Using GIS and Remote Sensing for Assessing Riparian Ecosystems along the Naryn River, Kyrgyzstan

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Abstract

In the extremely continental and semi-arid climate of Kyrgyzstan, the rivers and their floodplains have an enormous importance as a regional hotspot of biodiversity and for the provision of ecosystem services to local people. For a comprehensive assessment of riparian ecosystem services objective and conscientious information about the structure and processes of the natural environment is required. The integration of remote sensing and GIS analysis can provide such information in an efficient way. In this paper, we present a workflow for the derivation of the extent and spatial distribution of floodplain ecosystems along the main streams within the Naryn catchment. Riparian ecosystems are characterized by natural to semi-natural vegetation which is connected to rivers via potential flooding, erosion or deposition of sediment or the recharge of groundwater from the river discharge. To capture this conceptual idea, we combine terrain analysis for deriving areas structurally connected to the river channels with multispectral remote sensing for distinguishing vegetated from non-vegetated areas. Applying this approach to the catchment of the Naryn River, 2369.84 km² of areas connected to the main streams could be identified. From this area, 65.74 % are vegetated, 18.18 % covered with water and 16.08 % are characterized by bare soil. While we could demonstrate the general ability of this approach for delineating riparian ecosystems, further field calibration will be required for testing and enhancing the reliability of the results.

1. Introduction

In the extremely continental, semi-arid climate of Kyrgyzstan, the rivers and their floodplains are not only a regional hotspot of biodiversity but provide also important ecosystem services (ESS) to local people (Karthe et al., 2015). Taking the Naryn River as an example, relevant ESS are the collection of fuel wood and the berries of the sallow thorn. Furthermore, riparian forests are important pastoral land, help mitigating erosion and – from a global perspective – climate change via the storage of carbon. For a comprehensive analysis of ecosystem services – especially in the context of decision making – conscientious and objective information about the structure and processes of the natural environment is required. As for the analysis of river systems the catchment scale matters, GIS and remote sensing provide important tools for an efficient assessment of geomorphological and ecological parameters (Fryirs and Brierley, 2013).

One such information is the extent and spatial distribution of riparian areas within the catchment. There has been a range of attempts to characterize these riparian areas e.g. via species composition, soil condition or influence by hydrological processes (Holmes and Goebel, 2011). We focus on a process-based approach and define riparian ecosystems as natural or near-natural vegetation connected to hydrological processes of a river network (Hupp and Osterkamp, 1996 and Clerici et al., 2013). These processes include potential flooding, fluvial morphodynamics like erosion and deposition of sediment as well as the influence of river discharge on ground- and surface water. Consequently, for GIS-based derivation of riparian ecosystems, flood prone area need to be estimated and vegetated pixels distinguished from non-vegetated ones. While the identification of vegetation from remote sensing has become a standard task e.g. via thresholding of vegetation indices (Wulder et al., 2012), the identification of flood prone areas is challenging.

The most sophisticated method for assessing flood probabilities would be hydraulic modeling. However, hydraulic models have a high data demand for parameterization which is not widely available. Therefore, approaches based on digital elevation models are a reasonable alternative. These approaches use for instance the relative topographic position, the flow accumulation or the relative position of the river channel as indicators for potential flooding (Williams et al., 2000, Gallant and Dowling, 2003, Nardi et al., 2006 and Manfreda et al., 2008). In this study, we take the Naryn catchment in Kyrgyzstan as an example and demonstrate the estimation of potential flooded areas from digital elevation data as well as the delineation of riparian vegetation based on multispectral remote sensing.

2. Regional Overview

The Naryn River is located in Kyrgyzstan in Central Asia (Figure 1). For this study, we focus on the catchment till the Toktogul Reservoir with a size of 52,130 km². Within these boundaries, the Naryn River has an entire length from its uppermost headwaters to the reservoir of 622 km and drops from 5133 m down to 868 m (values derived from the SRTM-1 elevation model). The discharge shows a glacial regime with one single peak in July, average discharge for the gauge Naryn City is 92.12 m³/s. The climate is highly continental with hot summers with monthly summer averages up to 25 °C and cold winters with minimum monthly averages of -25 °C. Figure 2 gives the climate diagram and the hydrograph of Naryn City. Until the Toktogul Reservoir, the Naryn is a near natural river with no dams and very few embankments guarantying full lateral and longitudinal connectivity.

The river is characterized by a deep incision into bedrock and Quaternary sediments. Consequently, recent floodplains which are connected to hydrological and hydro-morphological processes can be distinguished from terraces. The actively shaped part of the river shows laterally confined reaches with forced meanders as well as braided river sections. The main (woody) species of this recent floodplain's ecosystem are *Salix spp.* and *Populus spp.* as well as *Hippophae Rhamnoides*.

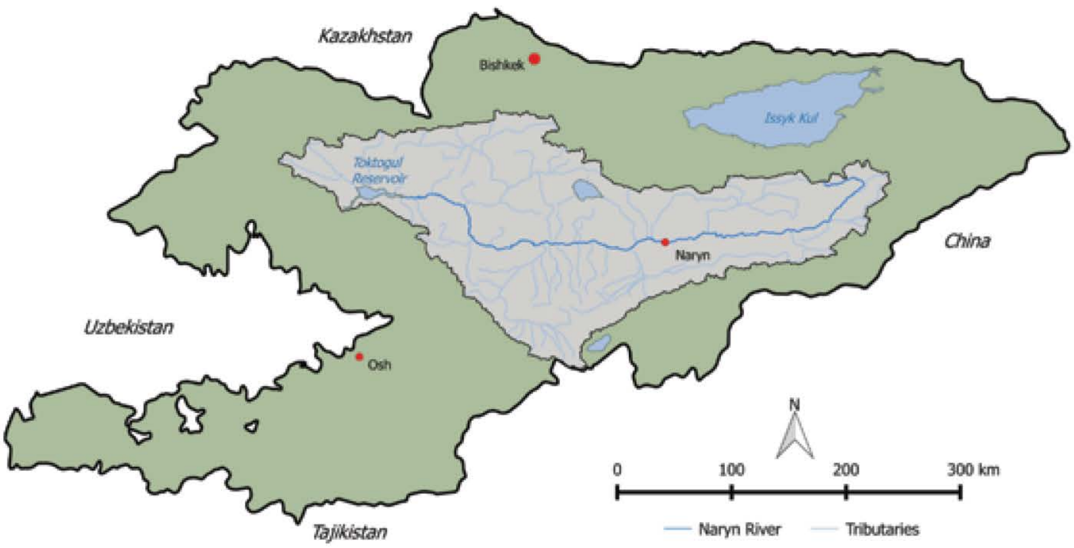

Figure 1: Overview over the study area with the Naryn catchment in gray

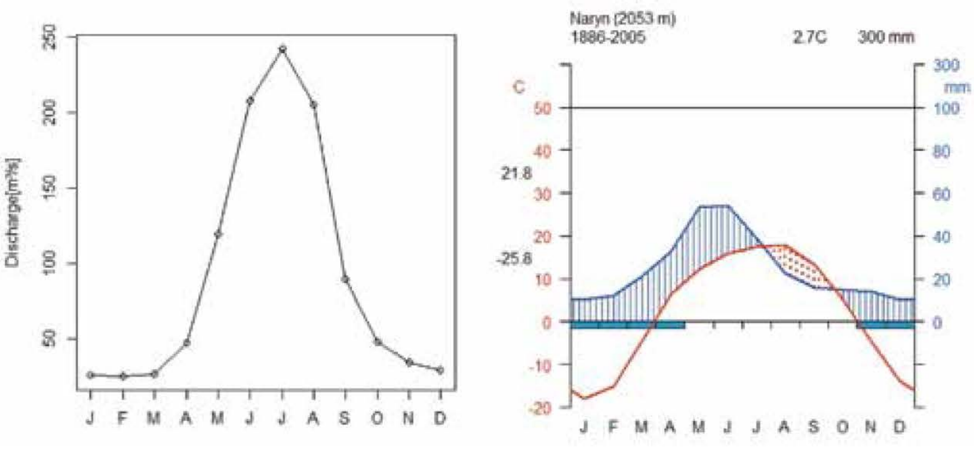

Figure 2: Hydrograph (l) and Climate Diagram (r) of Naryn City

3. Material and Methods

In a first step, we use the r.stream toolkit in GRASS GIS for the extraction of a stream network from the SRTM-1 elevation model (24.05 m horizontal resolution). This toolkit offers an efficient and user-friendly way for hydrological derivations from elevation data and analysis of stream networks (Jasiewicz and Metz, 2011). After the extraction, the stream network has been thinned using Horton orders bigger than 3. As riparian areas are characterized by connectivity to the river channel, areas potentially influenced by the river need to be derived. We use a DEM approach and combine the vertical distance above the river channel with the multiresolution valley bottom flatness index (Williams et al., 2000 and Gallant and Dowling, 2003).

For extracting information related to vegetation, we use Landsat-8 imagery from July 2015. A total number of 7 scenes is required to cover the entire catchment. The data was processed to surface reflectance by the USGS L8SR algorithm. This data can be obtained on demand from espa.cr.usgs.gov. Clouds and cloud shadows have been masked out from further analysis. We use the tasseled cap angle as vegetation index for separating vegetated from non-vegetated areas (Powell et al., 2010).

$$TCA = \arctan(\frac{TCG}{TCB})$$

Equation 1

Where TCA is the tasseled cap angle, TCG is the tasseled cap greenness and TCB the tasseled cap brightness. Details about the tasseled cap transformation for LANDSAT 8 OLI can be found in Baig et al., (2014). As TCG defines the vegetation plane and TCB the bare soil plane, tasseled cap angle values < 0 can be interpreted as no-vegetation, whereas TCA values > 0 can be interpreted as vegetated. In the next step, a water mask is applied using a threshold of the modified normalized difference water index (Xu, 2006). Its calculation is given by equation 2. MNDWI is the index, G is the green band and SWIR1 the short wave infrared band. A threshold of 0.07 was selected to separate water from non-water.

$$MNDWI = \frac{(G-SWIR1)}{(G+SWIR1)}$$

Equation 2

Finally, we combine the information about flood susceptibility, vegetation abundance and the presence of water. Pixels classified as connected to the river and covered with water belong to the permanent river channel or flooded areas, while non-vegetated areas not covered with water are likely to be gravel bars. Finally, pixels classified as being connected to the river channel and vegetated are considered as riparian vegetation.

4. Results and Discussion

First result is the network of the main stream channels. This thinned river network has an entire length of 4872.4 km and is shown in the study area map in Figure 1. This is the basis for the further calculation of the vertical distance to stream network which is the simplest indicator for flood prone areas. Figure 3 shows the map of vertical distance to channel network. The areas in dark blue indicate areas with a relative elevation of smaller than 6 m, which was found as the upper boundary of the active floodplains in cross section surveys in the field.

As the local floodplain morphology can cause differences in this threshold, the Valley Bottom Flatness Index (Gallant and Dowling, 2003) was used as an additional indicator for flood prone areas (Figure 4). The bright colors refer to steeper terrain, the blue colors to flat terrain. In this map, the lake Son Köl and the Toktogul Reservoir, as well as some parts of the Naryn valley south from Son Köl appear as obvious flat features. The detailed view in figure 4 shows a section of the Naryn River close to Emgek Talaa village. There, the valley bottom of the river is visible in dark blue while the bright linear feature can be interpreted as terrace edge. When considering areas lower than 6 m above the river channel and a high MRVBF, there are 2369.84 km^2 of potentially flooded areas. Even if this method provides valuable insights in the morphology of the Naryn River, there are several issues. Due to the coarse resolution and errors resulting from radar noise within the used SRTM-1 elevation model, this approach of deriving potentially flooded areas has some uncertainty. Thus, future work has to include not only a straightforward approach for flood prone area derivation but also a careful evaluation of the used method.

Second relevant input for the assessment of riparian areas are actually flooded areas. Within the area classified as connected to the river channel, 430.92 km^2 have been covered with water in July 2015, what is a relative amount of 18.18 %. The Naryn River is represented well with the braided river characteristics (detailed view in Figure 5). The final step is the delineation of vegetated pixels connected to the processes in the river channel. Setting the threshold of the tasseled cap angle to 0 (what means the inclusion also of sparse vegetation) we get a total area of riparian vegetation of 1557.93 km^2 (65.74 % of the potential floodplain area).

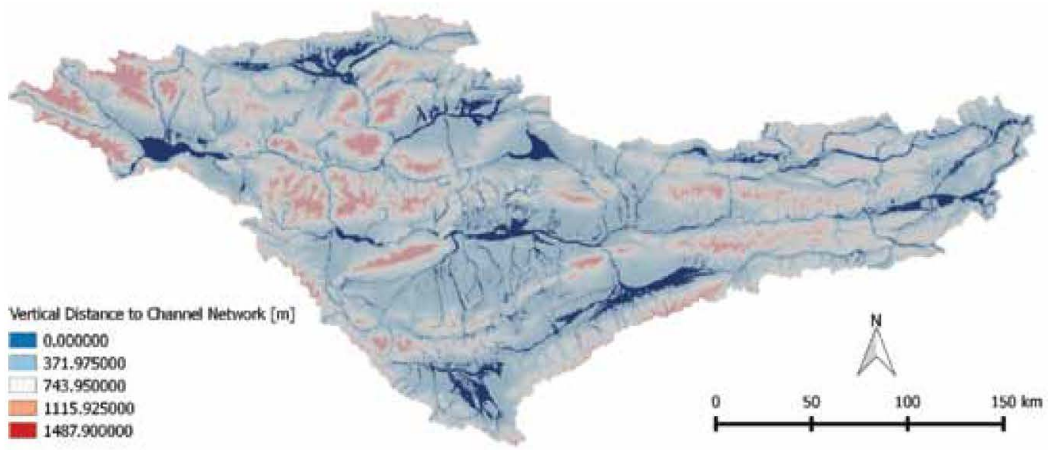

Figure 3: Vertical Distance to Channel Network relative to the main rivers; the dark blue colors indicate distances smaller 6 m

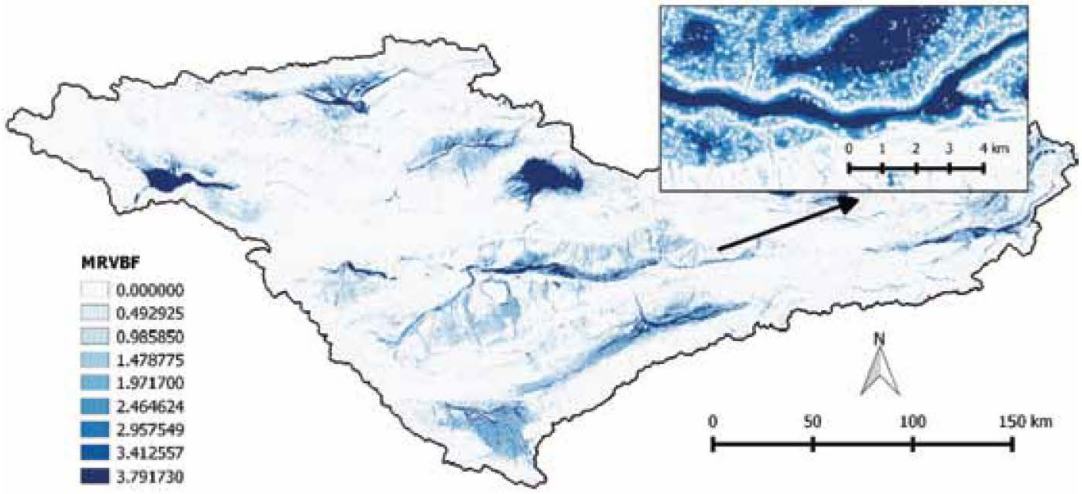

Figure 4: Multiresolution Valley Bottom Flatness Index (MRVBF) for the Naryn Basin; the dark blue indicates flat areas while the bright linear feature can be interpreted as terrace edge

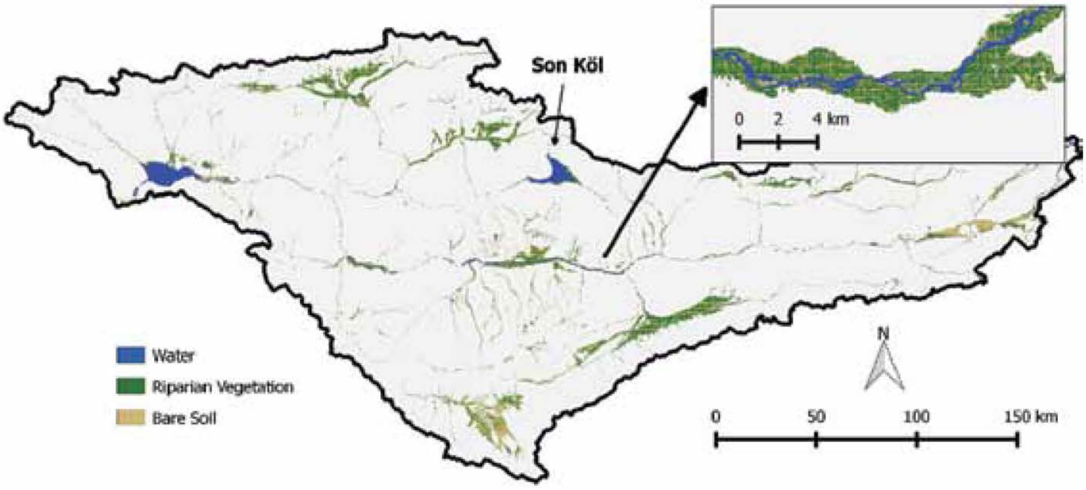

Figure 5: Map of the riparian ecosystem in the Naryn Basin; green color represents riparian vegetation, blue color water; the misrepresentation of the highlighted lake Son Köl is discussed in the text

Furthermore, 380.99 km² of bare soil have been detected within the floodplain area (tasseled cap angle <0).

When interpreting these results, we see a relatively low share of bare soil or gravel what is not typical for an active braided river. As July is the peak of the flooding season at the Naryn River, it is likely that low elevation gravel bars will be covered with water while higher elevation areas are in a further succession stage and are also covered with vegetation not completely submerged. From an ecosystem service point of view, the extent and distribution is an important basic parameter for their assessment. Nevertheless, ESS have a strong socio-economic component which cannot be directly captured via remote sensing and GIS. Thus, further interdisciplinary research is required for a sound analysis. However, remote sensing can deliver an important contribution to making statements about the biophysical part of ecosystem services.

From a methodological point of view, the misrepresentation of the lake Son Köl which is caused by creating river channels through the lake during the flow routing process. This is of course not a suitable representation of reality and needs further (manual) correction. However, digital elevation data and multispectral remote sensing imagery even with a coarse resolution of 30m are able to capture important characteristics of riparian ecosystems. Of course, no detailed statements about the exact extent of a single vegetation patch will be possible, but on the scale from reach to catchment, there is the opportunity for meaningful results. Based on the concept presented here, ongoing work includes the analysis of LANDSAT time series offering the possibility for investigating ecosystem dynamics of the Naryn floodplain vegetation from the 1990's until the present.

5. Conclusion

For an efficient assessment of the ecosystem services of riparian vegetation GIS and remote sensing are suitable tools to generate information on the catchment scale. The key factors characterizing riparian vegetation – abundance of natural or near-natural vegetation and connectivity to hydrological and geomorphological processes of the river channels – can be derived with the methods of terrain analysis and multispectral remote sensing. We applied LANDSAT imagery and SRTM-1 elevation data for the delineation of riparian ecosystems along the main streams of the Naryn catchment. Within this region, 2369.84 km² are connected to processes of the river channel. From this area, 65 % are vegetated, 18.18 % covered with water and 16.08 % are characterized by bare soil. Even if we could get meaningful results with the suggested approach, further methodological evaluation and field calibration will be necessary to be able to provide reliable information about the Naryn floodplain ecosystems.

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