Floodplain areas along the Naryn River in Kyrgyzstan: assessment of hydrological and climate changes, and its dynamics

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In this paper, to study the floodplains along the Naryn River they have been selected two investigation areas in the distance and nearby of settlements, in case Emgek-Talaa and Ak-Tal villages of Naryn region in Kyrgyzstan. We analyse anthropogenic impacts on these areas and ecosystem services provided by floodplain forests in a comprehensive way including ecosystem structures. Floodplain areas deliver multi-functional services as forest, pasture land, habitats of plant and animal species, and also as resting place for local people. The methodology contains exploration of the study the landscape changes of the investigation areas by using remote sensing and GIS. The climatic conditions for the investigated area, as well as the magnitude and frequency of annual, monthly and daily water discharge of surface runoff and also groundwater level of the Naryn River were investigated.
Increasing temperature and climate variability, flooding and drought, alteration of intensity of precipitation and melting glaciers in high mountain areas affect the physical condition of natural resources. Climate change might cause larger and potentially hazardous summer floods. Due to the highly dynamic flow conditions of the Naryn River, this enhances water erosion especially of the river banks. Conservation and restoration of riparian forests is important for strengthening river banks and preserving biodiversity. We elaborate recommendations for the communities. Reducing negative impacts of climate change and mitigating anthropogenic influences on ecosystems should be a priority task building upon the involvement of stakeholders.

Keywords: floodplains, water erosion, hydrological regime, climate change.

Introduction

Floodplains are characterized by a dynamic connectivity to the water flow in the river channel. During flood events, they are partly or completely covered by water (Junk et al. 1989; Makkaveev 1998; Woessner 2000; Tockner et al. 2000; Butturini et al. 2002; Jolly&Rassam 2009). The extreme events of floods occur naturally, predicting the location, timing and magnitude of such events is related with high uncertainties especially in data-poor environments like Kyrgyzstan. Above a certain stream flow floods occur and overbank flow spreads out onto the floodplain areas. Floodplain areas along the Naryn River in Kyrgyzstan are important in flood to decrease peak of discharge. In addition, as the riparian ecosystems provide fuel wood and pastoral land for local people. Changes in vegetation cover resulting from land use influence the sediment transport (Harrison & Keller 2007; Benjarkar et al. 2011). Near the villages, deforestation of the floodplain reduces bank stability and leads to higher vulnerability towards bank erosion (Simon&Collison 2002). However, the roughness from riparian vegetation and woody debris deposits reduces the flow velocity of the water (Thorne 1990; Abt et al. 1994; Makkaveev 1998; Darby 1999).

Global climate change is a highly relevant topic in Central Asia visible in rapidly rising average annual temperatures. At the same time, alteration of temporal and spatial variability and magnitudes of precipitation occurs and extreme weather phenomena becomes more frequent. Furthermore, all components of ecosystems are exposed to impacts of climate change. Water resources in the high mountain regions dependent on glacier and snow melt are extremely vulnerable to climate change. Water availability is particular important in upstream and downstream areas of Naryn River and also to conserve of environment conditions. In recent years, relevant studies focus on trends in climate change related with glacier retreatment in Tien-Shan of Central Asia (Aizen et al. 1995; Bolch 2006; Kriegel et al. 2013; Gan et al. 2015). Other researches is devoted to water management and transboundary issues with generation of electricity (Trouchine and Giese 2006). Little attention has been given to the importance of floodplains along the Naryn River and their preservation, a knowledge gap we want to help filling with this study.

For a sound understanding of the human-environment interaction of the Naryn River floodplain, not only information about flood risk and riverbank erosion are relevant, but also knowledge about the rejuvenation processes of natural riparian ecosystems. Conservation of biodiversity and maintenance of forest ecosystem functions for climate regulation are significant in preventing global climate change and mitigating its consequences. Negative impacts of climate change on water resources are an increase in runoff and rising water levels in rivers during spring time and accelerate the glacier melting. Also an increase in the intensity of precipitation changes and the extreme weather events can be observed. Altering of hydrological regimes of rivers from snow and glaciers modify the characteristics of hazards and risks in high-mountain regions. The glaciers of the mountains of the Central Tien Shan have significant influence on the formation of summer surface runoff of the Naryn River (Aizen et al. 1995; Kriegel et al. 2013; Gan et al. 2015). It is important to understand how runoff is altering environmental conditions of the floodplain areas. Obtaining knowledge on these environmental issues provides information for water resource management of settlements. Therefore, the aim of this study is to assess hydroclimatic changes, potential pressures on the floodplain areas along the Naryn River and the alteration of the river channel and also their dynamics by using remote sensing databases.

Materials and methods

Study area

Study area is the floodplain along the Naryn River in Kyrgyzstan. Two specific study sites, one nearby and one distant from settlements have been selected for the field based investigations (Fig.1). The Naryn River shows a diverse morphology along its course, the largest floodplain areas are located in the central part of the catchment downstream from Naryn City (Betz et al., 2018). The Naryn River is the main and a right tributary of the Syr Darya in Central Asia. Its catchment is located in the north and central Tien Shan region. The source of the Naryn River starts at the north-western part from the formation of the two rivers, Big and Small Naryn and from the glaciers of the Ak-Shiyrak mountain range. Then in Ferghana Valley this river merges with Kara-Darya. Overall, about 2 % of the basin area is occupied by glaciers of Central Tien Shan mountains. Contribution of these glaciers to the annual discharge is significant (Aizen et al. 1995, Kriegel et al. 2013; Gan et al. 2015). The vegetation species in floodplain areas consist of species such as poplar (*Populus nigra),* willow *(Salix spp.),* and shrubs as honeysuckle (*Lonicera spp.*), sea buckthorn (*Hippophae rhamnoides*), Cotoneaster (*Cotoneaster spp.*), Spirea (Spiraea spp.), Tamarisk (*Tamarix spp.*), Rosa (*R –osa cinnamomea*) and Oleaster (*Elaeagnus angustifolia*).

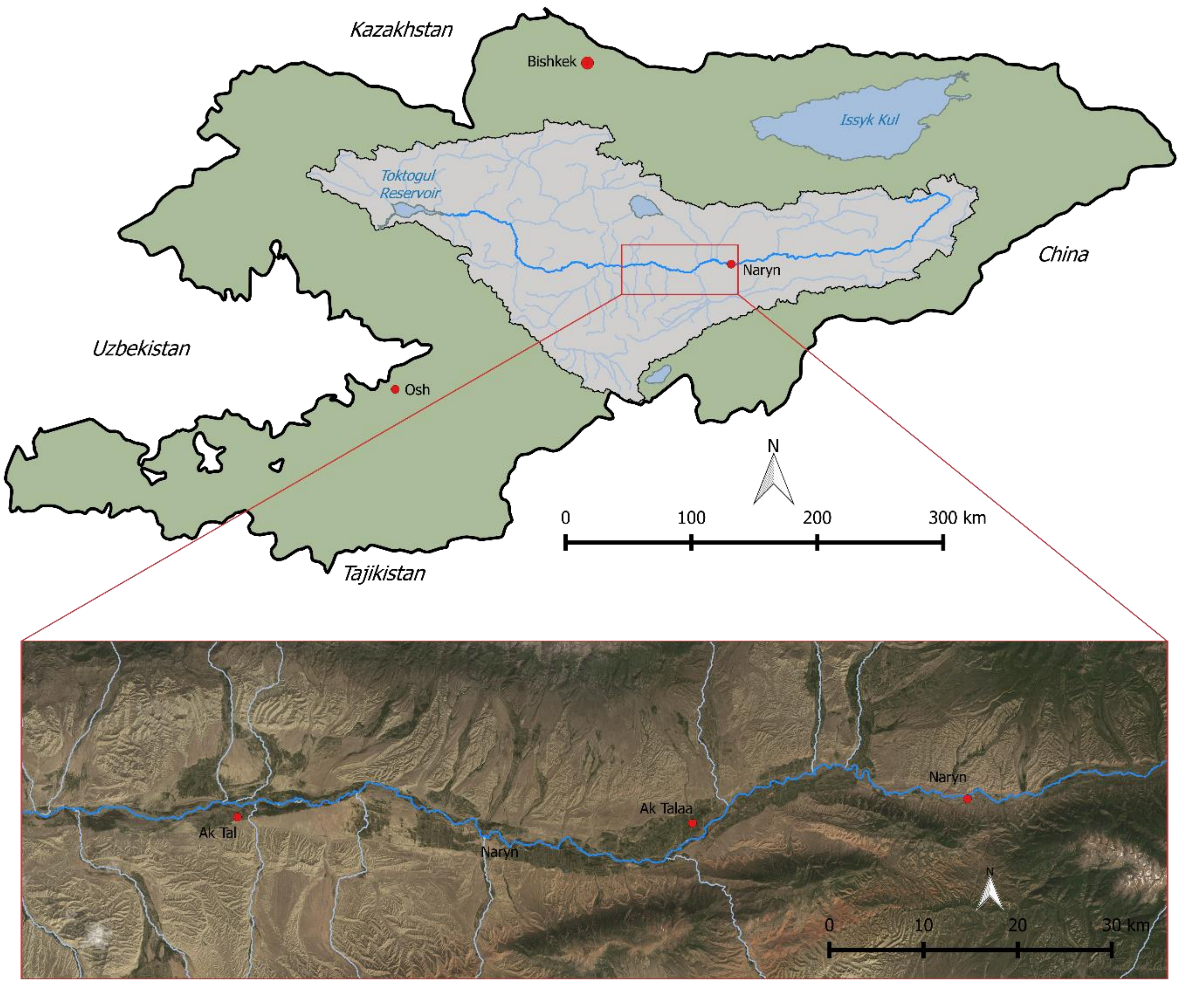

Figure 1. The location of the Naryn River catchment with the two investigation areas, "Emgek-Talaa" (floodplain area 1) and "Ak-Tal" (floodplain area 2) villages of Kyrgyzstan

Data analysis

The methodology of our study consists the analysis of the SRTM-1 digital elevation model (DEM) and Landsat imagery. These data sets have been retrieved from the United States Geological Survey (USGS) (http://earthexplorer.usgs.gov/). The DEM analysis includes watershed delineation to extract the length of the stream with elevation distribution in the catchment of the river. For this analysis, we used the r.stream modules in GRASS GIS (Jasiewicz and Metz, 2011). The DEM was used to extract a detailed topographical description of river length and bank areas. The geographic location of the watershed pour point for this study located from upper Tian Shan Mountains to the Toktogul Reservoir (Fig. 1). For analyzing the channel migration, multi–temporal Landsat imagery from 1972 to 2015 has been used following the approach suggested by Kummu et. al (2008). We selected images from the flood season (June to August) with a sufficiently small cloud cover. To cover our study area requires one Landsat scene, due to the temporal range, imagery from MSS, TM and OLI has been used. The river bank changes have been manually digitized using a false colour composition of the imagery. To analyze the lateral channel bank changes, we split the river into sub-reaches of 1 km length as shown in Fig 9 and 10. This segmentation resulted in 8 (floodplain area 1) respectively 5 segments (floodplain area 2). For this analysis, there were measured the changes of the riverbank location for five time steps. The erosion and accretion have been assessed for the left and right bank separately. In addition to these large scale investigations, the structure of the floodplain ecosystem has been assessed locally based on high resolution World-View2 imagery.

Statistical analysis of discharge and climate data has been used to assess hydro-climatic changes. The data collection determined by characteristics of observations such as the river runoff regime and seasonal changes in the water level, the flood and duration of the freezing river. Field observations have been made for changes in terrain and vegetation of floodplain channel sections. Data collection is provided by using HOBO data logger hardware. The climate data recorded every 30 minutes for wind speed and direction, air temperature, relative humidity, rainfall and solar radiation. Information on soil characteristics and land use of the study area was derived from the Harmonized World Soil Database (HWSD) of the Food and Agriculture Organization of the United Nations (FAO). Climate and hydrological data of the study area obtained from the World Center of surface water (Global Runoff Data Centre (GRDC) (https://www.bafg.de/GRDC/EN/01_GRDC/13_dtbse/database_node.html [Accessed 2015]), and also used data of Naryn City station. The groundwater level has been monitored in 2 wells during three years from 2014 in each investigated floodplains areas. The depth of ground water table continuously gathered using a water pressure sensor which connected to a data logger with parallel hydraulic gradients to the river channel.

Results

Temperature and precipitation are highly relevant parameters for runoff and their interactions are crucial issues for understanding discharge variability. Climatic conditions of the Naryn River watershed are characterized by a continental climate and determined by cold and long winters and hot, short summers. The diurnal variations of temperatures are extreme, frost may even occur in summertime. According to the Naryn meteorological station data the average annual temperature for the period from 1886 to 2005 is 2.7 °C. The fluctuation of the coldest is with an average temperature -25.8 °C in January and the warmest is July with an average temperature of 21.8°C. The average annual rainfall is about 300 mm with one clear rain season in spring (Fig. 1b). The temperature shows a significantly increasing trend while the precipitation is slightly decreasing (Fig. 2).

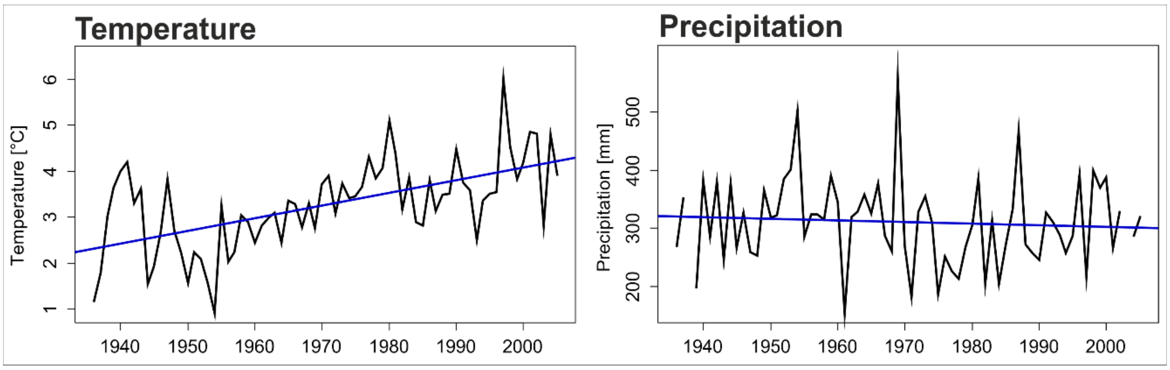

Figure 2. The long-term trends of temperature and precipitation of Naryn City

As a main factor of the hydrological regime is the runoff water of considered river and this indicated in the Fig. 3 for period 1988-2017. According the daily discharge measurements mean discharge at the Nary City Station about 102.81 m^3/sec for the considered time.

For analyzed 29 years the maximum daily discharge 674 m^3/sec occurs on 15 June in 2016. Fig.3 shows the hydrograph from 1988 to 2017. Between 1995 and 2003, there has been a series of larger flood events followed by calm years before the large flood event in 2016.

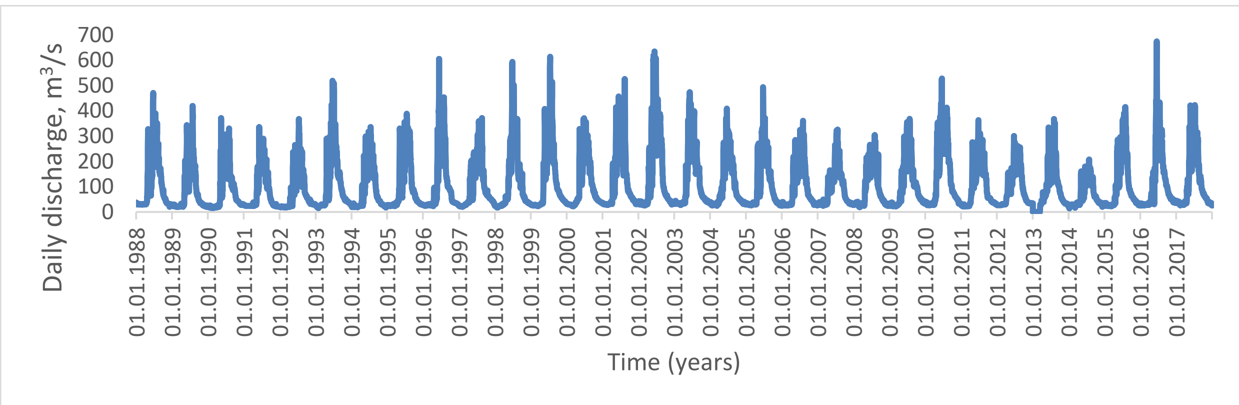

Figure 3. The long-term discharge of the Naryn River from 1988 to 2017

The analysis of the Naryn River discharge detected an increase of volume of water within the extreme flood events in the investigated floodplain areas. As determining factors are regular changes in the state of the water body of the investigated river there was observed the level of flow of water and ice phenomena in time. We analyzed mean, maximum and minimum summer water flow from April to September each year (Fig. 4). The flood starts from May to August with a maximum runoff in June-July. Figure 4 shows the rise of discharge starts from April till September month. The intensity of spring floods was observed in June and lasted until September. Its magnitude and character of distribution shows the complex interaction of various natural factors within the river basin.

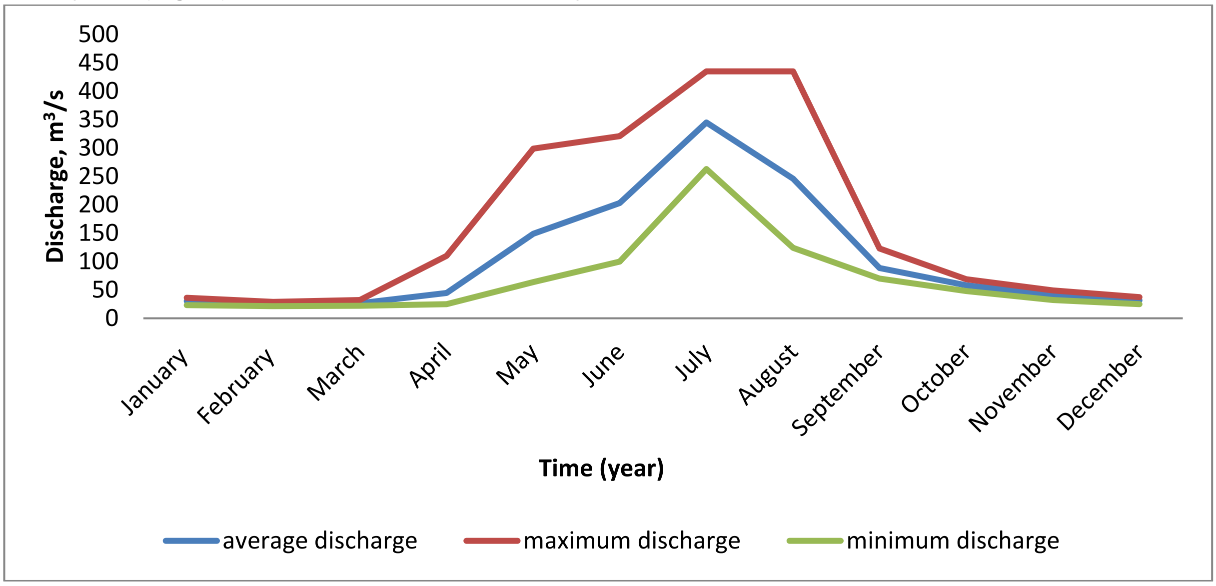

Figure 4. Comparison of discharges of the Naryn River for 2016

The rise in the groundwater level in the coastal zone occurs during floods (Fig. 5). The depths of groundwater vary with time. After the flood, the groundwater level is in the same position. On the floodplain areas of the Naryn River the ground flow appears as small streams in the form of surface water bodies.

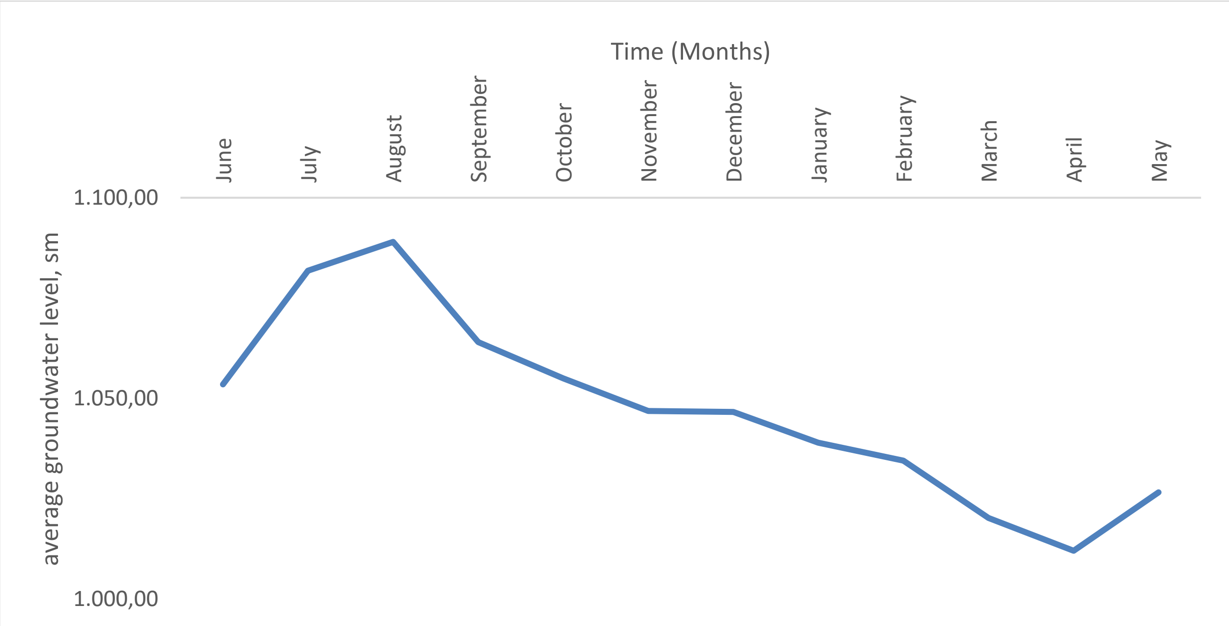

Figure 5. Average groundwater level of the floodplain areas of Naryn River

Determination of the water level in the floodplain areas helps to understand the hydrologic variables, including flood frequency and flood duration to study the impact of an altered hydrologic regime. This discharge is the most effective at doing the work that maintains the channel's morphological characteristics. Figure 6 indicates the maximum water flow on the floodplain areas according to maximum discharge in June 2016.

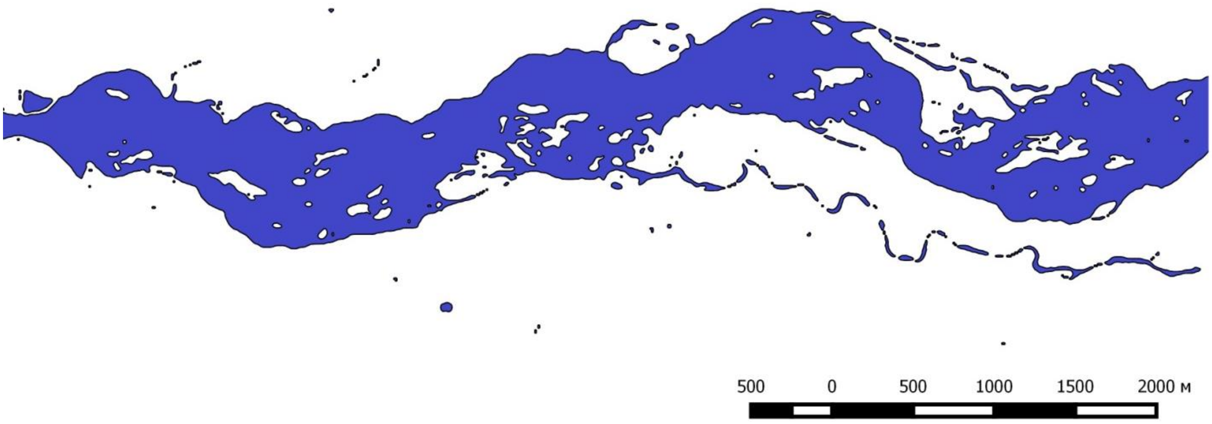

Figure 6. Overbank inundation pattern of the Naryn River along the floodplain areas in June 2016

The runoff of the Naryn River is mainly formed by snow and glacier melt. As a consequence, floods occur from June to September. Average annual discharge has shown a significantly increasing trend, especially since the early 1990s (Fig. 7). On a monthly basis, this increase is strongest in June and July (Fig. 7). Reason might be enhanced glacier melt due to climate change.

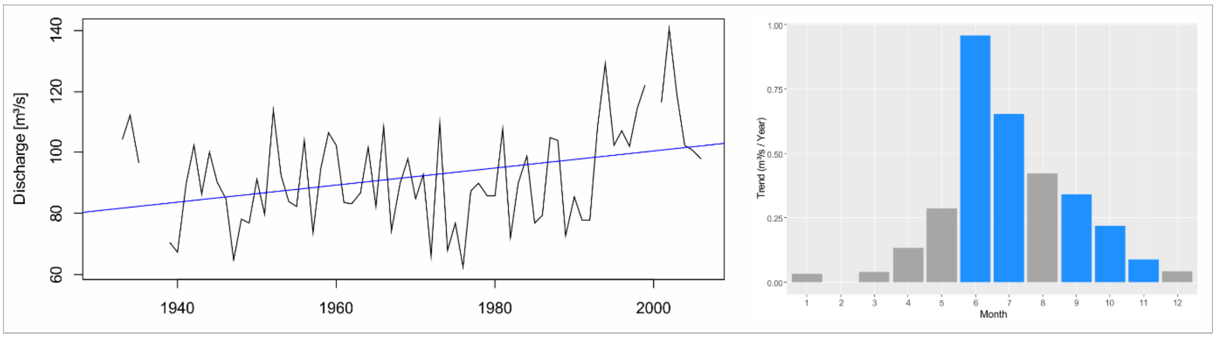

Figure 7. The discharge trends of the Naryn River; the left figure shows the annual trend, the right figure the monthly trend where blue bars indicate trends significant under the 95 % confidence level

The relationship between a river channel and floodplain depicts the several forms of surface relief. The recent floodplain structure of the investigation areas near Ak-Tal and Emgek-Talaa can be described as a braided river channel with extended bars and islands confined by a discontinuous high terrace (Fig. 8) (Betz et al. 2018). The geomorphological shape of the upper and the middle part of the Naryn River is characterized by various planforms like straight reaches forced by terraces and braided river sections. The river channel shows a high morphological dynamic over the past more than 43 years (Degembaeva et al., 2017, see Fig. 9). The sediment loads are high consisting of both – suspended as well as bed load. The high morphodynamics are expressed in the formation and re-working of gravel bars and fine sediment deposits as well as by a dynamic succession of riparian vegetation (Fig. 8).

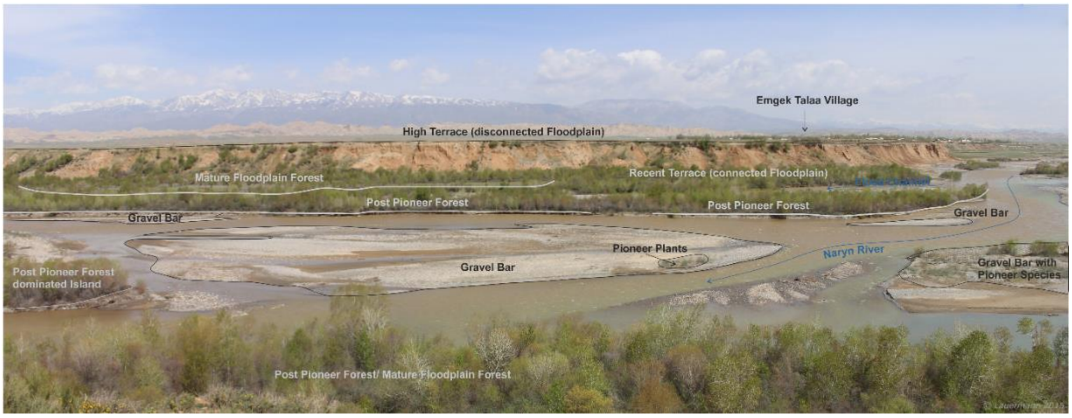

Figure 8. Structure of geomorphologic units of the floodplain area near Emgek-Talaa

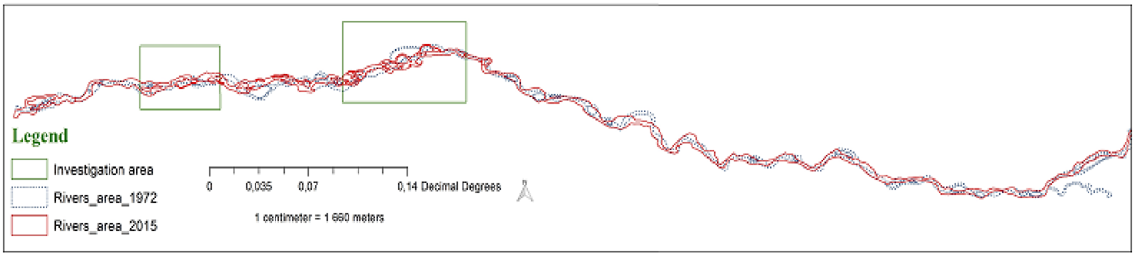

Figure 9. Lateral migration of pathways of the Naryn River for 1972-2015

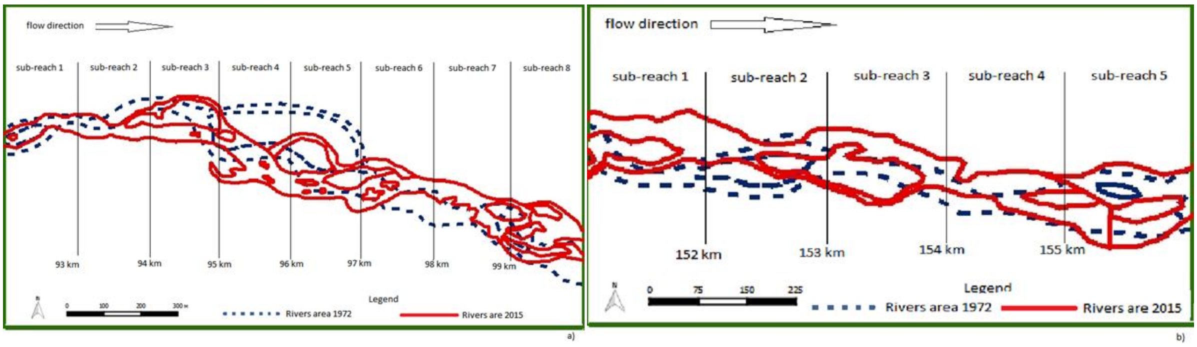

Figure 10. The accretion and erosion rates of the floodplain areas Naryn River

Figure 9 and 10 show the erosion and accretion identification on the floodplain areas. The erosion areas of the bank movement rates are plotted as a function of distance along the river banks of the two floodplain areas. The analysis for 1972–2015 shows an average bank accretion of 0,8 m/a and an erosion of 0,4 m/a for the floodplain area 1. The average bank accretion of 0,6 m/a on the left bank and 1,0 m/a on the right bank for the floodplain area 2. Also the average erosion rate is 0,5 m/a and 0,3 m/a accordingly.

Environmental zoning maps are essential for the sustainable management of natural resources and reflect ecosystem services, ecosystems and their components. Mapping of floodplain forests helps to plan and effectively manage the activities of the Forestry Department and local self-government to improve soil protection and water protection functions (see Fig. 11 for an example). Such maps have also been used for stakeholder workshops with local communities to discuss more sustainable management alternatives. Based on ecological assessment and the workshops, our recommendations are the development of a rule for regulation of forest use, organizing of a local tree nursery, appointment of a responsible person controlling the forest use and rotation of areas in forest use.

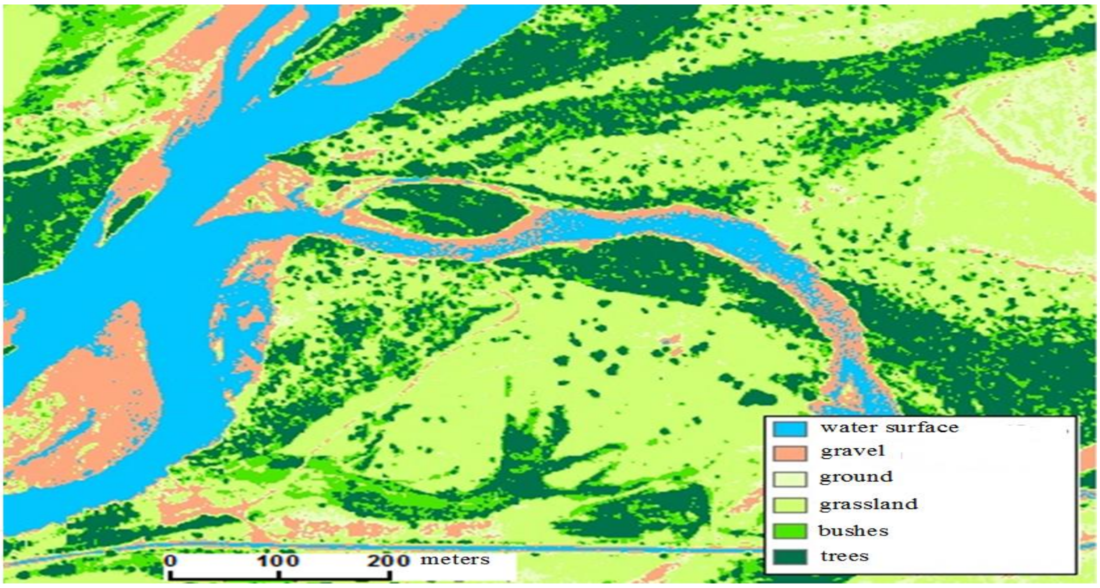

Figure 11. Mapping of ecosystem structure of floodplain areas along the Naryn River

Discussion

Land use and climate change have been recognized as driving factors for anthropogenic impacts on the floodplain areas along the Naryn River. Runoff of the river depends on climatic conditions which are vital issues for hydrological regimes. Our obtained results for the period from 1886 to 2005 in Fig. 2 show that the temperature of the investigated area has a significantly increased trend. At the same time the precipitation has a decreasing trend. Giese et al. 2007 noted that in the last decades the air temperature in all parts of Central Asia has increased. Hagg et al. 2013 mentioned that from 1943 to 1997 decrease of annual precipitation has a rate of 21 mm per decade. In the Naryn River watershed the highest intense of precipitation occurs during spring and early summer (Aizen et al., 1995; Schiemann et al., 2008). However, the climatic conditions of the river basin affect the distribution of river flow during the year. Thus, climate change is likely to affect the hydrological regime of the river including the seasonal pattern as well as the magnitude of the peak discharge.

Climate change leads to enhanced snow and glacier melt and thus to an increase of runoff and rising water levels during spring and summer time (Fig. 7). An alteration of hydrological regimes of snow and glacier fed rivers changes the characteristics of hazards and risks in high-mountain regions. As mentioned before, the main discharge of the Naryn River is generated from the melting of snow and glaciers. From Fig 3 and 7 can be seen that the floods occur from June to September. This monthly basis confirms and is strongest in June and July (Fig. 3 and 7). The annual discharge shows a significantly increasing trend, particularly in beginning of 1990s (Fig. 7). Hagg et al. (2013) revealed that the flood regime of the Naryn River is characterized by a high wave and short duration. In the formation of a large proportion of this river assigned to glaciers and glacial runoff is observed in summer from May to September. Contribution of glaciers melting from Northern Tien-Shan to the annual runoff is about 18-28% and for summer runoff reaches 40-70% (Aizen et al. 1996). For period 1956-2007 the annual runoff contributed consist 7,3-9,2% in total runoff volume in the Big Naryn basin (Hagg et al. 2013). This is due to an excess of water provided by the reduction of glacier masses.

Land-use change such as deforestation with vegetation removal and soil cover reduction leads to increased water erosion of river banks and channels. Also, anthropogenic pressure from grazing in the floodplain area influences hydrological properties and changes their structure. Deforestation makes the floodplain more susceptible and vulnerable to-bank erosion, as the stabilizing influence of the riparian vegetation is reduced (Simon&Collison 2002). River floodplain areas have a significant impact on the movement of the water flow, thus producing a greater resistance to the movement of water. Therefore, the river channel and floodplain flows have complex interactions (Makkaveev 1998).

Increasing the water flow velocity and flow depth in the flood period is accompanied by transport of suspended and bedload sediments. The largest discharges have higher power to form river channel. Sediment deposited in the floodplain area and accumulate on its banks as a part of the river. As it is known, water slows down with the change of water depth in the floodplain and flow encounters resistance from the roughness of its surface. Disturbed floodplain ecosystem are more sensitive towards the erosive power of the river, affecting the reduction of humidification and dehumidification of rivers neighborhood due to drainage of groundwater flow. Unstable riverbanks lead to a change in the channel in the left bank of the Naryn River (Fig 8, 9 and 10). In the observed floodplain areas different forest types like willow or, poplar forests, thickets of sea buckthorn shrubs and species of tamarisk from the characteristic vegetation cover. Forestes islands separates the riverbed into several small streams. Formed and sustainable forest reduces the destructive properties of mountain rivers, as it decreases the rate of flow. Sustainable floodplain ecosystems increase the level of the area moisture around the river.

With the change of vegetation due to intensive logging and overgrazing, as well as recreational use of floodplains, there occurs soil compaction, and consequently, a decrease in its infiltration capacity. Thus, the use result in local modifications of the hydrological cycle with increased overland and flow leading to soil erosion. The highest potential for natural hazards related to bank erosion is located in areas where deforestation of floodplains takes place near the villages. Local people are using fuel wood, timber and construction materials. In addition, they use floodplains for livestock grazing from autumn to late spring. Rejuvenation and seed establishment of woody floodplain species are affected by the pastoral use of the floodplain areas along the Naryn River. Therefore, such anthropogenic impacts can lead to increased flood risk and bank erosion (Fig. 9 and 10). In addition, the floodplain forest contains a variety of plants valuable as genetic resources (Naiman et al. 2005). For these forests, it is very important to build conservation plans together with local peoples. Furthermore, conservation of biodiversity and maintenance of forest ecosystem functions and services are significant in mitigating climate change consequences.

Conclusions

In the watershed of the Naryn River, hydrological processes proceed naturally. Therefore, in this study, the passage of extreme floods and the marking of surface runoff on the floodplain section of the river have been determined. Extreme flood events are an important issue when planning and managing watersheds. The development of erosion processes as consequence of climatic and hydrological conditions is also facilitated not only by intensive grazing of livestock, but also by cutting down forest in floodplain areas. Thus, studies on hydrological and geomorphological processes along the Naryn River should consider both, changing conditions resulting from climate change and anthropogenic impacts.

Nowadays, close attention has got the question related to the availability of water. The hydrological regime of the Naryn River floodplains is affected by the climate, the presence of glaciers as well as by human factors. At the same time the glaciers are melting rapidly due to the effects of global warming. The challenge of water scarcity and population growth causes humanity to reconsider the attitude to the environment and to find solutions for the efficient use of not only water, but also in the whole of natural resources. By integrated management of the natural environment, we provide only reasonable and rational use of natural solutions.

Acknowledgements

The authors express their thanks to the Volkswagen Foundation who supported the EcoCAR project (www.ecocar-centralasia.com) which was the frame of this research.

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