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Assessing the Impacts on Natural Ecosystems of the Future Kambarata-1 Hydropower Station on the Naryn River, Kyrgyzstan: A GIS-based Approach

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Abstract

In the semi-arid climate of Kyrgyzstan, the rivers have a particular importance in providing water for irrigation in agriculture, and for the production of hydropower. Kyrgyzstan is in general rich in water resources. Nevertheless, there are conflicts surrounding the operation of Toktogul, one of the most important reservoirs in the region. Exploiting the hydropower potential of the currently free-flowing upper Naryn River is therefore an ongoing planning issue. Despite the obvious advantages, the planned construction of Kambarata-1 hydropower station would cause a significant alteration of the natural conditions of the Naryn. However, there are no recent studies on the ecological impact of this hydropower project. The present study contributes to filling this gap, delivering up-to-date information on the potential impact of the reservoir construction on the natural ecosystems in the area. The results show that, due to the geomorphological characteristics of the reservoir site, it is mostly steppe ecosystems that will be affected by the reservoir construction, and only a relatively small area of floodplain forest will be destroyed. In conclusion, the ecological impacts of Kambarata-1 HPS are minimal due to the specific characteristics of the location.

Keywords:

hydropower, riparian ecosystems, ecological impact, naryn river, central asia

1 Introduction

In the semi-arid climate of Kyrgyzstan, the rivers are particularly important in providing water resources for irrigation in agriculture, and for the production of hydropower (Bernauer & Siegfried, 2012). An annual runoff of 48.6 million m³ in 2000 makes Kyrgyzstan, together with Tajikistan, the Central Asian water tower (Sorg et al., 2014). The Naryn merges with the Kara Darya to form the Syr Darya, the largest tributary of the Aral Sea. The water resources of the Kyrgyz rivers are crucial also for the downstream populations in Uzbekistan and Kazakhstan (Mamatkanov, 2013). While downstream countries have a major interest in the use of water resources for irrigation during the growing season, Kyrgyzstan, as an upstream country, wants to exploit the hydropower potential of the Naryn. This has led to an ongoing conflict about the management of the Toktogul reservoir, the most important infrastructure for water resource management in the region (Bernauer & Siegfried, 2012). Due to this conflict and the general shortage of electricity, Kyrgyzstan intends to further exploit the hydropower potential of its rivers.

The Naryn is the largest river in the country, with a maximum discharge of 2,880 m^3/s. It has high hydropower potential, of 36.5 billion kWh per year (Mamatkanov et al., 2006). Upstream of the Kambarata-2 hydropower station (HPS), which is itself located well upstream of the Toktogul reservoir (see Figure 1), the Naryn is still a free-flowing river, which makes it a regional hotspot of biodiversity (Betz, 2021; Betz, Lauermann, & Cyffka, 2020). At the same time, there have been plans for exploiting the hydropower potential of the Naryn since the Soviet era. A total of eight cascades of 28 larger and small HPSs producing 9.5–1,860 MW are planned in the Naryn river basin (Maratbekov, 2018). While the construction of these hydropower plants is expected to have negative impacts on biodiversity, it would allow water resource management to be modified, which could potentially reduce the regional conflict around the operation of the Toktogul reservoir (Mubarakshin, 2013; Namazova, 2016; Urmambetova & Chymyrov, 2017). As a consequence, there is a trade-off between biodiversity conservation and the production of hydropower. This trade-off should be carefully considered in order to allow sustainable development that takes into account both economic development and the conservation of natural ecosystems and their services (Lauermann et al., 2020).

One of these planned HPSs is Kambarata-1, located directly upstream from the Toktogul reservoir. Once completed, the height of its dam will be 275 m, leading to a normal water level of 1,198 m above sea level. The intended power is 1,860 MW, and an average annual generation of 5.1 GWh of electricity. This would make it the most powerful HPS in the whole of Kyrgyzstan (Düzdaban, 2021). In addition, the Kambarata-1 reservoir would allow using the Toktogul reservoir, designed to have a volume of 19.5 billion m^3, for long-term water regulation in order to satisfy the irrigation demands of the downstream countries and Kyrgyzstan's own need for hydropower production (Kasymova, 2013; Mubarakshin, 2013).

Despite the advantages that the construction of the Kambarata-1 HPS could have, the trade-off between hydropower production and impacts on the natural ecosystems should be examined closely. As the existing planning strategies were developed as early as the 1970s and 80s, updated information on the environmental impact is required (Namazova, 2016; Croix & Suyorkulova, 2015). The aim of this study is to fill this knowledge gap and provide reliable scientific information on the environmental impact of the Kambarata-1 reservoir. Due to its remote location and limited accessibility, remote sensing and GIS methods were used for this purpose.

2 Study area

The study area is located in the Naryn river basin in Kyrgyzstan, upstream from the Toktogul reservoir, which is currently among the largest reservoirs in the region (see Figure 1). It is bound by the Moldo Too and Ferghana ridges in the south, and the Suusamyr Too in the north. From a hydromorphological perspective, the Naryn is divided into multiple large sections: a steep headwater section upstream from Naryn City; an interplay of braided and straight reaches in the central Naryn Basin; a gorge section immediately upstream from the Toktogul reservoir (Betz, Lauermann, & Cyffka, 2021).

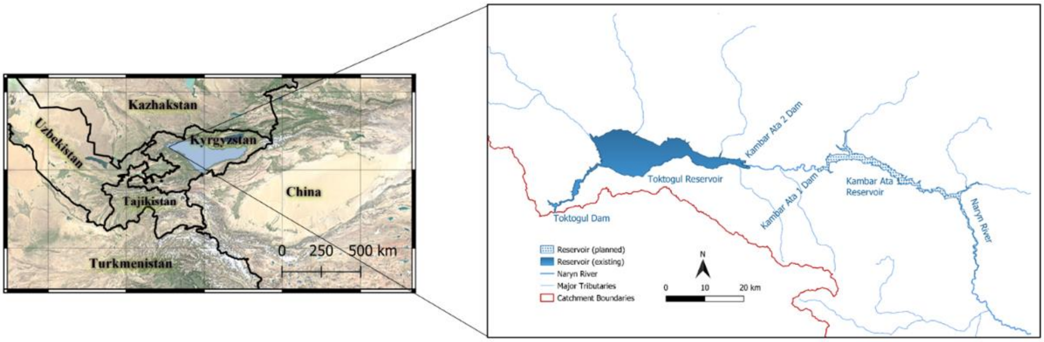

Figure 1: Overview of the study area (basemaps from Google Earth and https://gadm.org/; channel network, reservoirs and catchment boundaries are derived by the authors on the basis of a Tandem-X DEM)

The planned Kambarata-1 reservoir is located in the gorge section, which is more than 150 km long. Within the gorge, the Naryn shows a high degree of confinement, without extensive floodplains (Betz et al., 2020). The hydrological dynamics are currently characterized by annual summer floods arising from snow and glacier melt in the headwaters (Betz, 2021). The riparian ecosystems occurring under these conditions are dominated by *Populus nigra*, *Salix babylonica*, *Hippophae rhamno*ides and *Tamarix spp.*, where the species composition depends on the hydromorphological disturbance (Betz, 2021; Egger et al., 2022).

Kambarata-1 HPS is designed for construction upstream from the already existing Kambarata-2 HPS (see Figure 1). The intended dam height is 275 m, resulting in a reservoir area of approximately 60 km² and an estimated volume of 4.65 million km³ (estimations from this study). The eastern boundary of the reservoir is the mouth of the Kokirim River. The largest tributaries of the Naryn in this river section are the Kambarata, Kokomeren, Kokirim and Toluk, but all except the Kokomeren are shallow and contribute only a minor share of discharge compared to the Naryn itself.

3 Data and methods

The study comprises three major steps (see Figure 2). First, the reservoir area and volume were estimated using terrain analysis. In the second step, the landcover for the future reservoir area was derived from supervised classification of Sentinel-2 imagery as well as by using official cartographic material of the Kyrgyz authorities. Then, the landcover was analysed regarding the potential loss of natural ecosystems due to the reservoir construction. The reservoir delineation was carried out in ArcGIS pro. The landcover derivation and subsequent analysis were performed in R.

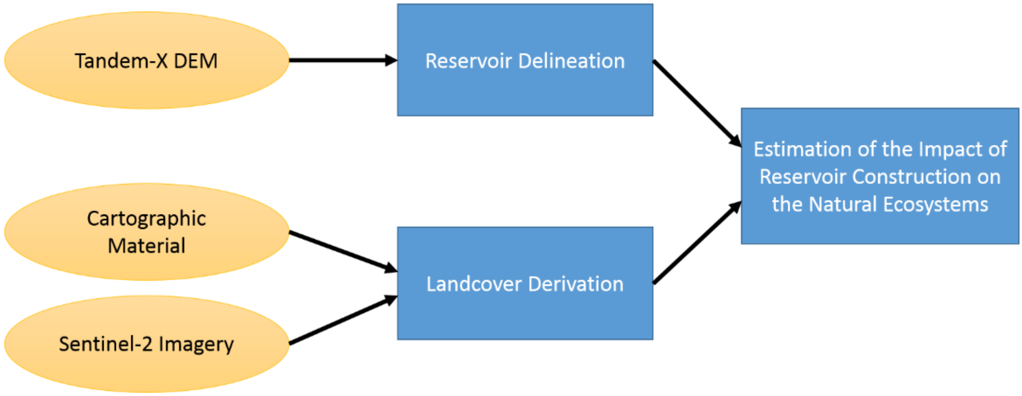

Figure 2: Workflow of the study

The reservoir delineation was carried out based on terrain analysis using a TanDEM-X digital elevation model (DEM) with a resolution of 12.5 m. The DEM was initially screened for artefacts and voids arising from issues in the data acquisition of the radar sensor. Artefacts were removed using filtering techniques. For void filling, the ALOS World DEM (30 m resolution) was used. After applying the cut/fill tool in ArcGIS pro, this corrected and void-filled DEM was used to compute the area and volume of the future Kambarata-1 reservoir based on the planned dam location and its height of 275 m.

The current landcover was mapped from Sentinel-2 and TanDEM-X data using a supervised classification approach. For this, a random forest model was used, which was originally developed for the riparian ecosystems in the central Naryn basin upstream from the area of interest of this study. However, due to the proximity of the locations and the similarity of the ecosystems, this model was deemed suitable for application to the area of the future Kambarata-1 reservoir as well. The model is based on atmospherically corrected and cloud-masked Sentinel-2 images from July and October 2019 as well as several terrain attributes computed from the TanDEM-X DEM. A total of 2,964 ground control points were used to create the random forest model. The set of ground control points were split randomly into a training dataset (75 %) and a validation (25 %) dataset. The confusion matrix derived from the prediction on the validation dataset was used to compute the overall accuracy.

In addition, ***existing cartographic material*** on vegetation and land use from the Kyrgyz authorities was used. The maps were originally developed by Soviet cartographers between 1975 and 1980 at a scale of 1:500,000. Although outdated, these maps are still used in the decision-making process by Kyrgyz authorities. The maps were scanned, georeferenced and clipped to the boundary of the future reservoir area. The information was then manually digitized.

Once the information about landcover had been derived and intersected with the area of the future Kambarata-1 reservoir, it was analysed in terms of environmental impact. ***To assess the impact of the construction of the reservoir on the natural ecosystems***, the result of the landcover classification was intersected with the area of the future reservoir. Of special interest was the assessment of riparian forests, as they are scarce compared to (for example) steppe ecosystems on the hillslopes. Thus, the current riparian area was delineated using a maximum vertical distance above the river channel of 5 m as an indicator for riparian zone membership (Betz, Lauermann, & Cyffka, 2018). After the delineation of the riparian zone, the landcover derived from remote sensing was analysed separately for areas inside and outside the riparian zone. Finally, the results were interpreted in terms of the ecological impact.

4 Results and discussion

The results show that the area of the planned Kambarata-1 HPS is 60.56 km², and the estimated volume is 4.65 million km³ (see Figure 3a). The area currently belonging to the riparian zone is 13.44 km² (21.83 %) while the non-riparian area is 48.12 km² (78.17 %) (Figure 3b). Due to the location in a gorge with a high degree of confinement, such a simplified DEM-based riparian zone delineation already yields satisfactory results, as the issue of a fuzzy transition zone rather than a sharp boundary does not arise (Betz et al., 2018).

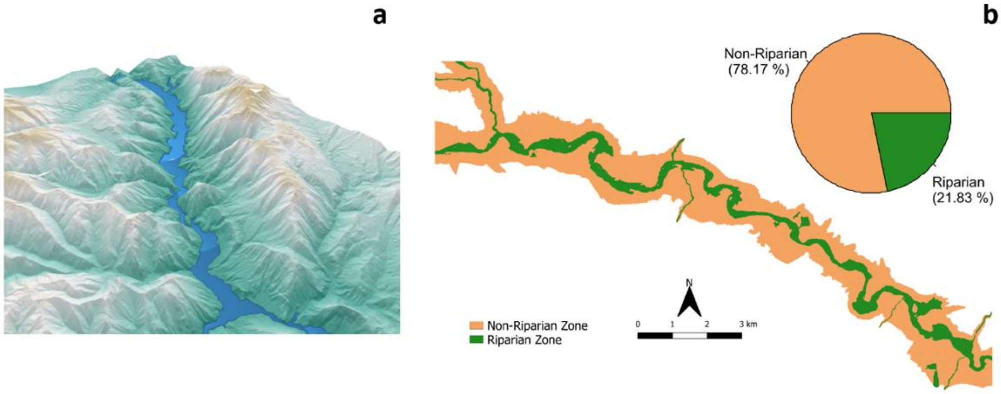

Figure 3: a) View from east towards the modelled reservoir area; b) riparian and non-riparian area within the future reservoir

The validation of the random forest model for the landcover classification shows an overall accuracy of 97.39±1.8 %, with similar accuracies across all classes. Thus, the resulting dataset can be considered a reliable source of information for analysing the impact of the construction of the Kambarata-1 reservoir. Figure 4 gives an impression of the resulting landcover map and shows the pattern within and outside the riparian zone. While this result is well suited for an initial assessment, future work might enhance the landcover classification using more detailed classes. In addition, ground control points collected directly in the area of the future reservoir area would be beneficial to validate the landcover model transferred from the upstream river stretch.

It becomes clear that there are significant differences between the riparian and the non-riparian zones. Most obvious is the dominance of the water class (7.5 km² or 52.4 %), even if the classification was created for the low-flow season, in October. Bare soil and rocks as well as shrubs are only minor classes, while forest and herbaceous vegetation are equally represented, with 22% and 21.6% respectively. This specific pattern arises from the geomorphological characteristic of the river section where the study site is situated. In such a gorge environment, the active channel directly borders the hillslope. Thus floodplains where riparian vegetation could occur are largely absent, found only in the form of isolated pockets (Betz et al., 2021). The vegetation outside the riparian zone is clearly dominated by herbaceous vegetation (82.6%). With 8.2%, the share of forest here is significantly lower than within the riparian zone. Outside the riparian zone, bare soil and rock are more common, making up 6.4%. Thus, we can consider the non-riparian zone to be governed by steppe ecosystems, while the area inside the riparian zone is characterized by an active river channel and only isolated floodplain pockets where riparian forest occurs. From an overall perspective, the area of the future Kambarata-1 reservoir is dominated by herbaceous vegetation, which can be interpreted as steppe ecosystems. Forests are rare and make up 6.3% of the total area only. Nevertheless, there are 11.4 km² of forest.

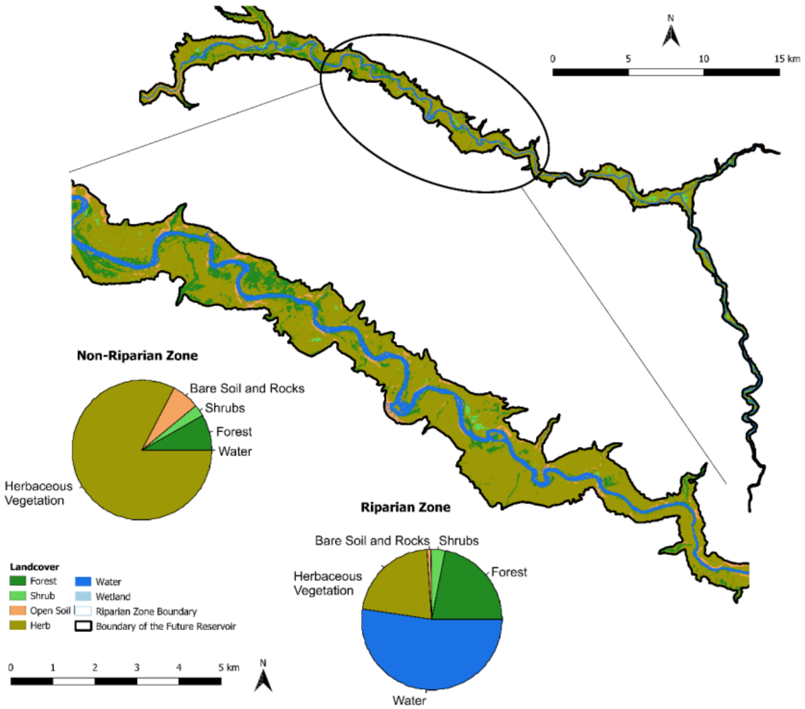

Figure 4: Landcover map of the area of the future Kambarata-1 reservoir; the pie charts show the landcover within and outside the riparian zone for the entire area of the future reservoir.

For further information, the Soviet-era vegetation and land-use maps were used. Figure 5 shows the digitized Soviet-era vegetation map in comparison with the landcover map derived for this study. It is obvious that it has only a very low degree of spatial detail, due to the scale of 1:500.000. The legends of the two maps describe the common vegetation communities, but while the modern, satellite-based landcover map has a much higher level of spatial detail, it does not have the same level of thematic detail. Both data sources are in general agreement with each other, as they highlight the dominance of steppe ecosystems in the area of interest. However, in the Soviet map, the floodplain ecosystems are not included. This is a drawback as these ecosystems are scarce in Kyrgyzstan, which makes them relevant from a conservation perspective. This need for updated information on the natural environment in Kyrgyzstan is an ongoing issue. Remote sensing offers great potential to contribute information on the floodplain ecosystems of Central Asian rivers when carefully applied (Betz et al., 2020; Chymyrov et al., 2019). An assessment of the ecological impact based on the cartographic material alone is insufficient, because the riparian ecosystems, for example, would not be considered in decision making.

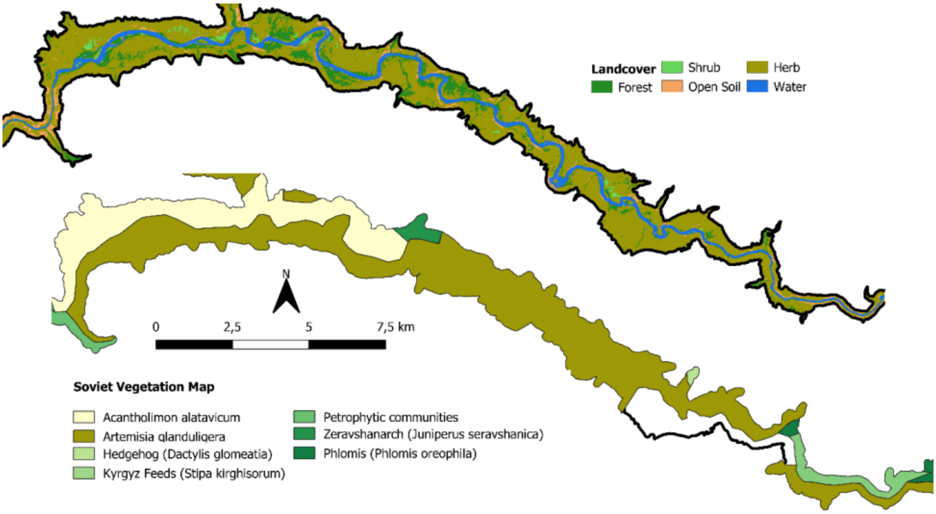

Figure 5: Top: Satellite-based landcover map derived in this study; bottom: Soviet-era vegetation map developed on a scale of 1:500.000

For a comprehensive assessment of the ecological impact of hydropower dams, the downstream effects also have to be discussed along with the impacts on the area flooded by the reservoir (Poff & Zimmerman, 2010). From this perspective, the location of the Kambarata-1 dam and its reservoir is ideal, as the planned location is immediately upstream from the already existing Toktogul reservoir (see Figure 1). Thus, even if the reservoir operation causes a modification of the natural flow regime, the impacts will be minimal as the river corridor affected by the altered hydrological dynamics is already highly modified. In addition, the upstream effects are relatively small. Due to the geomorphological characteristics within the gorge, there are no extensive floodplains with valuable riparian habitats such as floodplain forest or wetlands. The estimated forest loss of 11.4 km² could be compensated for by afforestation at other locations. In the Soviet land-use map, the entire area is classified as pastoral land. Assuming that most of the herbaceous vegetation is suitable for livestock grazing, there would be a potential loss of approximately 40 km² of pastoral land. However, due to the limited accessibility, it is likely that the pastures in the region have not been used frequently since the end of the Soviet period, when remote pastures tended to be abandoned

(Dörre, 2014). Nevertheless, it should be noted that confirmation regarding recent pasture use was beyond the scope of this study.

The impacts of dams on a river system are complex. Dams lead to a significant modification of connectivity in river systems. This modifies the pattern of erosion, transport and deposition of sediment (Schmitt et al., 2019), and the ability of species to migrate (Zarfl et al., 2019). Based on remote sensing and GIS methods alone, only a qualitative evaluation of the impacts can be made. For a more detailed evaluation of future scenarios, ecological and hydromorphological modelling has the ability to deliver comprehensive information (see e.g. Nguyen et al., 2018 for a recent review). In-depth evaluation of the impacts of the Kambarata-1 HPS based on modelling approaches was beyond the scope of this study; future work should take advanced modelling techniques into account. Information derived from remote sensing as presented in this study could serve as the basis for parameterizing sophisticated models.

5 Conclusions

In this study, we derived the reservoir area and volume of the planned Kambarata-1 HPS based on digital terrain analysis. Together with a landcover map derived from remote sensing and existing cartographic material, this was the basis for assessing the potential ecological impact. It became obvious that the cartographic material still used by Kyrgyz authorities is outdated and does not provide the required level of detail for informed decision-making. Nevertheless, it contains valuable information which can be used to complement products such as those based on information from remote sensing.

The evaluation of the ecological impact of the HPS construction reveals that the impacts are comparatively low. Due to the specific geomorphological characteristics of the future construction site, which is located in a gorge, there are only small patches of floodplains and a limited area of riparian ecosystems. It is mainly steppe ecosystems, which are not considered scarce in Kyrgyzstan, that are affected. The forest loss caused by the hydropower project might be offset by afforestation in other locations. Whether there will be an impact on the provision of pastoral land is currently not fully clear and should be further analysed by onsite investigation. Downstream effects of the dam on natural ecosystems due to a modified flow regime are not expected, as the Kambarata-1 HPS is located directly upstream of the existing reservoirs Kambarata-2 and Toktogul. The river section receiving the discharge from the future reservoir thus no longer has ecosystems with natural dynamics. This is in great contrast to potential hydropower dams further upstream, which could be expected to have significant negative impacts on the extensive floodplain ecosystems in the central Naryn basin and on their biodiversity. As, in addition, the Kambarata-1 HPS could contribute to a reduction of the transboundary conflict around the management of the Toktogul reservoir, it can be concluded that the construction of this particular hydropower plant has the potential to contribute to sustainable development in Kyrgyzstan.

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