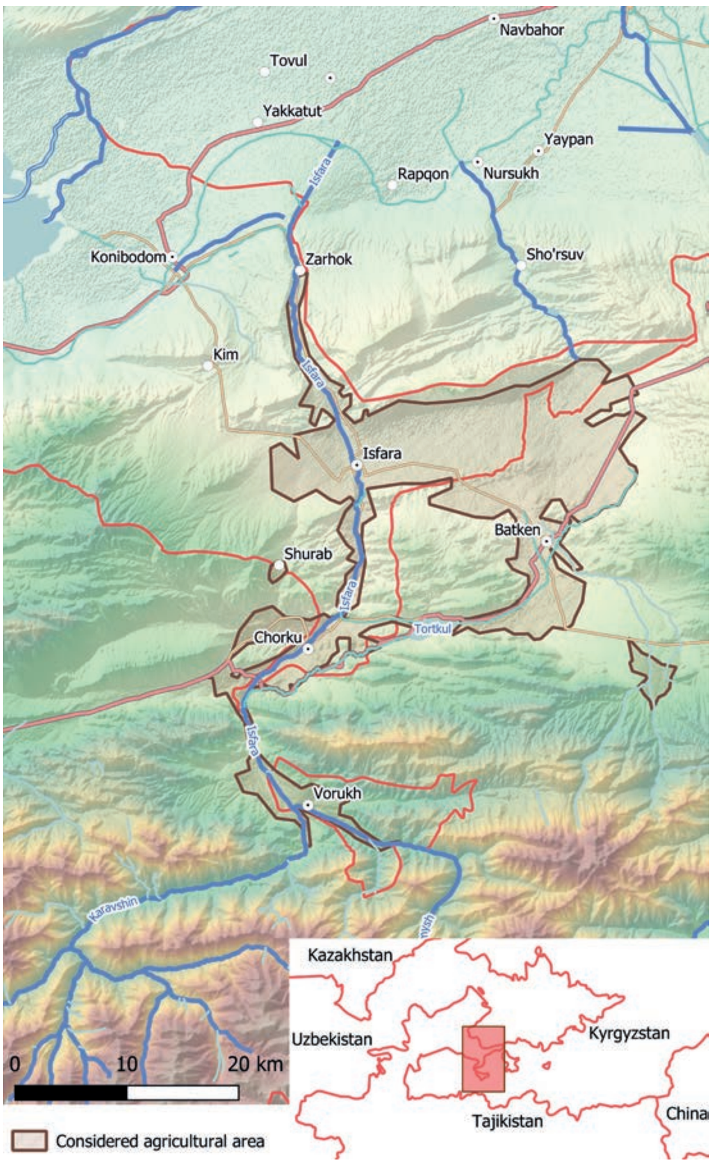

Figure 1. Research area.

Mean temperature in January ranges from -4°C in the lower basin to -8°C in the higher part of the Isfara basin, with predominantly easterly winds of up to 2 m s^{-1}. The mean temperature in July ranges from 4°C in the higher part of the basin to 24°C in the lower part of the basin, and the easterly and westerly winds are equally frequent with a speed of 2 m s^{-1}. The winds in the region have mainly longitudinal directions due to orographic influences of the Alai and Turkestan ridges. The mean air temperature in spring rises above 0°C on average after May in the upper reaches of the river, and before March in the lower parts of the basin. The mean air temperature drops below 0°C in the upper course of the Isfara River before October and after December in the lower part of the basin. On average, the latest spring frosts occur in June in the upper reaches of the basin and in April in the lower plains. The first autumn frosts are in October in the upper parts of the basin and in November in the lower part of the basin. The topsoil temperature ranges from 4°C in the upper part of the basin to 15°C in the lower plains in April and from 8°C in the upper reaches to 30°C in the lower reaches in July. The relative air humidity ranges from 40% in the upper basin to 50% in the lower part in January, and from 40% in the upper basin to 25% in the lower basin in July. The annual amount of precipitation in the upper reaches of the basin is 800 mm per annum, and below 200 mm per annum in the lower reaches of the basin. Most of precipitation falls in spring and there is an obvious positive vertical gradient of precipitation which increases with elevation. The number of days with precipitation greater than 1 mm per annum ranges from 70 in the upper reaches to 40 in the lower plains. The daily precipitation maximum ranges from 60 mm in the upper basin to 40 mm in the lower basin (Adyshev et al., 1987).

Figure 2. Isfara River. The photo was taken near Ak-Sai village in late February 2019 during low flow conditions. Crop fields and orchards are in the background without any snow. Photo: Maksim Kulikov.

The mean annual evapotranspiration ranges from 400 mm in the upper reaches of the basin to 1400 mm in the lower plains. The ratio of precipitation to evapotranspiration ranges from 0.7 in the upper reaches of the basin to 0.3 in the lower reaches of the river. The number of days with snow cover ranges from 200 in the higher part of the basin to 50 in the lower part of the basin with the maximum thickness from 40 cm in the upper part to less than 10 cm in the lower part. The period of steady snow cover ranges from November until April in the higher part of the basin and from December to February in the lower part of the basin. The climate in the upper reaches of the Isfara River basin, including Vorukh exclave, provides sufficient moisture and the area is considered suitable for agriculture, whereas the areas below Vorukh have a dry steppe climate based on the total annual precipitation and mean annual temperature. The winters in the area are mild and not frosty; the summers are hot and clear. In general, the weather is rarely cloudy. Most precipitation is concentrated in March, April, and May. The snow line is at 3800 m a.s.l. The area around Vorukh is slightly prone to avalanches, experiencing 1 avalanche per 10 years of a volume less than 10 000 m^3. The areas around and above Vorukh are prone to rainfall-initiated debris flows, which occur on average once per year, and the area below Vorukh is the area of debris accumulation in channels.

The soils in the upper reaches of the Isfara River are represented by *Leptosols Mollic* and *Leptosols Umbric*. Particularly thick *mollic* or *umbric* horizons in the area of *Juniperus spp.* shrubs extend to the south of the Vorukh exclave. Mountain meadows often have *Umbrisols*, and the agricultural areas in Vorukh mostly consist of *Cambisols* and *Leptosols*. The lower plains of the basin include different variations of *Calcisols* with *Anthrosols* due to a long history of cultivation in this area, with some intrusions of *Cambisols*. The soils suffer mainly from water erosion, but also from wind erosion along the valley bottoms and from water erosion on pastures exacerbated by livestock trampling. In highland pastures, about 40%-50% of the soil profile has been lost (*Leptosols*) due to erosion; on agricultural lands on foothills around Vorukh about 40% (*Cambisols* and *Leptosols*), and on submontane plains about 30%-40% (*Calcisols* and *Anthrosols*). The soils are nitrogen deficient (<6 mg/100 g of soil) and need nitrogen fertilizers for agriculture. About half of the area is also phosphorus deficient (P_2O_2 <1.5 mg/100 g of soil) requiring fertilizer for agricultural production, while the other half has average to high content (P_2O_2 2-5 mg/100 g of soil) and an average content of potassium (K_2O 20-40 mg/100 g of soil). In general, the agricultural and pasture soils have average to good productivity. The agricultural soils do not require any special amelioration measures apart from standard plowing. The pastures require proper grazing rotations and monitoring of grass species, the highland pastures should preferably be used only in summer, while midland pastures can be used in spring and autumn as well (Adyshev et al., 1987; IUSS Working Group WRB, 2014; Mamytov and Ashirakhmanov, 1988).

The plant communities in the highest sub-nival belt (3500 – 4000 m a.s.l.) include petrophilic species with *Sibbaldia tenrandra, Smelowskia calycina, Ajania tibetica, Potentilla biflora, Saxifraga oppositifolia, Chorispora macropoda, Draba fladnizensis, Lagotis decumbens, Paraquilegia caespitosa,* and *Pyrethrum leontopodium*. Below that belt the pasture areas (2000 – 3500 m a.s.l.) are represented by *Phlomis oreophila*. *Carex stenocarpa. Ranunculus alberti. Aquilegia karelinii, Poa angustifolia, P. bulbosa, Festuca alatavica, Pachypleurum gayoides, Polygonum viviparum,* and *Kobresia stenocarpa*. Large thickets of *Juniperus turkestanica, Rosa platyacantha, R. fedtschenkoana, Lonicera microphylla, Cotoneaster oliganthus, Spiraea hypericifolia, Amygdalus spinosissima, Berberis integerrima, Betonica foliosa, Nepeta pannonica,* and *Prangos pabularia* shrubs cover the area to the south of Vorukh. Some plant communities consist of *Artemisia prolixa, Elytrigia trichophora, Bromus danthoniae, B. tectorum, Rochelia leiocarpa* with shrubs of *Rosa kokanica, Spiraea hypericifolia, Cerasus tianschanica.* The foothills and submontane plains (1300 – 2000 m a.s.l.) are actively used for agriculture, however the original plant communities consist of sparse dry steppe species, including *Clima-*

coptera brachiata, Salsola lanata, Camphorosma lessingii, Suaeda arcuata, Filago arvensis, Chondrilla lejosperma, Jurinea winkleri, Bromus tectorum, Boissiera squarrosa, and *Strogisella africana.* Desert species communities consist of *Artemisia subsalsa, Salsola australis, Kochia prostrata, Halogeton glomeratus, Girgensohnia oppositiflora, Helianthemum songaricum, Convolvulus tragacanthoides.* Other species include: *Artemisia eremophila, Cousinia microcarpa, Delphinium semibarbatum, Eremurus sogdianus, Taeniatherum crinitum, Atraphaxis pyrifolia* (Adyshev et al., 1987; Lazkov and Sultanova, 2011; Vykhodtsev, 1966, 1956).

Figure 3. Isfara River. The photo was taken near Ak-Sai village in September 2019. The orchards can be seen in the background and the river itself in the foreground – the runoff in September is much greater than that in February (Figure 2). Photo: Maksim Kulikov.

The research area belongs to Turkestan district of the Turkestan-Alai geobotanical province. The area is divided between two subdistricts: the upper mountain part belongs to the juniper-shrub-meadow subregion and the lower plain part belongs to the desert-steppe subregion. Dominating species that define the landscape include: *Artemisia namanganica, A. prolixa, Krascheninnikovia ceratoides, Salsola orientalis, Girgensohnia diptera, Stipa caucasica, Elytrigia trichophora, Festuca sulcata, Inula macrophylla, Juniperus semiglobosa, J. seravschanica, Stipa trichoides, Cousinia pseudoarctium, Onobrychis echidna, Poa relaxa, Agrostis canina, Kobresia humilis, Festuca alaica, Oxytropis immersa, Potentilla flabeliata* (Adyshev et al., 1987; Lazkov and Sultanova, 2011; Vykhodtsev, 1966).

Fauna of the area is rich in species. Reptiles include *Asymblepharus alaicus* and *Gloydius halys.* Species of birds include *Aquila chrysaetos, Gypaetus barbatus, Accipiter brevipes, Accipiter* *nisus, Falco tinnunculus, Asio otus, Streptopelia turtur, Streptopelia orientalis, Columba oenas, Columba palumbus, Cuculus canorus, Lanius collurio, Anthus trivialis, Turdus viscivorus, Turdus merula, Myophonus caeruleus, Monticola saxatilis, Monticola solitarius, Phoenicurus erythronotus, Phoenicurus ochruros, Phoenicurus caeruleocephalus, Sylvia nisoria, Sylvia communis, Luscinia svecica, Phylloscopus trochiloides, Phylloscopus inornatus, Phylloscopus griseolus, Locustella naevia, Acrocephalus dumetorum, Parus rufonuchalis, Parus montanus, Parus major, Troglodytes troglodytes, Regulus regulus, Leptopoecile sophiae, Carduelis caniceps, Carduelis chloris, Serinus pusillus, Carpodacus erythrinus, Carpodacus grandis, Mycerobas carnipes, Corvus corone, Pica pica, Lepus tolai, Ochotona rutile, Marmota baibacina, Dryomys nitedula, Sicista tianshanica, Mus musculus, Apodemus uralensis, Microtus gregalis, Ursus arctos, Canis lupus, Vulpes vulpes, Meles meles, Martes foina, Mustela erminea, Mustela nivalis, Lynx lynx, Sus scrofa,* and *Capreolus pygargus* (Adyshev et al., 1987).

The landscape at the source of the river is represented by highland tundras at elevations > 3000 m a.s.l. They comprise rugged terrain with steep slopes with rocky and stony ridges and young moraines with skeletal soils (*Leptosols*) and patches of sparse cryophilic vegetation. Below the tundra belt lie juniper forests and highland meadows on steep rocks and hilly highlands between 2000 and 3000 m a.s.l. These areas feature *Umbrisols* and *Cambisols*, juniper forests and woodlands, meadows, and shrubs. At elevations of 1500 – 2000 m a.s.l. the landscape is dominated by steppe and semi-deserts on steep slopes and on foothills with *Calcisols* and feather grass, sagebrush, fescue and shrubs as the dominate vegetation. The areas at 1000 – 1500 m a.s.l. are occupied by semi-deserts on alluvial deposits with gentle, rolling slopes, which are used in agricultural production.

GLACIATION AND RUNOFF IN CENTRAL ASIA

Glaciers play an important role in freshwater supply in the region, and glacial runoff is particularly important for the Isfara River during the summer months. In the region, the precipitation maximum occurs during spring and falls mostly in mountains, glaciers accumulate the moisture and release it in the hottest season, when it is in high demand from agriculture (Sorg et al., 2012). Glacier runoff comprises only around 5% of the water in the rivers of the Syrdarya basin (Glazyrin, 2015; Sorg et al., 2012), and around 15% of all runoff in Kyrgyzstan is derived from glaciers, although this can increase up to 3 times during the melting season (Konovalov, 1985; Konovalov and Shchetinnicov, 1994). Nonetheless, glacial runoff still provides a significant contribution to summer discharge (Hagg et al., 2007, 2006), when water is the most demanded for irrigation. Aizen et al. (1995) indicate that on average 15-20% of the water in Tian Shan rivers originates from glaciers, and can reach 35% in dry years, however the main source of water is melting seasonal snow cover and precipitation in the warm season. The decrease in Tian Shan glaciation has been occurring since the Little Ice Age (Solomina et al., 2004). Seasonally delayed water contribution of glaciers due to summer melting is higher in arid areas than in lowlands with monsoon climates (Kaser et al., 2010) making the glaciers important sources of water discharge during summers in the region. However, global assessments indicate runoff increase in the short term due to increased ablation and decreases of 10-20% in the long term (Kundzewicz et al., 2008).

More than 90% (567million people) of the world's population that is at risk due to climate change-driven glacier runoff change live in Asia (Schaner et al., 2012). Immerzeel et al. (2010)

identified a general decline in Asian glacier mass based on modelling glacial and snow-fed rivers (Indus, Ganges, Brahmaputra, Yangtze and Yellow river), however the uncertainty of these results is substantial, even evaluated by the authors themselves. The authors suggest that water discharge will decrease due to climate change in 2046-2065. From this, based on the irrigation requirements, crop yield, human population and energy consumption, the authors conclude that after 2065 only 4.5% of the local population living in this area will be food secure, and that human communities living in the basins of these rivers will be threatened due to reduced water availability. They further suggest that Asia's water sources are threatened with climate change, however its effect is different among basins and cannot be generalized (Hijioka et al., 2014). The decrease of glaciers and snowfields can result in decreased water discharge in glacier-fed and snow-fed rivers, however increased spring rainfalls in upstream areas of rain-fed rivers can provide more water in dry seasons if water storage infrastructure is available (IPCC WGII, 2014).

Urumqi Glacier No. 1 is one of the reference glaciers in Asia with the longest history of observations and records in China. Between 1962 - 2009 the length of this glacier decreased by 9.7% and its surface area shrank by 15.6% (Li et al., 2014; Xu et al., 2018). This is an important glacier in the region and is located at the head of the Urumqi river. The total area of glaciers in the Qilian mountains in western China reduced by 21.7% over the past 50 years (Wang et al., 2011). Around 10% of river water is provided by glacier meltwater, which stabilized and regulates seasonal discharge (Li et al., 2014).

Similar patterns of glacial retreat were identified for the northern Tian Shan glaciers as well (Bolch, 2015, 2007; Farinotti et al., 2015; Goerlich et al., 2017; Narama et al., 2006; Osmonov et al., 2013). Bolch (2007) investigated the surface area of glaciers in the northern Tian Shan using Landsat images from 1999 and compared the areas to that in the Soviet Glacier Inventory (1966-1983), investigating also the climatic conditions at the glaciers (temperature, precipitation, solar radiation). The author identified an increase in temperature in the northern Tian Shan two times greater (comprising 2°C per 100 years in 1950-2000) than the global average in northern Tian Shan in 1950-2000, due mainly to temperature increases in autumn and winter, whereas precipitation increases were small without any obvious trend. The average extent of glacial decrease over 1955-1999 was 32% (Bolch, 2007), with proximity to Issyk-Kul lake having a temperature stabilizing effect and the decrease rates were not so high. At the same time, Chen et al. (2014) described the general increase of freezing level height (FLH) in the Tian Shan. The summer runoff of Tian Shan rivers has increased significantly due to the rising of the FLH, which is one of the factors, together with topography and human impact, contributing to increased glacial melting (Chen et al., 2014). FLH was found to have a significant connection with summer runoff in the Tian Shan, however the strength of runoff response to increased FLH was different between north-facing and south-facing slopes (Chen et al., 2014). The rivers on southern slopes give a greater surplus in runoff than rivers on northern slopes in response to FLH increase, which itself is controlled by the runoff source components (Chen et al., 2014).

Based on analysis of data covering the period 2003-2009, Gardner et al. (2013) identified the elevation of Central Tian Shan glaciers to be decreasing by -0.58 ± 0.21 m a^{-1} (meter per annum) and the elevation of glaciers in the Alay and Pamir ranges by for -0.13 ± 0.22 m a^{-1} based on 2003-2009 data analysis. A different study by Pieczonka and Bolch, (2015) identified glacial mass loss of -0.35 ± 0.34 m w.e. a^{-1} (meter water equivalent per annum) for the entire Central

Tian Shan region based on a 1975-1999 time-series, which corresponds to the global average. The Glacier No. 354 in the Central Tian Shan (Ak-Shyirak range) indicates a negative mass balance of -0.43 m w.e. a^{-1} over 2003-2014 (Kronenberg et al., 2016) and -0.79±0.25 m w.e. a^{-1} over 1975-1999 (Pieczonka and Bolch, 2015), which indicated a decrease of the rate of mass loss. Overall, the Ak-Shyirak range glaciers lost -0.4±0.2 m w.e. a^{-1} between 1964 and 1973 (Goerlich et al., 2017). The average mass balance of Batysh Sook glacier was found to be -0.39±0.26 m w.e. a^{-1} for the period of 2003-2015 (Kenzhebaev et al., 2017). Sokoluk catchment glaciers lost a total of 28% of glaciated area over 1963-2000 (Niederer et al., 2008). All the glaciers in the Central Tian Shan show consecutive mass loss over 2004-2014, except for the year 2009, when they appear to have either gained mass or loss less mass than in other years (Kenzhebaev et al., 2017; Kronenberg et al., 2016), which can be explained by the climatic conditions of that year.

Mass balance time-series for the Abramov glacier, a reference glacier approx. 80 km to the east of our study site, and belonging to Kyzyl-Suu catchment (part of the Amudarya basin), includes the period from 1968 to 1998, with measurements recommencing only after 2011 (Barandun et al., 2015; Hoelzle et al., 2017). The old and new data reanalysis combining both datasets and modelling the missing data, indicate a steady decrease of the mass of the glacier from the year 1970 until 2015 (Barandun et al., 2015), with an approx. 12% loss of glacial area over 1960-2008 (Hijioka et al., 2014), which comprised -0.57 m w.e. a^{-1} (Sorg et al., 2012). Barandun et al. (2015) also found that the glacier is very sensitive to temperature (R^2=0.67), with its sensitivity estimated at -0.47 m w.e. $a^{-1}C^{-1}$ (Rasmussen, 2013), which would indicate high temperature sensitivity of Central Asian glaciers.

The mass balance indicates mass increase at higher elevations in the Tian Shan and more ablation at lower elevations (Barandun et al., 2015). Similar trends were observed in the Pamir mountains (Glazirin et al., 2002; Khromova et al., 2014, 2006). Similar dynamics were also apparent in other regional glaciers (Hijioka et al., 2014), and is anticipated to continue as mean annual temperatures increase. No significant interannual precipitation trends were identified (Hijioka et al., 2014), however precipitation is expected to change from snowfall to rainstorms due to temperature increases, which may result in a larger number of floods and redistribution of seasonal water discharge (Kure et al., 2013). The glaciers in the inner ranges of the Tian Shan are experiencing less shrinkage than those on the edges, and small and fragmented glaciers are also decreasing faster than larger ones due to greater surface area to mass ratio (Sorg et al., 2012). According to Aizen et al. (2007a) mean annual temperature increase for every 1°C should be compensated by annual precipitation increases of 100 mm to maintain the Tian Shan glacier equilibrium line altitude at the same level. However, the region has experienced temperature increases but no increase in mean annual precipitation (Aizen et al., 2007a, 2006, 1997, 1996; Hijioka et al., 2014). The surface of the Ak-Shyirak and Ala-Archa glaciers decreased by 4.2% and 5.1% during 1943-1977 and by 8.6% and 10.6% during 1977-2003 respectively (Aizen et al., 2007b, 2006).

The seasonal peak runoff times from the Abramov glacier are similar to those in Isfara (Hagg et al., 2007), however in the case of climate change with the current glaciation levels, the water discharge is expected to increase nearly two-fold (Hagg et al., 2007), likely resulting in subsequent glaciation decrease. With decreased glaciation the seasonal peaks of water discharge are projected to shift from July-August to June with a drastic decrease later in the summer season (Hagg et al., 2007). This may lead to a change of the main water source of the Isfara River from glacier to snowmelt and precipitation (Braun and Hagg, 2010), which may result in greater interannual runoff variability and consequently to severe ecological and political impacts. But since glacier only account for about 15% of flow, it is also important to study the snowmelt dynamics, which can be highly variable from year to year.

Tian Shan rivers are fed by a variety of water sources, including glacial melt, snowmelt, precipitation, and different combinations of these. Depending on the water source the discharge can be impacted by different climatic factors, thus different rivers are expected to respond in different ways as the climate continues to change, connectivity of water sources to rivers is also an important factor. Chen et al. (2014) conducted an analysis of Tian Shan rivers in northwest China and identified different patterns of runoff response to climatic factors depending on the primary source of water. The Aksu river runoff is better correlated with precipitation than with temperature (P = 0.41, T = 0.23), whereas the Yarkand river runoff had a higher correlation with temperature (P = -0.147, T = 0.276). Based on this, the rivers can be divided into three categories with regards to climate change sensitivity: those determined by temperature, by precipitation, and both temperature and precipitation (Chen et al., 2014). The authors conclude that in general the runoff has considerably increased in recent years, especially on southern slopes, and only few rivers demonstrated runoff decreases. However, this research did not consider the connectivity of water sources to the river.

Various simulations indicate a redistribution of peak runoff timing from late summer to late spring and early summer with increase of atmospheric CO_2 and consequent decrease of glaciation on the Abramov glacier and in Central Asia in general (Hagg et al., 2007, 2006). Abramov glacier runoff is expected to grow with increased atmospheric CO_2 but then decline and shift to earlier in the season as glaciation decreases (Hagg et al., 2007). Similar behavior is expected for the Isfara River, since the Abramov glacier is very close to the head of the Isfara River glaciers and they experience similar conditions.

CLIMATE CHANGE AND VEGETATION IN CENTRAL ASIA

Over 60% of Kyrgyzstan's population resides in rural areas, where agriculture and animal husbandry based on seasonal livestock transhumance are the main livelihoods (FAO, 2011). Thus, natural resources are vital to the well-being of most people in the country. In this dry region, vegetation, including crops and rangelands, depend on water availability (Kulikov and Schickhoff, 2017) either from direct precipitation, rivers or irrigation systems (Aralova et al., 2018; Gessner et al., 2013; Klein et al., 2012; Propastin et al., 2008a). Mountain rivers, as noted, originate in glaciers and snowfields on mountaintops, and some are also rain-fed. Most precipitation in our study site falls in winter and spring in the form of snow and rain, which are then conserved in glaciers and snowfields to flow as water in the summertime.

Many studies have been devoted to understanding the impact of climatic factors (e.g., temperature and precipitation) on vegetation resources, as well as temporal trends and spatial patterns of climatic factors and vegetation (Aralova et al., 2018; Gessner et al., 2013; Klein et al., 2012; Kulikov and Schickhoff, 2017; Propastin et al., 2008b, 2008a, 2007). However, these studies did not consider river runoff or irrigation systems nor underground water and the soil's capacity to store moisture, factors that also provide water to vegetation and which can have considerable impact on vegetation resources, but which are usually ignored in regression analyses.

Eckert et al. (2015) conducted time series trend analysis of MODIS NDVI data over Mongolia. They employed linear regression to approximate the NDVI (normalized difference vegetation index), temperature and precipitation trends. The authors also classified the area into different vegetation types, noting qualitative changes in vegetation with time. Areas with significant NDVI trends were associated with vegetation type change. The authors suggest that precipitation influenced NDVI as locations with significant precipitation trends (positive and negative) were associated with the areas of significant NDVI trends (positive and negative respectively), while temperature did not show any significant trend. However, there were areas where precipitation and NDVI showed opposite trends (i.e. negative correlation), and this indicates that precipitation can have a negative impact on vegetation.

Inner Asia (the area including east of Central Asia, Mongolia, Altai, Buratia and Northern China) vegetation trends were calculated using a linear trend analysis of AVHRR NDVI time series (Mohammat et al., 2013). Correlation analysis was undertaken between NDVI and precipitation and between NDVI and land surface temperature rasters separately for different seasons. The greatest correlation coefficients between NDVI and temperature were identified in spring. Temperature appeared to be the main promoting and limiting factor for vegetation development in the different regions. The area of Kyrgyzstan showed mostly positive NDVI trends. The authors did not apply seasonal decomposition and cross-correlation analysis to identify the lagged effect of climatic factors on vegetation: this is probably why they failed to identify meaningful correlations between NDVI and precipitation.

Vegetation (NDVI), precipitation and temperature time series trend analysis were conducted by Zhao et al. (2011) over the Xinjiang area in northwest China for 1982-2002. Factor trends were estimated with least square linear approximation of spatially averaged mean values for different bioregions within the study area. The researchers detected a slight increase in NDVI over the entire research area. In general, NDVI trends had a weak negative correlation with temperature trends and significant positive correlation with precipitation, but the coefficient value and significance of the correlations were spatially heterogeneous between the different bioregions. The largest increase in NDVI was registered in the Altai and Tian Shan and was accompanied by significant increase in both temperature and precipitation. The Jungar and Tarim areas also witnessed a significant increase of NDVI. All the biomes analyzed showed NDVI growth, but the largest growth of NDVI was seen in agricultural and forest lands. Analysis between different seasons was undertaken, however the only considerable positive correlation of NDVI and temperature found was with the temperature of the preceding winter, this can be because the authors did not employ cross-correlation analysis. In contrast, NDVI and precipitation showed considerable positive correlation between all the seasons except autumn. This implies that precipitation is the main factor, controlling seasonal variations of vegetation, however, cross-correlation analysis could reveal more patterns.

Another research on NDVI and precipitation time series analysis over Central Asia was conducted by Propastin et al. (2008b). The authors attempted to separate precipitation-driven NDVI trends from human-induced trends to calculate the degree of human impact on environment. To this aim, they estimated NDVI and precipitation trends by conducting regression analysis with NDVI as the response variable and precipitation as predictor per pixel and derived a spatially explicit residual time series. The regression line indicates the precipitation-driven trend and residuals the human-driven trend. Following this, the trend of residuals was estimated using least square linear approximation. Assuming a positive correlation between precipitation and NDVI, the increase of the regression residuals would indicate a decrease of NDVI in response to precipitation. The authors show that most NDVI variability in Central Asia during the period 1982-2000 was conditioned by precipitation. A generally increasing NDVI trend over most of Central Asia can be attributed to a decrease in human activity due to the collapse of the Soviet Union. The authors deem precipitation to be the main controlling factor of NDVI and support this conclusion through the fact that around 75% of the area has a significant relation to precipitation, making this the main vegetation controlling factor of all variables considered.

Another way to look at the vegetation trends is to conduct temporal and spatial averaging by season and vegetation types respectively. Du et al. (2015) conducted trend analysis of NDVI over the Xinjiang region in China using linear regression analysis. The authors divided a NDVI time series into several periods with increasing length and estimated a linear trend for each. They also estimated trends within different seasons by considering them separately over the entire time period. Positive NDVI trends were identified in summer and autumn. Among the vegetation types, forest grassland shrub and forest showed the greatest NDVI increase rates. The areas with positive trends were geographically larger than those with negative trends. The areas with positive trends were also shown to increase over the 30-year study period. Growing season NDVI indicated significant correlations with precipitation and temperature, however the significance of correlations varied depending on the season and vegetation type. A combination of temperature and precipitation conditions were identified as limiting NDVI development.

Gessner et al. (2013) conducted a thorough analysis of Central Asian vegetation response to precipitation anomalies with cross-correlation analysis considering temporal lags and different precipitation accumulation periods for different vegetation classes. The authors used AVHRR NDVI time series for approximation of vegetation changes and GPCC Full data reanalysis as spatially explicit precipitation time series. The results indicated that rain-fed agricultural areas and grasslands are more responsive to precipitation than irrigated agricultural areas. The vegetation response lag for Central Asia varied from one to three months, and the strongest relations were found with accumulated precipitation for two to four months. The study also covered the Isfara catchment area and found that the rainy season is from May through September and the maximum correlation coefficient (considering different lags) between NDVI and precipitation was 0.4-0.6, with 3-months accumulated precipitation delayed for another 3 months.

A more recent and detailed study by Kulikov and Schickhoff (2017) concentrates on the area of Kyrgyzstan, where the authors used seasonal and trend decomposition of MODIS NDVI, land surface temperature and precipitation (GPCC) with further cross-correlation and regression analysis and spatial clustering, based on vegetation and climatic interactions. The Isfara catchment area is less controlled by climatic factors than other areas of Kyrgyzstan, mainly due to the presence of irrigation systems. The area was placed in the same cluster as other agricultural areas, revealing similar vegetation-climate patterns with immediate response of the vegetation seasonal component to temperature, and a 3-4-month delayed response to precipitation.

These studies outline that vegetation is greatly controlled by climatic factors, but that temporal behavior analysis of cropland may reveal different patterns, mainly due to irrigation, which has rarely been considered. A delayed impact of climatic factors on vegetation should also be considered, as should different relations of seasonal and trend components of time series of vegetation and climatic factors. In general, the different vegetation classes indicate around 3 months of delayed reaction to precipitation variations and almost immediate response to temperature variations. However, the impact of irrigation on the development of vegetation has yet to be studied but is urgently needed since much of Central Asian agriculture is dependent on irrigation with river water being of the most important resource contributing to irrigation in the region.

ISFARA RUNOFF AND ITS RESPONSE TO CLIMATIC FACTORS, ANALYSIS OF HISTORICAL DATA

Data and Methods

We used historical Isfara River runoff data (GRDC, 2019) to assess the response of Isfara River runoff to climatic factors such as temperature and precipitation. The dataset represents mean monthly discharge in m^3 s^{-1} covering the period 1933-1991, comprising 59 years of continuous records at Tash-Kurgan station (E70.62°, N40.25°, 1283 m a.s.l.) provided by GRDC (2019). The catchment area covers 1560 km^2. Another dataset of monthly runoff covering the period 1999-2018 was obtained from the Batken RaiVodKhoz (Regional water management department) of the Kyrgyz Republic. The data were not collected between 1991 and 1999 due to difficult economic and political situation in the region.

The climatic data used for this analysis represent monthly precipitation values, collected at Tangivoruh station (E70.55°, N39.85°, 1311 m a.s.l.) for the period 1943-1988 and monthly temperature mean values collected at the same station over 1948-1988 (Williams and Konovalov, 2018). The datasets had several sporadic gaps that were filled with the mean values of the corresponding month of the previous and consequent three years.

All datasets represent a time series with monthly sampling, and which overlap temporarily but start and end at different times. The overlap period spans the timing of the precipitation time series, i.e. 1943-1988. Therefore, the interactions of the different factors (monthly runoff, precipitation, and temperature) have been assessed during 1943-1988, and the trends of separate variables have been assessed based on the individual dataset available.

The time series of each variable (runoff, temperature, precipitation) were decomposed into trend, seasonal, and remainder components with “mstl” (multiple seasonal decomposition) package of R-3.5.3 (R Core Team, 2016), which allows for multiple seasonality and extracts seasonal components with STL (seasonal-trend decomposition based on loess; Cleveland et al., 1990) as implemented in the “forecast” package of R-3.5.3 (R Core Team, 2016). We used this method because the time series are relatively long and multiple seasonality could occur. Then, we used cross-correlation analysis separately for the trend and seasonal components to identify the interrelations between the variables on interannual and seasonal levels.

The cross-correlation analysis used Pearson’s correlation analysis between the contemporary observations of two time series variables. And it also performs correlation analysis using lag shifts, i.e. conducting correlation analysis between observations of one variable coming before (or after) the observations of the second variable to assess for delayed (lagged) relations of the two variables. Such a shift is called a lag and is measured in time units – months in our case. Thus, “1-month lag” would mean that the observations of the first variable precede the observations of the second for 1 month and the correlation analysis is conducted between the lagged observations.

We also conducted a two-sided Welch's unequal variances t-test to compare the runoff mean values of the two datasets (1933-1991 and 1999-2018) per month with a 0.95 confidence interval.

Results

Isfara runoff together with temperature and precipitation show clear seasonality (Figure 4). The runoff in summer is greater than during other seasons, and has greater variability, probably due to amount of snow, as can be seen by the difference between mean runoff values in summer when comparing the periods 1933-1991 and 1999-2018 (Figure 4 a and b). The t-test results indicate that the Isfara River runoff did not change in April, May, June, October or November, while other months indicate statistically significant increase from the 1933-1991 period to the 1999-2018 period mean (Table 1). The runoff growth is attributed to the coldest and hottest seasons, which may be related to annual mean temperature increase (see the section 'Glaciation and runoff in Central Asia') or precipitation increase (see the section 'Vegetation response to abiotic factors in Isfara catchment area'). Unfortunately, temperature and precipitation data are not available for the period 1999-2018 to test this hypothesis. This change could also be attributed to the fact that the data sets come from different sources.

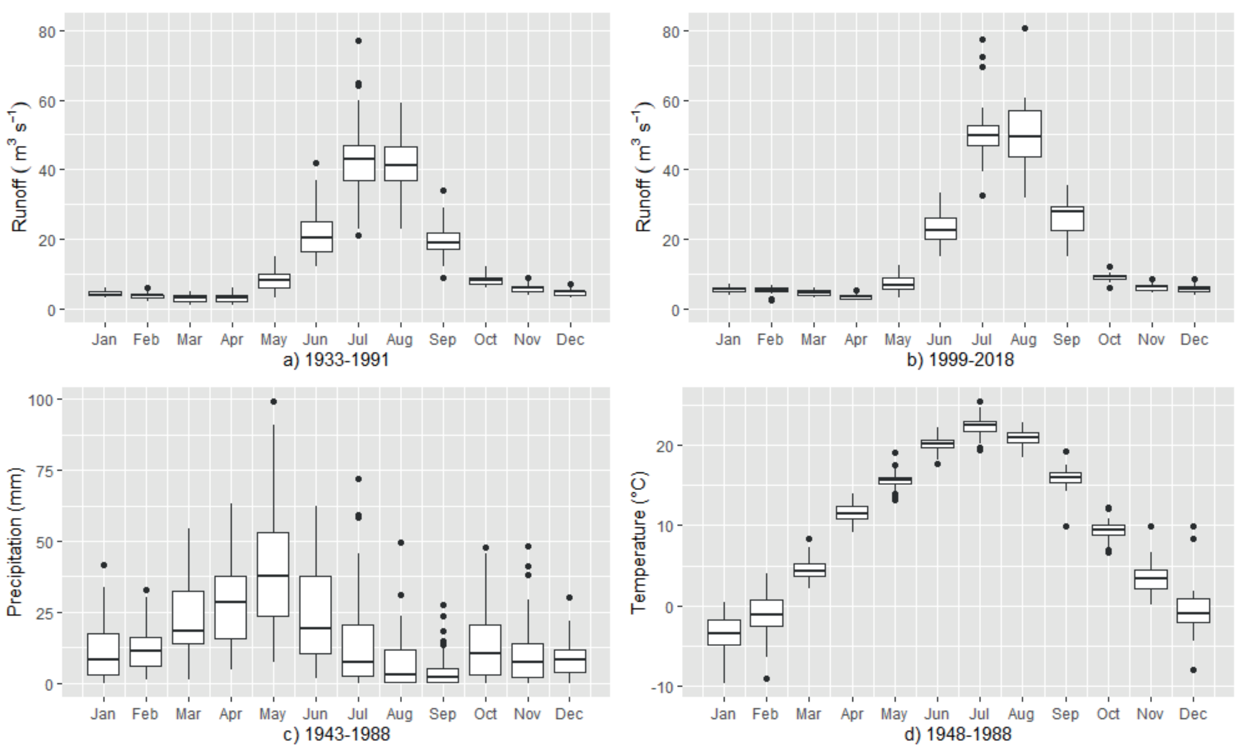

Figure 4. Monthly distribution of the Isfara River runoff, precipitation, and temperature.

The cross-correlation analysis of trend and seasonal components of the variables indicate that seasonal components of runoff and precipitation have a slightly negative correlation at lag0 (-0.23) and a large positive correlation at 3-months lag (0.86), which means that the correlation coefficient of runoff and precipitation 3 months earlier comprises 0.86 (Figure 5 a). This can also be seen by the seasonal runoff peak (cyan color in Figure 5 g), which lags three months behind the seasonal precipitation peak (blue in Figure 5 g). However, the correlation of seasonal components of runoff and temperature are the greatest at lag0 and 1-month lag - 0.790 and 0.793 respectively (Figure 5 c), which means that runoff delayed by 3 months is positively correlated with precipitation and is positively correlated with temperature at the same time. The trend component of runoff also indicates a positive correlation both with temperature and precipitation at lag0. However, the greatest correlation coefficient for precipitation is at 8-months lag (Figure 5 b), when the correlation coefficient is 0.255 between runoff and precipitation eight months earlier.

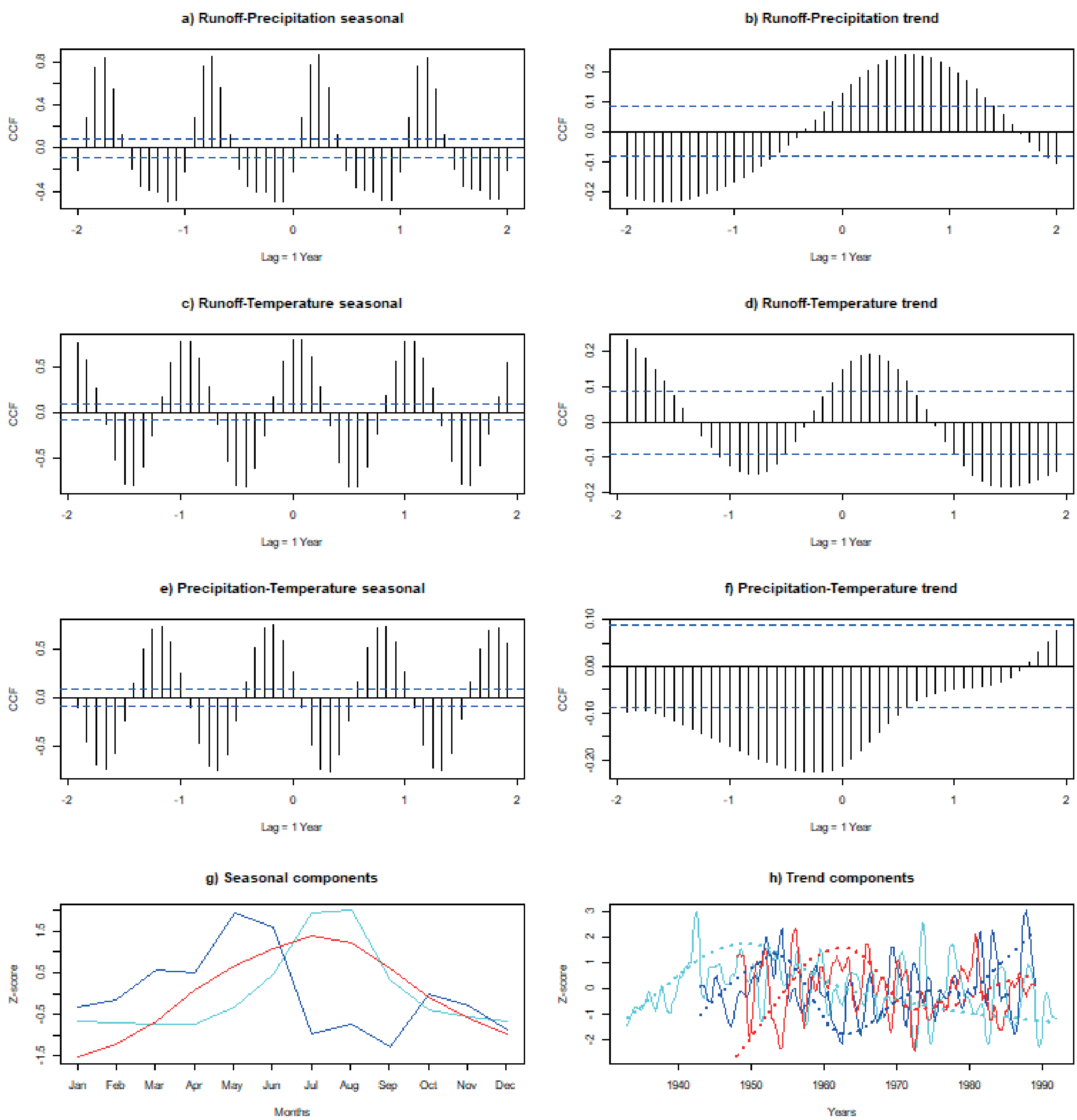

Figure 5. Cross-correlation analysis of trend and seasonal components of historical data (1933-1991) (red - temperature, blue - precipitation, cyan – runoff, horizontal blue dashed line – significance level), dotted bold lines are smoothed trend components of respective variables. Lag on the graph = 1 year, whereas in the text lag = 1 month. The lag k correlation value of x-y is the correlation between x[t+k] and y[t].

The cross-correlation charts of trend and seasonal components indicate that rainfall in April-July is the main source of water of the Isfara River, and that the snowfall in November-February play a secondary role in runoff formation, since the correlation coefficients of seasonal components with 3-months lag are greater than those of the trend components with 8-months lag. This is because part of the snowfall contributes to the formation of glaciers and snowfields, saturate soils, and evaporates due to slow discharge in the ablation period, whereas rainwater can reach the river much faster. Unfortunately, it is not possible to estimate the proportions of precipitation and glacier melt contributing to runoff as no glacier melt data are available.

The trend components of runoff and temperature indicate weak positive correlation at lag0 (0.147) and a stronger correlation coefficient at 3-months lag (0.193) (Figure 5 d). Thus, seasonal components indicate greater correlation coefficients (Figure 5 a, c), which indicates that the runoff is greatly determined by the seasonality of temperature and precipitation, rather than interannual variations in climatic factors. This indicates that the amount of water accumulated in glaciers and snowfields at the head of the Isfara River was enough to provide for stable runoff in the past.

The smoothed trend component of runoff indicates steady growth from 1933 until about 1950, followed by a steady decline from 1950 until 1991 (dotted cyan curve on Figure 5 h), which may contradict our findings in the section ‘Vegetation response to abiotic factors in Isfara catchment area’ (Figure 4 a and b), or could indicate a trend change to positive correlation after 1991 as temperature and precipitation also have positive trends in 1988 (red and blue dotted lines on Figure 5 h) and runoff shows a positive correlation with precipitation and temperature (Figure 5 b and d).

Table 1. Welch’s unequal variances t-test results to compare the monthly means of Isfara runoff of 1933-1991 and that of 1999-2018.

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**
t	-4.98	-5.63	-7.08	-1.35	1.27	-1.08
df	28.16	24.98	37.43	57.51	37.35	44.39
p	2.84e-05	7.34e-06	2.02e-08	0.17	0.21	0.28
	Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
t	-3.12	-3.35	-5.33	-1.98	-1.55	-3.57
df	31.00	25.85	28.96	37.66	35.36	30.94
p	0.003	0.002	1.002e-05	0.054	0.12	0.001

Seasonal components of precipitation and temperature have a weak positive correlation at lag0. Interpretation of cross-correlation of seasonal components of temperature and precipitation does not have much practical sense as these parameters are conditioned by annual cycles and not closely interrelated, so their cross-correlation chart is provided for reference only (Figure 5 e). However, their trend components indicate the greatest negative correlation coefficient of -0.226 at -3-months lag, i.e. precipitation preceding temperature for three months. This indicates that interannually the years with greater precipitation will be cooler on average.

VEGETATION RESPONSE TO ABIOTIC FACTORS IN ISFARA CATCHMENT AREA

Data and methods

Data

We used the time series of LANDSAT8 images from April 2013 through December 2018 for calculating a NDVI (normalized difference vegetation index) time series of that period. NDVI is widely used as a remotely sensed proxy for vegetation abundance. It is based on the difference of vegetation reflectance in red and near infrared spectra and calculated according to the following equation:

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{1}$$

where:

NDVI – normalized difference vegetation index

NIR – reflectance in near infrared spectra (LANDSAT8 band 5)

RED – reflectance in visible red spectra (LANDSAT8 band 4)

We used images with less than 40% cloud cover, and scarce clouds were masked with the QA band of LANDSAT8. The remaining cloud holes were closed with the "Close Gaps with Stepwise Resampling" module of SAGA GIS (Conrad et al., 2015). LANDSAT8 bands spatial resolution was increased to 15 m. using the panchromatic channel and "Color Normalized Spectral Sharpening" module of SAGA GIS (Conrad et al., 2015). The acquired irregular NDVI time series were temporarily resampled to monthly frequency with Pandas (Mckinney and Pydata Development Team, 2019), and the "resample" method using mean values to forward fill the missing data in Python (Python Software Foundation, 2016). Following this, a regular monthly spatially explicit NDVI time series from April 2013 through December 2018 was obtained.

Isfara River monthly water runoff (RNF) data were obtained for January 1999 through December 2018 from Batken RaiVodKhoz (Regional Water Management Department) of the Kyrgyz Republic. As the data were of monthly frequency, they did not undergo any resampling.

The precipitation data (PRC) were obtained from the weather station in the city of Batken through the Kyrgyz Hydrometeorological service. These data were also of monthly frequency from January 2013 through December 2018 and did not need any resampling. As the data were obtained from a single weather station, they were not spatially explicit, however we assume they can be applied to the entire survey area.

Land surface temperature (LST) values were obtained from the MOD11C3 v006 product, which is monthly MODIS/Terra land surface temperature/emissivity at 0.05° spatial resolution from January 2013 through December 2018. All spatial data were resampled to the WGS84/UTM42N projected coordinate system with 15 m spatial resolution using b-spline interpolation in SAGA GIS (Conrad et al., 2015) to accommodate the NDVI resolution.

Regression analysis of spatially explicit data

We conducted linear trend analysis of NDVI over time with the "Polynomial Trend from Grids" module of SAGA GIS (Conrad et al., 2015). This analysis is a least squares linear approximation of NDVI trends per pixel. The second polynomial coefficient of the regression equations would indicate the direction and magnitude of NDVI development trend.

We also conducted temporal regression analysis predicting NDVI with precipitation and Isfara runoff without any temporal shifts (at lag0), as well as with temporal lags of up to 3 months (precipitation and runoff preceding NDVI). The respective R^2 values for each pixel were then plotted to assess the spatial distribution of precipitation and river runoff immediate and delayed control over vegetation resources. Both regression and trend analysis were conducted using the "Polynomial Trend from Grids" module of SAGA GIS (Conrad et al., 2015).

Multiple linear regression analysis of temporal data

We derived spatially averaged time series of NDVI of agricultural areas (NDVIagr) (Figure 1) and LST (land surface temperature), which yielded one-dimensional time series representing the mean NDVI of agricultural areas and land surface temperature. Precipitation data were already one-dimensional.

We conducted cross-correlation analysis between NDVIagr, and LST, precipitation, runoff to identify the lags of the maximum correlation coefficient to use them in the multiple regression analysis. After that we shifted the data time series accordingly to meet the maximum correlation lags and fit the multiple regression with NDVIagr as a dependent variable and LST, precipitation, and runoff as predictors. In other words, we conducted a multiple regression analysis to predict NDVIagr with LST, PRC and RNF at lags of their maximal correlation. This was done to identify the extent to which the NDVI of agricultural areas is defined by climatic factors and Isfara runoff.

Trend and seasonal decomposition

The spatially averaged values of NDVI of agricultural areas (Figure 1), precipitation, LST and Isfara runoff were decomposed to seasonal and trend components using "stl" (Seasonal decomposition of time series by Loess) (Ripley, 2013) function of R-3.5.3 (R Core Team, 2016). The resulting seasonal and trend components of the variables were subjected to cross-correlation analysis to identify their interrelation in the temporal domain.

Results

Polynomial trends

The linear trend analysis indicates both positive and negative NDVI trends in agricultural areas (Figure 6). The areas with negative trends are located around Batken city and the cities of Isfara and Chorku. The remote fields indicate a positive trend. The trend variations are connected to different field patches, i.e. the variations are observed between the patches, whereas the areas within patches show spatially homogenous trends. This indicates that vegetation trends are greatly dependent on cropland management and differ based on crop types, irrigation, use of fertilizers, and other agricultural techniques.

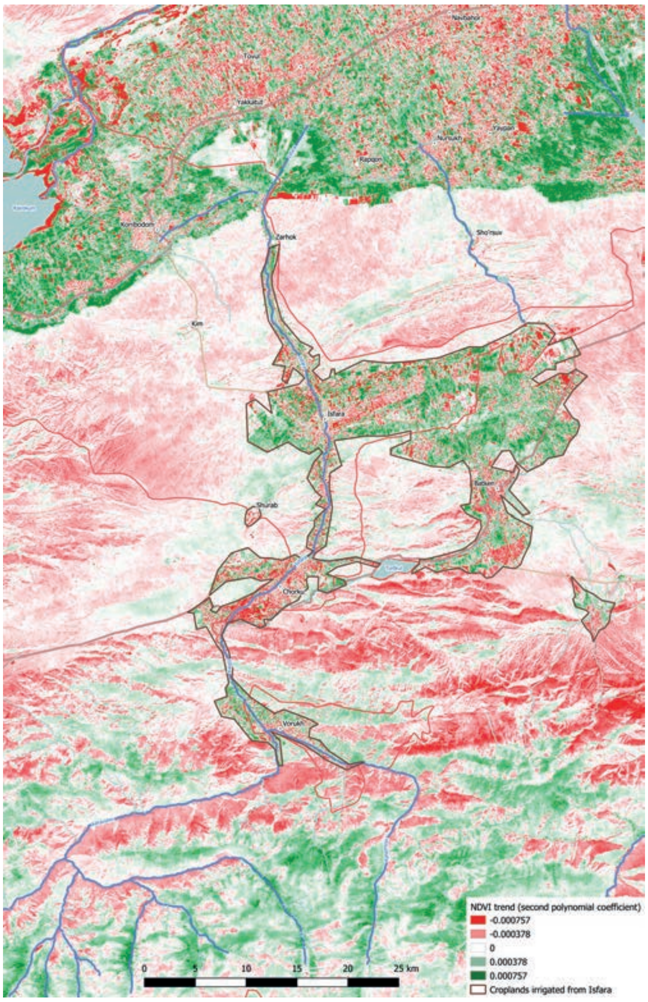

Figure 6. Polynomial trend of NDVI (2013-2018).

The lowland plains around the croplands show predominately negative NDVI trends (Figure 6). This means that vegetation mass in these areas is declining, something that could be attributed to overgrazing or the impacts of climate change. However, NDVI on rangelands in highlands areas (south at Figure 6) shows a positive trend. This, in turn, indicates an increase of vegetation mass in the highlands at the source of the Isfara River, possibly because of lower grazing pressure due to inaccessibility or because of climate change impacts and a redistribution of precipitation in the area.

Coefficients of determination of NDVI by runoff, precipitation, and temperature

The temporal regression analysis of spatially explicit NDVI data as a response variable and Isfara River water runoff as a predictor indicate its greater predictive capacity (R^2) for agricultural areas, reaching 0.8 at lag0 compared to surrounding lowland rangelands (0.2) (Figure 7 a). However, agricultural areas have great spatial heterogeneity of R^2 due to human activity and some of them show values of 0.15: these areas are close to settlements, which could indicate that they are used for purposes other than agriculture, e.g. construction.

The agricultural areas at the lower reaches of the Isfara River in Uzbekistan also have high R^2 values at lag0 (northern part Figure 7 a), but they also have high coefficients of determination at 1-month lag (northern part Figure 7 b), this is because these areas have more diversity in water sources (Syrdarya and Big Fergana Channel) than the Isfara River, as in our study case.

The mountain rangelands also show high R^2 values at lag0 ~ 0.8 (southern part Figure 7 a). This is the location of the Isfara River catchment, so water gathers in these areas before it arrives in Isfara and flows further downstream. Since this occurs almost simultaneously, natural vegetation in this area responses to runoff together with crops. The NDVI coefficient of determination by runoff is almost 0 at 2 and 3-months lag (Figure 7 c and d), and is very low in agricultural areas at 1-month lag (Figure 7 b), suggesting that runoff has almost no delayed impact on croplands and rangelands. The desert areas outside the croplands show almost no reaction to runoff since these areas are not irrigated and have very sparse vegetation. The croplands in the north of the study site are more affected by the runoff at 1-month lag, again due to greater water source diversity, in contrast to the croplands in the center of the study site, which are more influenced by the runoff of the Isfara River at no lag (Figure 7 m).

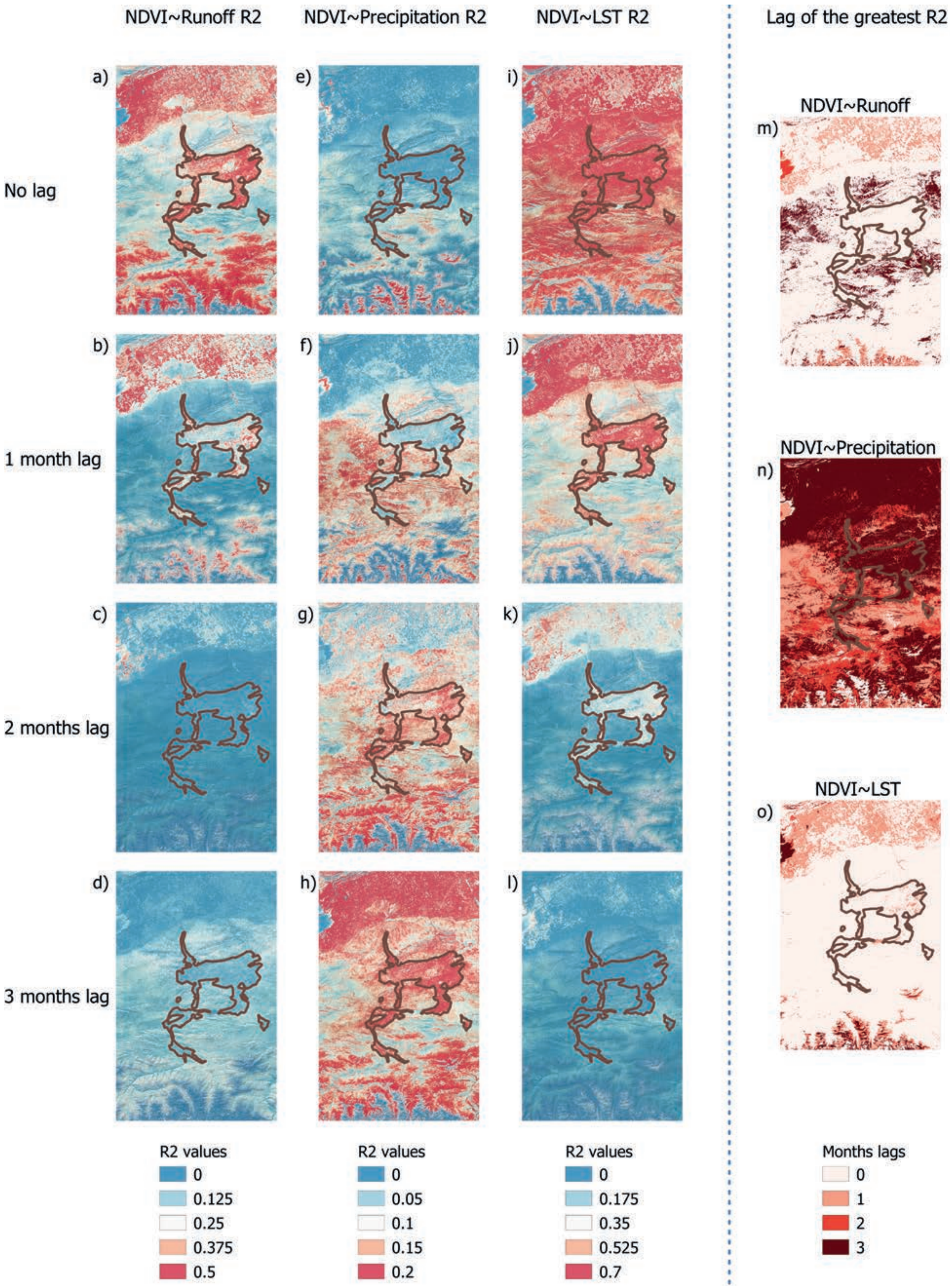

**Figure 7. Coefficient of determination (R2) at different lags.
Brown border outlines agricultural areas.**

Precipitation has almost no direct impact on vegetation as indicated by the low R^2 of NDVI predicted by precipitation at lag0 (~0.02) in agricultural areas and reaches only 0.15 in some rangelands (Figure 7 e). In contrast, rangelands and deserts have much higher R^2 values (<0.25) at 1-month lag, but cropland R^2 is still low (Figure 7 f). This indicates that rangelands and deserts get water mainly from precipitation and there is about a 1-month delayed impact on vegetation (Figure 7 f). The coefficient of determination values exhibit a more uniform spatial distribution at 2-months lag, but with a greater variability of values (0.02-0.27) (Figure 7 g). This is most likely due to the mixed effect of precipitation and runoff, which are cross-correlated at 2-month and 3-month lags (Figure 5 a), i.e. precipitation maximum in May and June provide for runoff peaks two to three months later. This means precipitation indirectly impacts vegetation through runoff. The agricultural areas in the north of the study site have more spatial variability in R^2 (Figure 7 g), which also indicates that these areas have more variability in water sources. The coefficient of NDVI determination by precipitation is the highest at 3-months lag (Figure 7 h), reaching 0.35 especially for croplands, which is also attributed to a mixed indirect effect of precipitation followed by consequent runoff. The mountain rangelands have high R^2 at lag0 (Figure 7 e) and low R^2 at greater lags (Figure 7 f, g, h), which reveals spatial patterns in precipitation impact on vegetation. On average, precipitation has less control over NDVI than runoff, as can be seen when comparing legend spans for NDVI~Runoff and NDVI~Precipitation (Figure 7), and the impact is more delayed (Figure 7 m and n). Deserts and rangelands experience about one to two months delayed reaction to variations in precipitation (Figure 7 n).

Land surface temperature (LST) is the factor that has the highest and most immediate control over NDVI, more than precipitation and runoff (Figure 7 i). It is a universal parameter that impacts deserts, rangelands and croplands uniformly, with R2 reaching 0.8. This is because vegetation phenology depends greatly on soil and air temperature and solar radiation. However, in contrast to the rest of the study site, croplands are also greatly influenced by temperature conditions at 1-month lag (Figure 7 j); this can also be attributed to the mixed effect with runoff. The croplands north of the study site are influenced more by LST at 1-month lag than the croplands in the center (Figure 7 o).

In general, runoff has a greater and more direct impact on NDVI than precipitation (Figure 7 m, n), and the areas downstream of the Isfara River north of our study site have a 1-month lag to runoff (Figure 7 m). However, although precipitation has a lower impact on NDVI, it is lagged for 2-3 months (Figure 7 n), partially attributed to the indirect effect through runoff. Land surface temperature has the greatest direct impact on vegetation (Figure 7 o), and only the areas north of the study site have 1-month lag. This can also be attributed to mixed indirect effects through runoff.

Multiple regression analysis

NDVI of agricultural areas (NDVIagr) is strongly controlled by runoff and LST at lag0 (Figure 7 a, i) and more weakly by precipitation at 3-months lag (Figure 7 h). Therefore, multiple regression analysis was conducted with NDVI as a response variable, with runoff, LST, and precipitation at 3-months lag as predictors to estimate their cumulative control over NDVIagr. The equation used for the multiple regression analysis is shown here:

$$NDVI_t \sim PRC_{t-3} + LST_t + RNF_t \quad (2)$$

where:

NDVI – normalized difference vegetation index

PRC – precipitation

LST – land surface temperature

RNF – Isfara runoff

t – time in months

The adjusted R^2 of the multiple regression analysis is 0.89 (Table 2), indicating that the NDVI of agricultural areas in the study site is about 90% controlled by climatic factors and runoff. The significance coefficient is the highest for LST, followed by runoff and precipitation (even with 3-months lag shift). Precipitation does not appear to be a significant predictor (Table 2). However, precipitation is an important factor for local vegetation providing water for summer runoff and thus has a direct impact on greening. The results of the regression equation can be used for modelling vegetation behavior in response to climate change.

Table 2. Multiple regression analysis results.

Residuals:

Min	*1Q*	*Median*	*3Q*	*Max*
-0.085510	-0.014154	0.002063	0.014135	0.060183

Coefficients:

	Estimate	*Std.Error*	*t-value*	*Pr(>|t|)*
(Intercept)	3.976e-02	5.880e-03	6.763	4.55e-09***
Precipitation (PRC)	-1.483e-05	2.695e-04	-0.055	0.9563
Runoff (RNF)	3.184e-04	1.085e-04	2.935	0.0046**
Land surface temperature (LST)	5.299e-03	3.659e-04	14.481	<2e-16***
Signif.codes:	0-'***'	0.001-'**'	0.01-'*'	0.05 '.'
Residual standard error:	0.02774	on 65 degrees of freedom		
(6 observations deleted due to absence of data due to temporal shifts)				
Multiple R^2:	0.8983,	*Adjusted R^2:*	0.8936	
F-statistic:	191.3	on 3 and 65 DF,	*p-value:*	<2.2e-16

Cross- correlation analysis of trend and seasonal components

NDVIagr shows a strong positive correlation with runoff both in seasonal and trend components (Figure 8 a, b) without any temporal lag. The correlation of seasonal components of NDVIagr and runoff is 0.79 at lag0, and 0.82 at -1-month lag (NDVIagr 1 month earlier then runoff). This can be explained by the contribution from precipitation, which peaks before the runoff peak (Figure 8 g). The correlation coefficient of NDVIagr and runoff trend components is greatest at lag0 and sits at 0.9 (Figure 8 b).

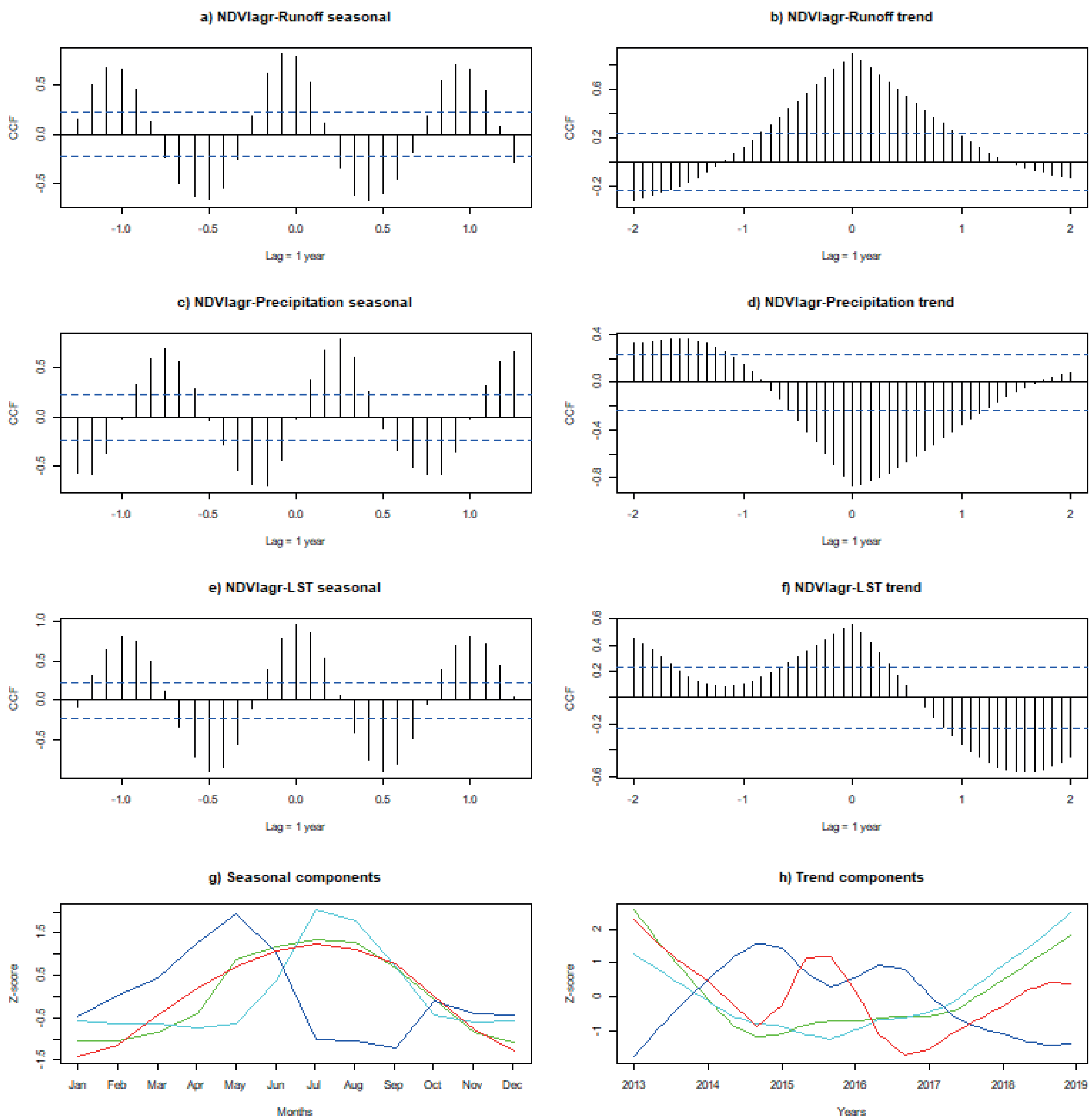

Figure 8. Cross-correlation analysis of trend and seasonal components of the modern data (2013-2018) (red – land surface temperature, blue - precipitation, cyan – runoff, green - NDVI, horizontal blue dashed line – significance level). The lag k correlation value of x-y is the correlation between x[t+k] and y[t].

The correlation coefficient of seasonal components between NDVIagr and precipitation at lag0 is -0.015, and the highest correlation coefficient is 0.79 at 3-months lag (NDVIagr 3 months after precipitation). The delayed NDVIagr reaction to precipitation variability indicates the indirect impact it has through runoff and the fact that the precipitation maximum occurs in spring when vegetation is just starting to develop due to its phenology, greatly influenced by air temperature and the low precipitation level in the lowlands (Figure 4 c). However, the trend components of NDVIagr and precipitation show a negative correlation with the least (greatest absolute value) correlation coefficient -0.87 observed at lag0, and which remains at a comparative level for the 3-months lag (Figure 8 d). The negative correlation of the trend components is caused by the negative correlation between precipitation and temperature (Figure 5 f), which shows that the years with more precipitation will be colder on average (and vise-versa), and that temperature has a greater impact on vegetation than precipitation (Table 2).

The seasonal components of NDVIagr and land surface temperature show a strong positive correlation of 0.96 at lag0 (Figure 8 e). The trend components also have a significant positive correlation of 0.56 at lag0 (Figure 8 f). This, again, indicates that temperature is the main factor influencing agricultural vegetation in the area, and is also illustrated by seasonal components, where the green NDVIagr curve closely follows the red LST curve (Figure 8 g).

PERCEPTIONS ABOUT CLIMATE CHANGE, NATURAL RESOURCES, AND LIVELIHOODS IN THE ISFARA CATCHMENT

Data and methods

To assess people's general awareness about and their perceptions of climate change and changes in natural resources in the Isfara River catchment we conducted semi-structured interviews with local residents and experts in the following villages: Ak-Sai (26 respondents), Ak-Tatyr (24 respondents), Kok-Tash (25 respondents), Pasky-Aryk (27 respondents), Samarkandek (21 respondents), Uch-Dobo (26 respondents), and Batken (3 experts). In total, 152 people were interviewed.

The questionnaire included the questions to assess the general understanding of climate change issue, respondents' observations of different climatic changes in their places of residences and well as some socio-economic questions. It is important to understand the population and economic trends in the study area, as well as perceptions about them, as these are crucial for natural resource management and understanding of future job demands. Official information sources are not always available, representative, or have the necessary details. The questionnaire was translated into Kyrgyz and all interviews were conducted either in Kyrgyz, with interviewers filling in questionnaires for the respondents, or respondents filled in questionnaires themselves following technical instructions from the interviewers. The questionnaire used for the interviews is provided in Appendix I. The respondents could skip any question they felt uncomfortable answering and were not requested to provide their personal information. Whenever they did provide this information, it was done voluntarily. Personal and other sensitive information was not provided to any third party and was processed entirely within the survey team.

The villagers that participated in the interviews were chosen randomly from the people we met in the street, in households, from among salesmen and buyers in village stores and markets, visitors in state agencies, and teachers in schools and kindergartens. Thus, we attempted to cover the entire variety of backgrounds, education and occupations to collect a representative sample of opinions.

The frequencies of different answers were tested using Pearson's chi-squared (χ^2) test for significant differences from uniform frequency (H0=uniform distribution) distribution with "chisq.

test" in R (R Core Team, 2016). This test was applied to categorical answers to identify the statistical significance of their distribution, i.e. if the dominance of most popular answers is meaningful and cannot be acquired just by a chance. Low χ^2 p values (<0.01) indicate that the distribution of answers is meaningful and statistically significant.

We also conducted hierarchical cluster analysis using Gower's distance as a metric of difference; this is used for clustering nominative data to identify the internal structure of the data. We used climatic, environmental, and livelihoods questions (second page of Appendix I) to cluster and omitted the questions related to awareness on climate change (first page of Appendix I) in order to cluster based on the respondents observations of natural resources, not their learned knowledge of climate change (Table 3 Variables).

Results

Of the 152 respondents, 85 people had heard about climate change and 48 had not, and 19 gave no answer. The most popular source of information about climate change was television, followed by the Internet, thus, unreliable and biased sources. Regarding an understanding of what climate change means, the greatest number (50 respondents), answered that the weather will be hotter and there will be less rain, and 41 respondents also think that there will be less water in rivers. These are the 3 most popular answers to the question "What is climate change?" and indicates that in general people have an understanding of the consequences of climate change and that overall, it is perceived negatively. The five most popular answers to the question "What effect will climate change have?" are: "crop yields will decrease" (49%), "people will get sick" (49%), "trees will develop diseases" (43%), "there will be less grass" (33%) and "livestock will get sick" (28%). These answers clearly indicate that respondents perceive the impact of climate change to be negative.

The reasons identified by respondents as the causes of climate change are: "unknown", meaning that no one knows the reasons for climate change (38% of respondents); because "people consume a lot [of natural resources]" (23%); it is natural process for the climate to change (22%); and because "people pollute the air" (20%). However, with regards to what should be done to alleviate climate change the majority think that more trees should be planted (61%, 93 respondents), that the number of cars should be reduced (31%), and that we should not do anything (20%). This shows that in general people have little understanding of the causes of climate change, but that they do understand the environmental benefit of planting trees and using less vehicles. Since planting more trees and reducing vehicle numbers are essential in mitigating climate change, the respondents unknowingly touched on issues that are important for climate change mitigation and their answers showed knowledge of actions than reduce environmental damage in general. Television was also named as the primary source of information in the village in general, and as such could be used effectively to increase people's understanding about the causes, impacts, and consequences of climate change.

Regarding observations of environmental changes, the majority of respondents (64%) said that the amount of snow that falls per year has decreased, the amount of rainfall also decreased (39%) and that on average, the temperature has increased (35%). So, the most obvious change was decrease in precipitation and temperature increase was less obvious, these observations correspond to our analysis of trends (see Figure 8 h). Among the main concerns regarding natu-

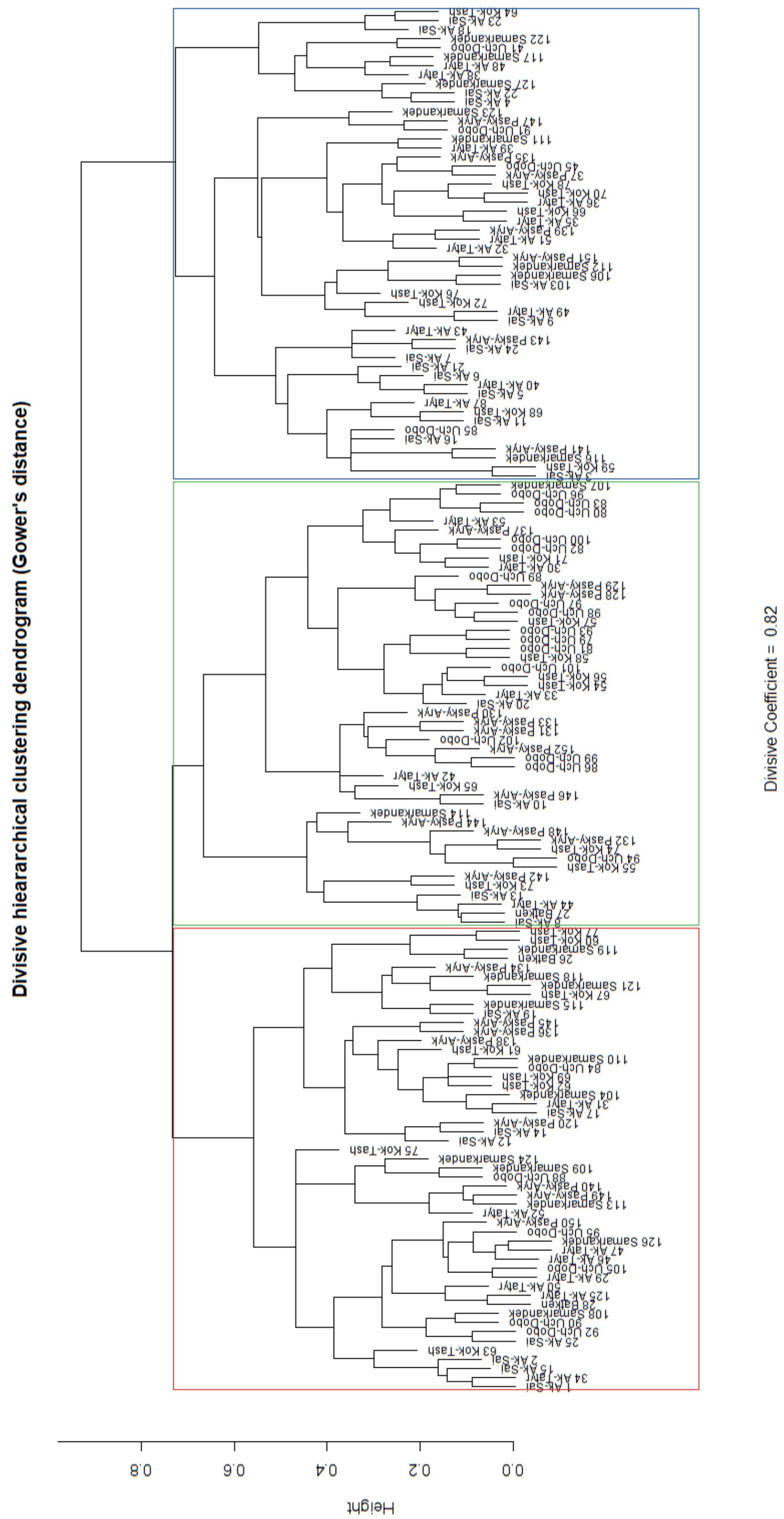

Figure 9. Divisive hierarchical clustering dendrogram (Gower's distance). Cluster 1 – red, cluster 2 – green, cluster 3 – blue. Respondents perceptions of climate change, natural resources and livelihoods were used for clustering. The figure shows 3 distinctive clusters, which appeared to be dependent on villages of residence.

ral resources is that trees develop diseases more often (58%, 88 respondents), that that there is less grass on pastures (44%), and that there is less irrigation water in canals (42%), and that crop yield is decreasing (42%).

With regards to a more detailed assessment of local climate change, the majority of respondents (72%) from all villages stated that winter precipitation (snowfall) has decreased in recent years (no answer – 4% of respondents, increased – 18%, not changed – 6%, decreased – 72%, χ^2 p <2.2e-16), that rainfall had decreased in spring (48% of respondents, χ^2 p=7.206e-11) and in summer (43% of respondents, χ^2 p=5.82e-10), and that autumn precipitation had not changed (41% of respondents, χ^2 p=1.151e-08). These observations are consistent with the trend component of precipitation (Figure 8 h). In general people noted that it was snowing less in recent years, an observation consistent with data from the Batken meteorological station (data used in "Vegetation response to abiotic factors in Isfara catchment area"), although however, we do not have separate snow data to directly support this and precipitation may be different upstream of the Isfara River.

The majority of respondents agreed that summers have become hotter (78% of respondents, χ^2 p<2.2e-16), and winters warmer (5% of respondents, χ^2 p<2.2e-16). Opinions regarding temperature increases in other seasons are not as unanimous, and the majority of respondents believed that temperatures have not changed in autumn (42% of respondents, χ^2 p=8.623e-11) or spring (no answer – 9%, hotter – 41%, not changed – 41%, colder – 9%). Opinions on summer and autumn temperatures were split among villages, with residents of Ak-Sai, Ak-Tatyr and Uch-Dobo thinking that spring and autumn have become warmer, whereas residents in Kok-Tash, Pasky-Aryk and Samarkandek think that the temperature has not changed.

Most respondents believe that the number of livestock has been increasing recently (53%), which supports the idea that negative NDVI trend on rangelands is caused by overgrazing (Figure 6). The respondents say that the main reason for the increase of livestock numbers is the lack of alterative livelihoods. Other studies have also shown that the main reasons for the increase of livestock numbers are the lack of alternative sources of income, population increase, and the fact that livestock is seen as a "bank" (Crewett, 2012; Dörre and Borchardt, 2012). Regarding wildlife living in mountains, 41% of respondents think that the number of wild animals has decreased, 14% think that it has increased, and another 14% think that it has remained the same, and 32% did not give any answer as they did not know. Further study of this topic, as a baseline wildlife survey would be best conducted with hunters, or people affiliated with hunting, who would likely have the best knowledge on this topic.

According to most respondents (55%) the number of trees in the area have increased, mainly because of the growth of orchards, which are planted by locals to create a source of income from fruit sales. According to the respondents, the main reason for felling trees is to provide materials for constructing new houses. However, 59% of respondents noted that recently fruit trees have been developing diseases more than before, while 28% think that the frequency of this has not changed. According to respondents the main reasons for tree diseases include variety monocultures (fruit trees are mainly apricots), a factor which supports the distribution of pests and diseases, as well as a lack of treatment of diseases, overgrazing, and aging trees.

Rangelands are the most important natural resource for local population, providing fodder for livestock. Almost two-thirds (60%) of respondents think that the amount of grass in pastures is decreasing, an observation supported by answers to other questions and NDVI linear trend on rangelands (Figure 6). The reasons for rangeland degradation are an increase of livestock and overgrazing, decrease of precipitation, and increase of summer temperatures (Borchardt et al., 2013, 2011; Dörre and Borchardt, 2012; Kulikov et al., 2016; Kulikov and Schickhoff, 2017).

Regarding crop yield, 46% of respondents think that crop yields deteriorated, while 28% of respondents think they have not changed. According to respondents, the main reason for deterioration of crop yield is lack of irrigation water, soil erosion, using too much chemicals, pests, and diseases. According to most respondents there is less water in the river then before (55% of respondents), while 10% think it has increased and 36% think it is same as before. According to our runoff trend analysis (see Figure 8 h), the runoff trend shows significant increase. This observation could be due to a misunderstanding of the survey question, and misjudgment of local population mainly because irrigation water has always been scarce in the area, and the perception of increased water deficit could come from the fact that expanded crop areas have caused an increased demand for water. The main reason for the runoff decrease, as reported by respondents, is due to a decrease of precipitation and glaciers, while the main reason given for runoff increase is an increase of temperature causing greater glacier ablation. The later opinion is supported by the studies outlined in section "Glaciation and runoff in Central Asia". This indicates that local residents have little understanding of climate change impact on natural resources.

With regards to the number of people living in the villages, 45% of respondents think that population has increased, 30% think that it has remained the same, and 24% think that is has decreased. In Ak-Sai and Ak-Tatyr, respondents strongly believed that the population is increasing, in Kok-Tash, Pasky-Aryk, Uch-Dobo and Samarkandek it remains the same according to responses. The main reason named for population increase is birth rate increase and the main reason for population decrease is labor migration of youth. NatStatCom (2019a) shows that both urban and rural population has been growing in 2016-2018 as well as emigration. So, we can conclude the different groups of respondents see and describe this issue from different perspectives. Thus, we can say that, in general, birth rate is increasing, according to respondents, and local population is increasing; at the same time unemployed youth is leaving for labor migration as there are not enough jobs for all of them.

Regarding the income trends in general, opinions were split, 27% of respondents think that income has increased, 29% think it has not changed, 24% think it has decreased, and 20% do not know (χ^2 p=0.41), meaning there is no clear consensus on income trends. The main reason given for income increases is due to remittances from labor migrants, and the main reason for income decrease is unemployment. Residents from Ak-Sai and Ak-Tatyr, again, agree that incomes have increased, while villagers from Kok-Tash believed that they have decreased, and in Uch-Dobo, Pasky-Aryk and Samarkandek respondents believe they have remained the same.

The opinions about the future were split between good and bad expectations, 39% of respondents think that life will get worse in the future, 16% think it will remain the same and 32% think it will get better, and 13% do not know. The main reason given for the belief that life will get better in the future is "we should do our best", which is not a reason but an attitude. Other reasons given less commonly for life improvement included migrants' remittances – people think that this is a good way to collect money to start a business, modern technologies – that they will improve life quality, and belief in the younger generation – that young and bright people would improve the economic situation. The most commonly mentioned reason for the belief that the quality of life will deteriorate in the future is the degradation of natural resources and lack of irrigation water, which decrease crop yields, as well as create unemployment and corruption.

Table 3. Summary of hierarchical cluster analysis results (Figure 9). Divisive hierarchical cluster analysis using Gower's distance. We provide the most frequent replies on perception of each parameter within each cluster.

Variable	Cluster 1	Cluster 2	Cluster 3
Village (not used in clustering)	*Samarkandek*	*Pasky-Aryk, Uch-Dobo, Kok-Tash*	*Ak-Sai, Ak-Tatyr*
Summer air temperature	*increasing*	*increasing*	*increasing*
Spring air temperature	*same*	*same*	*same*
Autumn air temperature	*same*	*same*	*same*
Winter air temperature	*increasing*	*increasing*	*increasing*
Summer rain	*decreasing*	*decreasing*	*same*
Spring rain	*decreasing*	*decreasing*	*increasing*
Autumn rain	*decreasing*	*same*	*same*
Winter snow	*decreasing*	*decreasing*	*increasing*
Livestock numbers	*increasing*	*same and decreasing*	*increasing*
Tree numbers (orchards)	*increasing*	*same and decreasing*	*increasing*
Tree diseases	*increasing*	*same*	*increasing*
Grass on pastures	*decreasing*	*decreasing*	*same and decreasing*
Crop yield	*same and decreasing*	*same and decreasing*	*same and increasing*
Population	*increasing*	*same and decreasing*	*increasing*
Water in river	*decreasing*	*decreasing*	*same*
People's income	*increasing*	*same and decreasing*	*same and increasing*
Life will be	*worse*	*better/worse*	*same and better*
Main village livelihood	*gardening*	*gardening*	*livestock*

Gardening was named as the main general source of income in villages by just under half of all respondents (49%), with animal husbandry the second most common primary livelihood (37%). Crop cultivation appeared as the most important single source of secondary income

(28%). These responses suggest that gardening is the main source of income in the region (based on 152 interviews) in contrast to other regions where livestock breeding is expected to be the main source. This also indicates that, regardless of the main source of income, villagers would also rely on cropland cultivation. Surprisingly, only 11% of respondents mentioned remittances as the primary source of income, and 13% as a source of secondary income. The contingency table indicates that the general most frequently mentioned source of income in Ak-Sai is animal husbandry (39% of respondents from Ak-Sai) and in Ak-Tatyr it is animal husbandry and gardening (each 29% of respondents from Ak-Tatyr), however gardening is the most frequently chosen source of income in Kok-Tash (56%), Samarkandek (52%), Pasky-Aryk (56%) and Uch-Dobo (69%). Thus, we can see that Ak-Sai and Ak-Tatyr respondents gave similar responses, and that these differed from Kok-Tash, Samarkandek, Pasky-Aryk and Uch-Dobo villages. Ak-Sai and Ak-Tatyr appear to be more livestock-oriented, however Kok-Tash, Samarkandek, Pasky-Aryk and Uch-Dobo are more gardening oriented (Table 3).

The divisive Gower's distance hierarchical cluster analysis split the data into three big clusters (Figure 9). The clusters are defined mainly by geographic distribution of respondents, and respondents from each village predominantly fall mainly into the same cluster with only Kok-Tash respondents distributed evenly among the clusters. Opinions about summer and winter air temperatures are unanimous, with most respondents in each cluster agreeing that they are increasing. Opinions about spring and autumn air temperatures are the same across all clusters. The difference among clusters appears in responses about precipitation change (Table 3). The responses of clusters 1 and 2 are more similar to each other, while the responses of cluster 3 are comparatively different, also indicated by the dendrogram (Figure 9).

DISCUSSION

The research presented in this publication is transdisciplinary, involving a literature review; analysis of historical data of Isfara River runoff, temperature and precipitation in the catchment; recent data on remotely-sensed vegetation index (NDVI); and interviews with the local residents to understand their observations of changes in climate and natural resources. Historical data analysis provides a basis to understand changes in Isfara River runoff and the influence that precipitation and temperature exert on runoff over a long time period. The break in data availability during the 1990's places certain constraints on direct comparison of recent and historical data, and further research is needed to model these years to fill the data gap and better understand runoff trends. However, remotely sensed products are available for the time periods for which more recent runoff and climate data also exist, allowing researchers to analyze the interactions between vegetation and driving factors. The time series decomposition methods, cross-correlation, and regression analysis applied in the spatial domain produce visually interpretable results and can inform decision-making to improve natural resource management. At the same time, the opinion of the local population is a valuable source of information and can provide an insight into how people perceive climate change, trends of natural resources, and their livelihoods to inform development of coping strategies and ways to better educate people. In this research we attempted to address these points to understand the socio-ecological nexus in the complex reality of the Isfara River catchment.

Analysis of historical data indicates a clear delayed positive correlation of Isfara runoff and precipitation with temperature, which corresponds with multiple studies in the region (Döll and Schmied, 2012; Gan et al., 2015; Gosling et al., 2011; Kogutenko et al., 2019; Liu and Xu, 2014; Oberhänsli et al., 2011; Sorg et al., 2012). Even though historical data indicates a negative runoff trend (Figure 5 h), the positive trend of temperature and precipitation, and positive correlation of the trend components with that of runoff and greater mean values of recent runoff measurements (Figure 4 a, b) suggest that runoff is increasing despite the opinion of the majority of the local population (Table 3). This finding also corresponds to studies of glaciers that project that runoff will increase with gradual annual temperature mean increase, and that a gradual loss of glacial mass will occur (Aizen et al., 1996; Glazyrin, 2015; Hagg et al., 2007; Sorg et al., 2012). However, after the disappearance or disconnection of these glaciers with streams, runoff will decrease and its peak will shift to spring rather than summer, as most of the runoff will be provided directly by spring precipitation rather than from ablation in summer. The glaciation decrease in the region is supported by observations of Abramov glacier (Barandun et al., 2018, 2015). But as glaciers provide 15%-30% of runoff it is also important to understand snow dynamics and melt.

Isfara River runoff has a greater direct impact on croplands than precipitation while precipitation has greater direct impact on rangelands than runoff. However, precipitation exercises a small positive delayed impact on croplands. Precipitation reaches its maximum in spring, when vegetation is still growing back after winter and the growth of crops has just started, and it provides moisture at the beginning of the growing season (Figure 8 g). Isfara River runoff peaks in July and August, when the temperature is also the highest, and water is very much needed by plants (Figure 8 g). Therefore, it is difficult to overestimate the importance of the snow-fed and glacier-fed rivers in the region since all the agriculture depends on irrigation.

Temperature has a direct positive effect on croplands, and is not a limiting factor, unlike elsewhere in Kyrgyzstan (Kulikov and Schickhoff, 2017); and this may indicate an overall sufficient water availability for irrigation. It could also be an indication that agricultural production is operating currently at its greatest possible volume with the current efficiency of existing irrigation systems. Sustainable agriculture and crop rotation can have significant effects on crop yields, as can the distance of crop fields to settlements and irrigation infrastructures (Löw et al., 2017b). Leakproof ditches, drip irrigation and mulching can significantly increase water use efficiency and soil moisture content, however different irrigation practices should be used for different types of crops (Li et al., 2015), and indeed, some modern technologies are already being used in Batken province (Figure 10). Drip irrigation, in contrast to furrow irrigation, can lead to water savings of 28-35% (Darouich et al., 2014). Irrigation schedule modelling can help to further increase irrigation efficiency (Fortes et al., 2005). However, this topic requires additional research.

The trend component of temperature over the recent study period (2013-2018) was observed to have grown gradually while the precipitation trend component was observed to have gradually declined (Figure 8 h). Isfara River runoff and NDVI were also increased during the study period. Temperature increase and a decrease in precipitation was supported by observations of the local population. The responses on changes of climatic factors are uniform among different groups of respondents and clusters. However, runoff increase does not agree with the opinion of respondents. The downstream villages with gardening as the main livelihood believed that water in the river was decreasing, however, upstream villages close to the river itself indicated that runoff is not changing. This supports the idea that the downstream villages have perceptions of reduced water volumes in contrast to the trend analysis of actual measurements (Figure 8 h) and comparison of old and recent runoff data (Figure 4 a, b). We suppose that this opinion is based rather on an increase of their water demand because of increasing garden areas, causing water deficit, or downstream water redistribution. In contrast, upstream villages, whose livelihoods are based predominantly on livestock herding and who thus are likely not as observant of water resources, believe that runoff remains at the same level as in earlier years.

Ground water could provide another source of irrigation. According to studies, ground water in the region were found to have strong correlation with surface runoff (Ibrakhimov et al., 2018), providing around 62% recharge of surface water supply (Ibrakhimov et al., 2018). About 23%-30% of water demand for irrigation can be provided from shallow groundwater (Ibrakhimov et al., 2018). In different years in the 1990's in Tajikistan, around 39% of extracted ground water was used for irrigation, and in Kazakhstan this was 71%, in China – 54%, and in Afghanistan and Pakistan the number stood at 94% (Todd Jarvis, 2013). In Kyrgyzstan, estimated groundwater abstraction reaches 0.96 km3 yr-1, 25% of which is for irrigation, another 25% for industry, and 50% for domestic use (Todd Jarvis, 2013). About 38% of agricultural areas worldwide have facilities for direct access to ground water (Siebert et al., 2010). However, if managed unsustainably high ground water levels can lead to soil salinization and over extraction can cause ground water tables to drop. Hydrological modelling and geographic information systems can provide valuable information on ground water availability and tools for sustainable management and decision making (Awan et al., 2017, 2013; Ibrakhimov et al., 2018). This field also requires additional research.

Figure 10. Cultivating watermelons using drip irrigation and plastic mulch in Batken province. Local communities invest in improvement of irrigation facilities to increase water use efficiency and crop production. Photo: Gulbara Omorova.

The rangelands in the research area experienced a decrease in vegetation (Figure 6). Livestock husbandry based on seasonal transhumance is one of the main livelihoods in the region and all areas that are not croplands are often used as pastures. Overgrazing can lead to substantial vegetation biomass loss and change in species composition (Borchardt et al., 2013, 2011, 2010; Dörre and Borchardt, 2012) as well as soil degradation (Kulikov et al., 2017, 2016). Multiple studies have considered pasture management issues and their impact on vegetation in Kyrgyzstan (Dörre, 2015; Hoppe et al., 2017, 2016a, 2016b; Isaeva and Shigaeva, 2017; Shigaeva et al., 2016; Zhumanova et al., 2018, 2016), however, these findings are the privy of academics and there is still little consensus on pasture management among local practitioners (Levine et al., 2019, 2017). Finding alternative income sources and developing more job opportunities and added value products can provide for a more sustainable local economy (Shigaeva et al., 2018, 2007) and create more climate resilient communities (Xenarios et al., 2018).

The great spatial heterogeneity of NDVI temporal trends (Figure 6) can be clearly divided into different field lots. This indicates a great dependence on cropland management practices and could be investigated further. The unplowed plain areas show an overall negative NDVI trend, a fact that could be attributed to overgrazing, as stated earlier. However, some highland rangelands show positive NDVI trends (Figure 6, southmost part), possibly indicating under-grazing of these areas due to infrastructural or other constraints. These are management issues and could be solved with better livestock distribution and pasture rotation practices. Many of the issues related to natural resources can be solved or improved by optimization of management practices and introduction of appropriate and affordable new technologies.

It is interesting that cluster 1 respondents (Figure 9), mainly Samarkandek villagers (Table 3), believe that their income is increasing, regardless of the fact that this area has the least irrigation water becuase it receives water through a transboundary channel. Cluster 1 also believed that orchard numbers are increasing, as is the population. In contrast, respondents in cluster 2 believe that the population is decreasing (due to people leaving for labor migration), as is the income in the villages. Villages in cluster 3 are Ak-Sai and Ak-Tatyr, which are located at a higher elevation than other villages, closer to Vorukh exclave; these indicate livestock as their main livelihood in contrast to other villages, which have gardening as the main livelihood. At the same time Ak-Sai and Ak-Tatyr seem to be more optimistic about the future of local economy then other villages.

NatStatCom (2018a) indicate gradual growth of gross output of the agricultural sector. Wheat yields in Batken district decreased from 2784 t in 2017 to 2593 t. in 2018 consistent with reductions in cultivated areas from 1818 ha to 1745 ha and productivity from 1530 to 1490 kg ha^{-1}. The bulk yield of cereals in Batken district has grown from 21 139 t in 2017 to 21 299 t in 2018 mainly because of the increase of agricultural areas from 6168 ha to 6239 ha, whereas productivity has decreased from 3430 to 3410 kg ha^{-1}. Production of corn, potato and vegetables indicate growth together with the cultivated area. Fruit yields grew from 22 520 t in 2017 to 25 102 t in 2018 together with cultivated area - from 3663 ha to 4038 ha and productivity from 6150 to 6220 kg ha^{-1} (NatStatCom, 2018b). At the same time, the agricultural sector in the entire Batken province indicates a steady decline in bulk production from 2014 to 2018, with only fruit and meat production showing revenue increases (NatStatCom, 2019b). These figures indicate overall preference of fruit and meat production and their growths in the study area, which indicates a refocusing of the agricultural sector on these products.

This interdisciplinary research reveals the environmental processes in the study area, which are driven by climatic and economic factors and have direct impact on residents and local economy. The livelihoods of local people are dependent on natural resources, which are scarce and will deteriorate as climate changes. The adaptation strategies and diverse and sustainable livelihoods still need to develop. Local residents are generally aware of the climate change and resource scarcity and intuitively adapt their income strategies to the changing environment. However, growing population demands more resources, which means that more efficient agricultural technologies need to be introduced, more added value products developed and thus, new jobs created. The irrigation systems can become more efficient and substantially increase agricultural production, which should be pursued by the decision-makers. Migrants' remittances can be a good source of investment in new technologies and alternative income generating activities, and also bring sustainability and security to the region.

REFERENCES

Adyshev, M.M., Kashirin, F.T., Umurzakov, S.U., Almaev, T.M., Voronina, A.F., Grigorenko, P.G., Dzhamgerchinov, B.D., Zabirov, R.D., Zinkova, Z.Y., Izmailov, A.E., Isabaeva, V.A., Kravchenko, A.V., Mamytov, A.M., Makhrina, L.I., Moldokulov, A.M., Murzaev, E.M., Otorbaev, K.O., Popova, L.I., Yar-Mukhamedov, G.K., Yashina, V.V., Chernova, L.I., 1987. Атлас Киргизской ССР [Atlas of the Kyrgyz SSR (vol. I)] (in Russian). Fabrika#4, Moscow.

Aizen, V.B., Aizen, E.M., Kuzmichonok, V.A., 2007a. Glaciers and hydrological changes in the Tien Shan: Simulation and prediction. Environ. Res. Lett. 2. https://doi.org/10.1088/1748-9326/2/4/045019

Aizen, V.B., Aizen, E.M., Melack, J.M., 1996. Precipitation, melt and runoff in the northern Tien Shan. J. Hydrol. 186, 229–251. https://doi.org/10.1016/S0022-1694(96)03022-3

Aizen, V.B., Aizen, E.M., Melack, J.M., 1995. Climate, Snow Cover, Glaciers, and Runoff in the Tien Shan, Central Asia. J. Am. Water Resour. Assoc. 31, 1113–1129. https://doi.org/10.1111/j.1752-1688.1995.tb03426.x

Aizen, V.B., Aizen, E.M., Melack, J.M., Dozier, J., 1997. Climatic and hydrologic changes in the Tien Shan, central Asia. J. Clim. 10, 1393–1404. https://doi.org/10.1175/1520-0442(1997)010<1393:CAHCIT>2.0.CO;2

Aizen, V.B., Kuzmichenok, V.A., Surazakov, A.B., Aizen, E.M., 2007b. Glacier changes in the Tien Shan as determined from topographic and remotely sensed data. Glob. Planet. Change 56, 328–340. https://doi.org/10.1016/j.gloplacha.2006.07.016

Aizen, V.B., Kuzmichenok, V.A., Surazakov, A.B., Aizen, E.M., 2006. Glacier changes in the central and northern Tien Shan during the last 140 years based on surface and remote-sensing data, in: Annals of Glaciology. pp. 202–213. https://doi.org/10.3189/172756406781812465

Aralova, D., Kariyeva, J., Khujanazarov, T., Toderich, K., 2018. Drought Variability and Land Degradation in Central Asia: Assessment Using Remote Sensing Data and Drought Indices, in: Vegetation of Central Asia and Environs. Springer International Publishing, pp. 15–47. https://doi.org/10.1007/978-3-319-99728-5_2

Awan, U.K., Ibrakhimov, M., Benli, B., Lamers, J.P.A., Liaqat, U.W., 2017. A new concept of irrigation response units for effective management of surface and groundwater resources: a case study from the multi-country Fergana Valley, Central Asia. Irrig. Sci. 35, 55–68. https://doi.org/10.1007/s00271-016-0521-9

Awan, U.K., Tischbein, B., Martius, C., 2013. Combining hydrological modeling and GIS approaches to determine the spatial distribution of groundwater recharge in an arid irrigation scheme. Irrig. Sci. 31, 793–806. https://doi.org/10.1007/s00271-012-0362-0

Barandun, M., Huss, M., Sold, L., Farinotti, D., Azisov, E., Salzmann, N., Usubaliev, R., Merkushkin, A., Hoelzle, M., 2015. Re-analysis of seasonal mass balance at Abramov glacier 1968–2014. J. Glaciol. 61, 1103–1117. https://doi.org/10.3189/2015JoG14J239

Barandun, M., Huss, M., Usubaliev, R., Azisov, E., Berthier, E., Kääb, A., Bolch, T., Hoelzle, M., 2018. Multi-decadal mass balance series of three Kyrgyz glaciers inferred from modelling constrained with repeated snow line observations. Cryosph. 12, 1899–1919. https://doi.org/10.5194/tc-12-1899-2018

Bolch, T., 2015. Glacier area and mass changes since 1964 in the Ala Archa Valley, Kyrgyz Ala-Too, northern Tien Shan. J. “Ice Snow” 129, 28–39. https://doi.org/10.15356/IS.2015.01.03

Bolch, T., 2007. Climate change and glacier retreat in northern Tien Shan (Kazakhstan/Kyrgyzstan) using remote sensing data. Glob. Planet. Change. https://doi.org/10.1016/j.gloplacha.2006.07.009

Borchardt, P., Oldeland, J., Ponsens, J., Schickhoff, U., 2013. Plant functional traits match grazing gradient and vegetation patterns on mountain pastures in SW Kyrgyzstan. Phytocoenologia 43, 171–181. https://doi.org/10.1127/0340-269X/2013/0043-0542

Borchardt, P., Schickhoff, U., Scheitweiler, S., Kulikov, M., 2011. Mountain pastures and grasslands in the SW Tien Shan, Kyrgyzstan - Floristic patterns, environmental gradients, phytogeography, and grazing impact. J. Mt. Sci. 8, 363–373. https://doi.org/10.1007/s11629-011-2121-8

Borchardt, P., Schmidt, M., Schickhoff, U., 2010. Vegetation patterns in Kyrgyzstan’s walnut-fruit forests under the impact of changing forest use in post-soviet transformation. Erde 141, 255–275.

Braun, L., Hagg, W., 2010. Present and future impact of snow cover and glaciers on runoff from mountain regions. IHP-HWRP-Berichte 36–43.

Chen, Y., Chen, Z., Li, B., Li, Q., 2014. Response of Runoff to Climate Change, in: Water Resources Research in Northwest China. Springer Netherlands, Dordrecht, pp. 145–191. https://doi.org/10.1007/978-94-017-8017-9_4

Cleveland, R.B., Cleveland, W.S., McRae, J.E., Terpenning, I., 1990. STL: A seasonal-trend decomposition procedure based on loess. J. Off. Stat. 6, 3–73. https://doi.org/citeulike-article-id:1435502

Conrad, C., Schönbrodt-Stitt, S., Löw, F., Sorokin, D., Paeth, H., Conrad, C., Schönbrodt-Stitt, S., Löw, F., Sorokin, D., Paeth, H., 2016. Cropping Intensity in the Aral Sea Basin and Its Dependency from the Runoff Formation 2000–2012. Remote Sens. 8, 630. https://doi.org/10.3390/rs8080630

Conrad, O., Bechtel, B., Bock, M., Dietrich, H., Fischer, E., Gerlitz, L., Wehberg, J., Wichmann, V., Böhner, J., 2015. System for Automated Geoscientific Analyses (SAGA) v. 2.1.4. Geosci. Model Dev. 8, 1991–2007. https://doi.org/10.5194/gmd-8-1991-2015

Crewett, W., 2012. Improving the Sustainability of Pasture Use in Kyrgyzstan. Mt. Res. Dev. 32, 267–274. https://doi.org/10.1659/MRD-JOURNAL-D-11-00128.1

Darouich, H.M., Pedras, C.M.G., Gonçalves, J.M., Pereira, L.S., 2014. Drip vs. surface irrigation: A comparison focussing on water saving and economic returns using multicriteria analysis applied to cotton. Biosyst. Eng. 122, 74–90. https://doi.org/10.1016/J.BIOSYSTEMSENG.2014.03.010

Döll, P., Schmied, H.M., 2012. How is the impact of climate change on river flow regimes related to the impact on mean annual runoff? A global-scale analysis. Environ. Res. Lett. 7. https://doi.org/10.1088/1748-9326/7/1/014037

Dörre, A., 2015. Promises and realities of community-based pasture management approaches: Observations from Kyrgyzstan. Pastoralism 5, 15. https://doi.org/10.1186/s13570-015-0035-8

Dörre, A., Borchardt, P., 2012. Changing Systems, Changing Effects—Pasture Utilization in the Post-Soviet Transition. Mt. Res. Dev. 32, 313–323. https://doi.org/10.1659/MRD-JOURNAL-D-11-00132.1

Du, J., Shu, J., Yin, J., Yuan, X., Jiaerheng, A., Xiong, S., He, P., Liu, W., 2015. Analysis on spatio-temporal trends and drivers in vegetation growth during recent decades in Xinjiang, China. Int. J. Appl. Earth Obs. Geoinf. 38, 216–228. https://doi.org/10.1016/j.jag.2015.01.006

Dukhovny, V., Kenjabaev, S., Yakubov, S., Umirzakov, G., 2018. Controlled Subsurface Drainage as a Strategy for Improved Water Management in Irrigated Agriculture of Uzbekistan. Irrig. Drain. 67, 112–123. https://doi.org/10.1002/ird.2259

Eckert, S., Hüsler, F., Liniger, H., Hodel, E., 2015. Trend analysis of MODIS NDVI time series for detecting land degradation and regeneration in Mongolia. J. Arid Environ. 113, 16–28. https://doi.org/10.1016/j.jaridenv.2014.09.001

FAO, 2011. FAOSTAT [WWW Document]. URL http://faostat3.fao.org/browse/area/113/E (accessed 4.29.16).

Farinotti, D., Longuevergne, L., Moholdt, G., Duethmann, D., Mölg, T., Bolch, T., Vorogushyn, S., Güntner, A., 2015. Substantial glacier mass loss in the Tien Shan over the past 50 years. Nat. Geosci. 8, 716–722. https://doi.org/10.1038/ngeo2513

Fortes, P.S., Platonov, A.E., Pereira, L.S., 2005. GISAREG—A GIS based irrigation scheduling simulation model to support improved water use. Agric. Water Manag. 77, 159–179. https://doi.org/10.1016/J.AGWAT.2004.09.042

Gan, R., Luo, Y., Zuo, Q., Sun, L., 2015. Effects of projected climate change on the glacier and runoff generation in the Naryn River Basin, Central Asia. J. Hydrol. 523, 240–251. https://doi.org/10.1016/J.JHYDROL.2015.01.057

Gardner, A.S., Moholdt, G., Cogley, J.G., Wouters, B., Arendt, A.A., Wahr, J., Berthier, E., Hock, R., Pfeffer, W.T., Kaser, G., Ligtenberg, S.R.M., Bolch, T., Sharp, M.J., Hagen, J.O., Van Den Broeke, M.R., Paul, F., 2013. A reconciled estimate of glacier contributions to sea level rise: 2003 to 2009. Science (80-.). 340, 852–857. https://doi.org/10.1126/science.1234532

Gessner, U., Naeimi, V., Klein, I., Kuenzer, C., Klein, D., Dech, S., 2013. The relationship between precipitation anomalies and satellite-derived vegetation activity in Central Asia. Glob. Planet. Change 110, 74–87. https://doi.org/10.1016/j.gloplacha.2012.09.007

Glazirin, G.E., Braun, L.N., Shchetinnikov, A.S., 2002. Sensitivity of mountain glacierization to climatic changes in Central Asia. Zeitschrift fur Gletscherkd. und Glazialgeol. 38, 71–76.

Glazyrin, G.E., 2015. Influences of deglaciation on the river run-off in Central Asia. Ice Snow 123, 20. https://doi.org/10.15356/2076-6734-2013-3-20-25

Goerlich, F., Bolch, T., Mukherjee, K., Pieczonka, T., Goerlich, F., Bolch, T., Mukherjee, K., Pieczonka, T., 2017. Glacier Mass Loss during the 1960s and 1970s in the Ak-Shirak Range (Kyrgyzstan) from Multiple Stereoscopic Corona and Hexagon Imagery. Remote Sens. 9, 275. https://doi.org/10.3390/rs9030275

Goibov, M., Schmitz, P.M., Bauer, S., Ahmed, M.N., 2012. Application of a Choice Experiment to Estimate Farmers Preferences for Different Land Use Options in Northern Tajikistan. J. Sustain. Dev. 5. https://doi.org/10.5539/jsd.v5n5p2

Gosling, S.N., Taylor, R.G., Arnell, N.W., Todd, M.C., 2011. A comparative analysis of projected impacts of climate change on river runoff from global and catchment-scale hydrological models. Hydrol. Earth Syst. Sci. 15, 279–294. https://doi.org/10.5194/hess-15-279-2011

GRDC, 2019. BfG - The GRDC - Global Runoff Database.

Hagg, W., Braun, L.N., Kuhn, M., Nesgaard, T.I., 2007. Modelling of hydrological response to climate change in glacierized Central Asian catchments. J. Hydrol. 332, 40–53. https://doi.org/10.1016/j.jhydrol.2006.06.021

Hagg, W., Braun, L.N., Weber, M., Becht, M., 2006. Runoff modelling in glacierized Central Asian catchments for present-day and future climate. Nord. Hydrol. 37, 93–105. https://doi.org/10.2166/nh.2006.001

Hagg, W., Hoelzle, M., Wagner, S., Mayr, E., Klose, Z., 2013. Glacier and runoff changes in the Rukhk catchment, upper Amu-Darya basin until 2050. Glob. Planet. Change 110, 62–73. https://doi.org/10.1016/j.gloplacha.2013.05.005

Hijioka, Y., Lin, E., Pereira, J.J., Corlett, R.T., Cui, X., Insarov, G.E., Lasco, R.D., Lindgren, E., Surjan, A., 2014. Asia, in: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. pp. 1327–1370.

Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S.I., Thomas, A., Warren, R., Zhou, G., 2018. Impacts of 1.5°C of Global Warming on Natural and Human Systems, in: Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change,.

Hoelzle, M., Azisov, E., Barandun, M., Huss, M., Farinotti, D., Gafurov, A., Hagg, W., Kenzhebaev, R., Kronenberg, M., Machguth, H., Merkushkin, A., Moldobekov, B., Petrov, M., Saks, T., Salzmann, N., Schöne, T., Tarasov, Y., Usubaliev, R., Vorogushyn, S., Yakovlev, A., Zemp, M., 2017. Re-establishing glacier monitoring in Kyrgyzstan and Uzbekistan, Central Asia. Geosci. Instrumentation, Methods Data Syst. 6, 397–418. https://doi.org/10.5194/gi-6-397-2017

Hoppe, F., Schickhoff, U., Oldeland, J., 2017. Plant species diversity of pastures in the Naryn Oblast (Kyrgyzstan). DIE ERDE – J. Geogr. Soc. Berlin 149, 214–226.

Hoppe, F., Zhusui Kyzy, T., Usupbaev, A., Schickhoff, U., 2016a. Rangeland degradation assessment in Kyrgyzstan: vegetation and soils as indicators of grazing pressure in Naryn Oblast. J. Mt. Sci. 13, 1567–1583. https://doi.org/10.1007/s11629-016-3915-5

Hoppe, F., Zhusui Kyzy, T., Usupbaev, A., Schickhoff, U., 2016b. Contrasting grazing impact on seasonal pastures reflected by plant functional traits: Search for patterns in Kyrgyz rangelands. GEOÖKO 37.

Horst, M.G., Shamutalov, S.S., Pereira, L.S., Gonçalves, J.M., 2005. Field assessment of the water saving potential with furrow irrigation in Fergana, Aral Sea basin. Agric. Water Manag. 77, 210–231. https://doi.org/10.1016/J.AGWAT.2004.09.041

Ibrakhimov, M., Awan, U.K., George, B., Liaqat, U.W., 2018. Understanding surface water–groundwater interactions for managing large irrigation schemes in the multi-country Fergana valley, Central Asia. Agric. Water Manag. 201, 99–106. https://doi.org/10.1016/J.AGWAT.2018.01.016

Immerzeel, W.W., van Beek, L.P.H., Bierkens, M.F.P., 2010. Climate Change Will Affect the Asian Water Towers. Science (80-.). 328, 1382–1385. https://doi.org/10.1126/science.1183188

IPCC WGII, 2014. IPCC's Fifth Assessment Report (WGII AR5), in: Climate Change 2014: Impacts, Adaptation and Vulnerability: Part B: Regional Aspects: Working Group II Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. https://doi.org/10.1017/CBO9781107415386.003

Isaeva, A., Shigaeva, J., 2017. Soviet Legacy in the Operation of Pasture Governance Institutions in Present-Day Kyrgyzstan. Rev. géographie Alp. https://doi.org/10.4000/rga.3631

IUSS Working Group WRB, 2014. World reference base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps, World Soil Resources Reports No. 106. https://doi.org/10.1017/S0014479706394902

Kaser, G., Großhauser, M., Marzeion, B., 2010. Contribution potential of glaciers to water availability in different climate regimes. Proc. Natl. Acad. Sci. U. S. A. 107, 20223–20227. https://doi.org/10.1073/pnas.1008162107

Kenzhebaev, R., Barandun, M., Kronenberg, M., Chen, Y., Usubaliev, R., Hoelzle, M., 2017. Mass balance observations and reconstruction for Batysh Sook Glacier, Tien Shan, from 2004 to 2016. Cold Reg. Sci. Technol. 135, 76–89. https://doi.org/10.1016/j.coldregions.2016.12.007

Khromova, T., Nosenko, G., Kutuzov, S., Muraviev, A., Chernova, L., 2014. Glacier area changes in Northern Eurasia. Environ. Res. Lett. 9. https://doi.org/10.1088/1748-9326/9/1/015003

Khromova, T.E., Osipova, G.B., Tsvetkov, D.G., Dyurgerov, M.B., Barry, R.G., 2006. Changes in glacier extent in the eastern Pamir, Central Asia, determined from historical data and ASTER imagery. Remote Sens. Environ. 102, 24–32. https://doi.org/10.1016/J.RSE.2006.01.019

Klein, I., Gessner, U., Kuenzer, C., 2012. Regional land cover mapping and change detection in Central Asia using MODIS time-series. Appl. Geogr. 35, 219–234. https://doi.org/Doi 10.1016/J.Apgeog.2012.06.016

Kogutenko, L., Severskiy, I., Shahgedanova, M., Lin, B., 2019. Change in the Extent of Glaciers and Glacier Runoff in the Chinese Sector of the Ile River Basin between 1962 and 2012. Water 11, 1668. https://doi.org/10.3390/w11081668

Konovalov, V.G., 1985. Таяние и сток с ледников в бассейнах рек Средней Азии [Melting and runoff from the glaciers in basins of Central Asian rivers] (in Russian). Leningrad, Gidrometeoizdat.

Konovalov, V.G., Shchetinnicov, A.S., 1994. Evolution of glaciation in the Pamiro-Alai mountains and its effect on river run-off. J. Glaciol. 40, 149–157. https://doi.org/10.3189/S0022143000003920

Kronenberg, M., Barandun, M., Hoelzle, M., Huss, M., Farinotti, D., Azisov, E., Usubaliev, R., Gafurov, A., Petrakov, D., Kääb, A., 2016. Mass-balance reconstruction for Glacier No. 354, Tien Shan, from 2003 to 2014. Ann. Glaciol. 57, 92–102. https://doi.org/10.3189/2016aog71a032

Kulikov, M., Schickhoff, U., 2017. Vegetation and climate interaction patterns in Kyrgyzstan: spatial discretization based on time series analysis. Erdkunde 71, 143–165. https://doi.org/10.3112/erdkunde.2017.02.04

Kulikov, M., Schickhoff, U., Borchardt, P., 2016. Spatial and seasonal dynamics of soil loss ratio in mountain rangelands of south-western Kyrgyzstan. J. Mt. Sci. 13, 1–14. https://doi.org/10.1007/s11629-1

Kulikov, M., Schickhoff, U., Gröngröft, A., Borchardt, P., 2017. Modelling Soil Erodibility in Mountain Rangelands of South-Western Kyrgyzstan. Pedosphere. https://doi.org/10.1016/S1002-0160(17)60402-8

Kundzewicz, Z.W., Mata, L.J., Arnell, N.W., DÖLL, P., Jimenez, B., Miller, K., Oki, T., ŞEN, Z., Shiklomanov, I., 2008. The implications of projected climate change for freshwater resources and their management. Hydrol. Sci. J. 53, 3–10. https://doi.org/10.1623/hysj.53.1.3

Kure, S., Jang, S., Ohara, N., Kavvas, M.L., Chen, Z.Q., 2013. Hydrologic impact of regional climate change for the snow-fed and glacier-fed river basins in the republic of Tajikistan: Statistical downscaling of global climate model projections. Hydrol. Process. 27, 4071–4090. https://doi.org/10.1002/hyp.9536

Lazkov, G.A., Sultanova, B.A., 2011. Checklist of vascular plants of Kyrgyzstan. Botanical Museum, Finnish Museum of Natural History, University of Helsinki, Bishkek.

Lerman, Z., 2012. Rural Livelihoods in Tajikistan: What Factors and Policies Influence the Income and Well-Being of Rural Families?, in: Rangeland Stewardship in Central Asia. Springer Netherlands, Dordrecht, pp. 165–187. https://doi.org/10.1007/978-94-007-5367-9_8

Levine, J., Isaeva, A., Eddy, I., Foggin, M., Gergel, S., Hagerman, S., Zerriffi, H., 2017. A cognitive approach to the post-Soviet Central Asian pasture puzzle: new data from Kyrgyzstan. Reg. Environ. Chang. 17, 941–947. https://doi.org/10.1007/s10113-017-1122-8

Levine, J., Isaeva, A., Zerriffi, H., Eddy, I.M.S., Foggin, M., Gergel, S.E., Hagerman, S.M., 2019. Testing for consensus on Kyrgyz rangelands: local perceptions in Naryn oblast. Ecol. Soc. 24, art36. https://doi.org/10.5751/ES-11222-240436

Li, X., Shi, H., Šimůnek, J., Gong, X., Peng, Z., 2015. Modeling soil water dynamics in a drip-irrigated intercropping field under plastic mulch. Irrig. Sci. 33, 289–302. https://doi.org/10.1007/s00271-015-0466-4

Li, Z., Wang, P., Sun, M., 2014. Glacier Change and Its Impact on Water Resources, in: Water Resources Research in Northwest China. Springer Netherlands, Dordrecht, pp. 193–246. https://doi.org/10.1007/978-94-017-8017-9_5

Liu, Z., Xu, Z., 2014. Climate Change Scenarios and the Impact on Runoff, in: Chen, Y. (Ed.), Water Resources Research in Northwest China. Springer Netherlands, Dordrecht, pp. 311–357. https://doi.org/10.1007/978-94-017-8017-9

Löw, F., Biradar, C., Fliemann, E., Lamers, J.P.A., Conrad, C., 2017a. Assessing gaps in irrigated agricultural productivity through satellite earth observations—A case study of the Fergana Valley, Central Asia. Int. J. Appl. Earth Obs. Geoinf. 59, 118–134. https://doi.org/10.1016/J.JAG.2017.02.014

Löw, F., Biradar, C., Fliemann, E., Lamers, J.P.A., Conrad, C., 2017b. Assessing gaps in irrigated agricultural productivity through satellite earth observations—A case study of the Fergana Valley, Central Asia. Int. J. Appl. Earth Obs. Geoinf. 59, 118–134. https://doi.org/10.1016/J.JAG.2017.02.014

Mamytov, A.M., Ashirakhmanov, S.A., 1988. Soils (in Russian), Natural Resources of Kyrgyz SSR. Tashkentskaya Kartograficheskaya Fabrika, Tashkent.

Mckinney, W., Pydata Development Team, 2019. pandas: powerful Python data analysis toolkit, Python package.

Mohammat, A., Wang, X., Xu, X., Peng, L., Yang, Y., Zhang, X., Myneni, R.B., Piao, S., 2013. Drought and spring cooling induced recent decrease in vegetation growth in Inner Asia. Agric. For. Meteorol. 178–179, 21–30. https://doi.org/10.1016/j.agrformet.2012.09.014

Narama, C., Shimamura, Y., Nakayama, D., Abdrakhmatov, K., 2006. Recent changes of glacier coverage in the western Terskey-Alatoo range, Kyrgyz Republic, using Corona and Landsat, in: Annals of Glaciology. pp. 223–229. https://doi.org/10.3189/172756406781812195

NatStatCom, 2019a. Кыргызстан. Краткий статистический справочник [Kyrgyzstan. Brief Statistical Handbook] (in Russian). Bishkek.

NatStatCom, 2019b. Сельское хозяйство Кыргызской Республики [Agriculture of Kyrgyz Republic]. Bishkek.

NatStatCom, 2018a. Kyrgyzstan. Brief Statistical Handbook. Bishkek.

NatStatCom, 2018b. О сборе урожая сельскохозяйственных культур в 2018 г. [About agricultural yield in 2018]. Bishkek.

Niederer, P., Bilenko, V., Ershova, N., Hurni, H., Yerokhin, S., Maselli, D., 2008. Tracing glacier wastage in the Northern Tien Shan (Kyrgyzstan/Central Asia) over the last 40 years. Clim. Change 86, 227–234. https://doi.org/10.1007/s10584-007-9288-6

Oberhänsli, H., Novotná, K., Píšková, A., Chabrillat, S., Nourgaliev, D.K., Kurbaniyazov, A.K., Matys Grygar, T., 2011. Variability in precipitation, temperature and river runoff in W Central Asia during the past ~2000yrs. Glob. Planet. Change 76, 95–104. https://doi.org/10.1016/j.gloplacha.2010.12.008

Osmonov, A., Bolch, T., Xi, C., Kurban, A., Guo, W., 2013. Glacier characteristics and changes in the Sary-Jaz River Basin (Central Tien Shan, Kyrgyzstan) – 1990–2010. Remote Sens. Lett. 4, 725–734. https://doi.org/10.1080/2150704X.2013.789146

Pak, M., Wegerich, K., Kazbekov, J., 2014. Re-examining conflict and cooperation in Central Asia: a case study from the Isfara River, Ferghana Valley. Int. J. Water Resour. Dev. 30, 230–245. https://doi.org/10.1080/07900627.2013.837357

Pieczonka, T., Bolch, T., 2015. Region-wide glacier mass budgets and area changes for the Central Tien Shan between ~1975 and 1999 using Hexagon KH-9 imagery. Glob. Planet. Change 128, 1–13. https://doi.org/10.1016/j.gloplacha.2014.11.014

Propastin, P.A., Kappas, M., Erasmi, S., Muratova, N.R., 2007. Remote sensing based study on intra-annual dynamics of vegetation and climate in drylands of Kazakhastan. Basic Appl. Dryland Res. 1, 138–154. https://doi.org/10.1127/badr/1/2007/138

Propastin, P.A., Kappas, M., Muratova, N.R., 2008a. Inter-annual changes in vegetation activities and their relationship to temperature and precipitation in Central Asia from 1982 to 2003. J. Environ. Informatics 12, 75–87. https://doi.org/10.3808/jei.200800126

Propastin, P.A., Kappas, M., Muratova, N.R., 2008b. A remote sensing based monitoring system for discrimination between climate and human-induced vegetation change in Central Asia. Manag. Environ. Qual. An Int. J. 19, 579–596. https://doi.org/http://dx.doi.org/10.1108/14777830810894256

Python Software Foundation, 2016. Python Language Reference, version 3.5. Python Softw. Found.

R Core Team, 2016. R: A Language and Environment for Statistical Computing. R Found. Stat. Comput. Vienna, Austria.

Ramesh, A., Conrad, C., Mannig, B., Schrader, F., 2013. Hydro-Meteorological Hazards Assessment Based Upon Climate Change Considerations in Isfara Basin. EGU Gen. Assem. 2013, held 7-12 April. 2013 Vienna, Austria, p.13472 15, 13472.

Rasmussen, L.A., 2013. Meteorological controls on glacier mass balance in High Asia. Ann. Glaciol. 54, 352–359. https://doi.org/10.3189/2013AoG63A353

Reddy, J.M., Jumaboev, K., Matyakubov, B., Eshmuratov, D., 2013. Evaluation of furrow irrigation practices in Fergana Valley of Uzbekistan. Agric. Water Manag. 117, 133–144. https://doi.org/10.1016/J.AGWAT.2012.11.004

Ripley, B.D., 2013. Seasonal Decomposition of Time Series by Loess.

Schaner, N., Voisin, N., Nijssen, B., Lettenmaier, D.P., 2012. The contribution of glacier melt to streamflow. Environ. Res. Lett. https://doi.org/10.1088/1748-9326/7/3/034029

Shigaeva, J., Dzhakypbekova, K., Nurdoolot Kyzy, C., Darr, D., Wolff, H.-P., 2018. Profitability of forest products of walnut-fruit forest of Kyrgyzstan vs agricultural production, case study from Kyzyl Unkur villages, in: World Mountain Forum. Bishkek.

Shigaeva, J., Hagerman, S., Zerriffi, H., Hergarten, C., Isaeva, A., Mamadalieva, Z., Foggin, M., 2016. Decentralizing Governance of Agropastoral Systems in Kyrgyzstan: An Assessment of Recent Pasture Reforms. Mt. Res. Dev. 36, 91–101. https://doi.org/10.1659/MRD-JOURNAL-D-15-00023.1

Shigaeva, J., Kollmair, M., Niederer, P., Maselli, D., 2007. Livelihoods in transition: changing land use strategies and ecological implications in a post-Soviet setting (Kyrgyzstan). Centr. Asian Surv. 26, 389–406. https://doi.org/10.1080/02634930701702696

Siebert, S., Burke, J., Faures, J.M., Frenken, K., Hoogeveen, J., Döll, P., Portmann, F.T., 2010. Groundwater use for irrigation – a global inventory. Hydrol. Earth Syst. Sci. 14, 1863–1880. https://doi.org/10.5194/hess-14-1863-2010

Siegfried, T., Bernauer, T., Guiennet, R., Sellars, S., Robertson, A.W., Mankin, J., Bauer-Gottwein, P., Yakovlev, A., 2012. Will climate change exacerbate water stress in Central Asia? Clim. Change 112, 881–899. https://doi.org/10.1007/s10584-011-0253-z

Soliev, I., Theesfeld, I., Wegerich, K., Platonov, A., 2017. Dealing with “Baggage” in Riparian Relationship on Water Allocation: A Longitudinal Comparative Study from the Ferghana Valley. Ecol. Econ. 142, 148–162. https://doi.org/10.1016/J.ECOLECON.2017.05.002

Solomina, O., Barry, R., Bodnya, M., 2004. The retreat of Tien Shan glaciers (Kyrgyzstan) since the little ice age estimated from aerial photographs, lichenometric and historical data. Geogr. Ann. Ser. A, Phys. Geogr. 86, 205–215. https://doi.org/10.1111/j.0435-3676.2004.00225.x

Sorg, A., Bolch, T., Stoffel, M., Solomina, O., Beniston, M., 2012. Climate change impacts on glaciers and runoff in Tien Shan (Central Asia). Nat. Clim. Chang. 2, 725–731. https://doi.org/10.1038/nclimate1592

TajStat, 2015. Tajikistan in Figures. Dushanbe.

Todd Jarvis, W., 2013. Groundwater Around the World: A Geographic Synopsis. Groundwater. https://doi.org/10.1111/gwat.12072

Vykhodtsev, I.V., 1966. Geobotanical research in Kirgizia (in Russian). Ilim, Frunze.

Vykhodtsev, I.V., 1956. Vertical zonation of vegetation in Kirgizia (in Russian). Akademia nauk SSSR, Moscow.

Wang, P., Li, Z., Gao, W., 2011. Rapid shrinking of glaciers in the Middle Qilian Mountain region of Northwest China during the last ~50 years. J. Earth Sci. 22, 539–548. https://doi.org/10.1007/s12583-011-0195-4

Williams, M.W., Konovalov, V.G., 2018. Central Asia Temperature and Precipitation Data, 1879-2003. https://doi.org/10.7265/N5NK3BZ8

Xenarios, S., Gafurov, A., Schmidt-Vogt, D., Sehring, J., Manandhar, S., Hergarten, C., Shigaeva, J., Foggin, M., 2018. Climate change and adaptation of mountain societies in Central Asia: uncertainties, knowledge gaps, and data constraints. Reg. Environ. Chang. 1–14. https://doi.org/10.1007/s10113-018-1384-9

Xu, C., Li, Z., Wang, P., Anjum, M.N., Li, H., Wang, F., 2018. Detailed comparison of glaciological and geodetic mass balances for Urumqi Glacier No.1, eastern Tien Shan, China, from 1981 to 2015. Cold Reg. Sci. Technol. 155, 137–148. https://doi.org/10.1016/j.coldregions.2018.08.006

Xu, Z., Liu, Z., 2014. Climate Change Scenarios and the Impact on Runoff, in: Water Resources Research in Northwest China. Springer Netherlands, Dordrecht, pp. 311–357. https://doi.org/10.1007/978-94-017-8017-9_9

Zhao, X., Tan, K., Zhao, S., Fang, J., 2011. Changing climate affects vegetation growth in the arid region of the northwestern China. J. Arid Environ. 75, 946–952. https://doi.org/10.1016/j.jaridenv.2011.05.007

Zhumanova, M., Mönnig, C., Hergarten, C., Darr, D., Wrage-Mönnig, N., 2018. Assessment of vegetation degradation in mountainous pastures of the Western Tien-Shan, Kyrgyzstan, using eMODIS NDVI. Ecol. Indic. 95, 527–543. https://doi.org/10.1016/J.ECOLIND.2018.07.060

Zhumanova, M., Wrage-Mönnig, N., Darr, D., 2016. Farmers' Decision-making and Land Use Changes in Kyrgyz Agropastoral Systems. Mt. Res. Dev. 36, 506–517. https://doi.org/10.1659/MRD-JOURNAL-D-16-00030.1

Zuo, D., Xu, Z., Zhao, J., Abbaspour, K.C., Yang, H., 2015. Response of runoff to climate change in the Wei River basin, China. Hydrol. Sci. J. 60, 508–522. https://doi.org/10.1080/02626667.2014.943668

APPENDIX I. CLIMATE CHANGE PERCEPTION QUESTIONNAIRE.

Dear respondent, according to scientists, climate change has been observed in recent years, which is expressed in changes in air temperature and rainfall. It is expected that these changes can affect people's lives. In this regard, we would like to know about your observations on this subject.

Have you heard about climate change: yes, no. **If yes: where did you hear about it:** TV, radio, newspapers, neighbors, other: ___________.

1) What is climate change? (several options possible): 1. The weather will get hotter 2. The weather will get colder 3. There will be less rain 4. It will rain more 5. There will be landslides and earthquakes 6. There will be a solar eclipse 7. There will be dirty air 8. There will be less water in the rivers 9. There will be more water in the rivers 10. Own answer: __________________	**2) What effect will climate change have? (several options possible):** 1. Crop production will decrease 2. Crop production will increase 3. Livestock will get sick 4. Trees will develop diseases 5. Trees will be more healthy 6. There will be more grass 7. There will be less grass 8. Prices will rise 9. Prices will fall 10. People will get sick 11. People will feel better 12. There will be more wild animals 13. There will be fewer wild animals 14. No effect 15. Own answer: __________________
3) What is the reason for climate change (several options possible): 1. Changes by itself 2. Unknown 3. People pollute the air 4. People pollute water 5. There are too many people 6. The sun shines too much 7. The sun shines a little 8. Too many cattle 9. People consume a lot 10. Water is taken for irrigation 11. Own answer: ___________________	**4) What needs to be done to prevent the climate from changing (several options possible):** 1. Nothing to do 2. Remove plants and factories 3. Reduce the number of cars 4. Reduce livestock 5. Increase livestock 6. Give loans to farmers 7. Stop taking water for irrigation 8. Plant more trees 9. We have to remove all the trees 10. Own answer: _________________
5) How has the weather changed in your area in recent years (several options possible): 1. It got hotter 2. It got colder 3. Temperature has not changed 4. It rains more 5. Less rain 6. The amount of rain has not changed 7. More snow 8. Less snow 9. The amount of snow has not changed 10. Own answer: ___________________	**6) How has the environment in your area changed in recent years (several options):** 1. More grass 2. Less grass 3. More crops 4. Less crops 5. Trees develop diseases more often 6. Trees develop diseases less often 7. Livestock gets sick less often 8. Livestock gets sick more often 9. There is less water in the canals 10. There is more water in the canals 11. Own answer: ___________________

7) What is the reason for the weather change?	8) What do you think needs to be done?

Cross out the option that seems right to you: **In recent years:** **Summer has become:** hotter, has not changed, colder **Winter has become:** hotter, has not changed, colder **Spring has become:** hotter, has not changed, colder **Autumn has become:** hotter, has not changed, colder
Snow in winter has become: More, has not changed, less **Rain in spring has become:** More, has not changed, less **Rain in summer has become:** More, has not changed, less **Rain in autumn has become:** More, has not changed, less
Livestock in the village has become: More, has not changed, less Why:
Wild animals in the mountains has become: More, has not changed, less Why:
The number of trees in the area has become: More, has not changed, less Why:
Fruit trees get sick: More, as usual, less Why:
Grass on pastures has become: More, has not changed, less Why:
Crops are growing: Better, as usual, worse Why:
The number of people in the village has become: Greater, has not changed, less Why:
Water in the river has become: More, has not changed, less Why:
Income of the population: Increased, did not change, decreased Why:
How do you think life will be in the future: better, will not change, worse Why:
What are the most important sources of income in the village? Put the numbers on top in order, where 1 is the most important. livestock, gardening, crop cultivation, trade, state service, remittances, other:
What are the most important media in the village? Put the numbers on top in order, 1 is the most important. television, radio, newspapers, neighbors, authorities, other:

Name of respondent ______________________________ **Village of residence** ______________________

Sex ______ **Age** ______ **Marital status** ___________ **Number of people in the household** __________

Education: incomplete secondary, secondary, technical, higher. **Occupation:** _______________________

The main source of income: livestock, gardening, crop cultivation, trade, state service, remittances, other: