Valuing Green Infrastructure: A Case Study of the Vakhsh River Basin, Tajikistan

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This report for the Vakhsh River Basin, Tajikistan, was developed by a World Bank core team led by **Paola Agostini** (Lead Natural Resources Management Specialist), **Sergio Vallesi** (Environmental and Water Resource Engineer), and **Juan Jose Miranda Montero** (Senior Environmental Economist), in collaboration with HYDROC GmbH, Altus Impact, University of Central Asia, Griffith University, Caritas Switzerland, and SedimentWorks GmbH.[1] Special thanks go to the following peer reviewers for their valuable contributions to the report: **Maged Mahmoud Hamed** (Lead Environmental Specialist), **Arame Tall** (Senior Environmental Specialist), and **Luis Diego Herrera Garcia** (Environmental Economist). In addition, the team would like to thank **Drita Dade** (Senior Natural Resources Management), **Elena Strukova Golub** (Senior Environmental Economist), **Juan-Pablo Castaneda** (Environmental Economist), **Leela Raina** (Environmental Economist), **Marc Massicotte** (Consultant) **Mathias Shabanaj Jankila** (Consultant), **William Young** (Lead Water Specialist), **Arthur Kochnakyan** (Lead Energy Specialist), **Kseniya Lvovsky** (Practice Manager, Environment, Natural Resources and Blue Economy for the Europe and Central Asia Region), **Andrea Liverani** (Lead Specialist), **Sascha Djumena** (Country Program Coordinator for the Europe and Central Asia Region), and **Ozan Sevimli** (Country Manager for Tajikistan) for their guidance and support.

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[2] https://www.worldbank.org/en/region/eca/brief/cawep.

[3] https://www.progreen.info/?redirect_id=block-views-block-slideshow-home-page-view-block-1.

[4] https://www.worldbank.org/en/programs/south-asia-regional-integration/brief/program-for-asia-connectivity-and-trade.

ABBREVIATIONS AND ACRONYMS

AFOLU	Agriculture, Forestry, and Other Land Use
BAU	Business-as-Usual
BCR	Benefit-Cost Ratio
CBA	Cost-Benefit Analysis
DEM	Digital Elevation Model
DFI	Development Finance Institution
DM	Dry Matter
DRS	Districts of Republican Subordination
ECO-DRR	Ecosystem-Based Disaster Risk Resilience
ESF	Environmental and Social Framework
EX-ACT	EX-Ante Carbon-balance Tool
FAO	Food and Agriculture Organization (of the United Nations)
FUG	Forest User Group
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIS	Geographic Information System
HPP	Hydropower Plant
IC	Implementation Cost
IFAD	International Fund for Agricultural Development
InVEST	Integrated Valuation of Ecosystem Services and Tradeoffs
IPCC	Intergovernmental Panel on Climate Change
JFM	Joint Forest Management
MC	Management Cost
MUSLE	Modified Universal Soil Loss Equation
NGO	Nongovernmental Organization
NPV	Net Present Value
NTFP	Non-Timber Forest Product
O&M	Operation and Maintenance
PES	Payment for Ecosystem Services
PPP	Public-Private Partnership
PUU	Pasture Users Union
RUSLE	Revised Universal Soil Loss Equation
SCC	Social Cost of Carbon
SDGs	Sustainable Development Goals
SWAT	Soil and Water Assessment Tool
UCA	University of Central Asia
UNFCCC	United Nations Framework Convention on Climate Change
USLE	Universal Soil Loss Equation

ABSTRACT

This report outlines the main results of a study conducted to assess the potential role of landscape restoration/nature-based solutions/green infrastructure in the Vakhsh River Basin, Tajikistan, to reduce the impacts of soil erosion on the hydropower cascade, increase agricultural productivity, improve livelihoods, and inform about investment opportunities. This assessment finds sediment sources and loadings in the Vakhsh River Basin, considers the potential correlation between soil erosion and sedimentation in hydropower reservoirs, proposes possible and cost-effective landscape restoration measures, and estimates the value of ecosystem services provided. The study also presents recommendations for implementing the proposed interventions for the Vakhsh River Basin and for scaling up to other degraded areas throughout the country.

To find, prioritize, and value the contribution of sustainable landscape restoration investments within the Vakhsh catchment, advanced biophysical models and economic valuations were combined and informed by literature reviews, stakeholder interviews, and field visits. The report consists of the following chapters:

Chapter 1 overviews the land degradation problem currently faced in Tajikistan and in the Vakhsh catchment and how it relates to and affects hydropower generation, the idea of addressing the issue through landscape restoration interventions and a catchment management approach, and the purpose of the study.

Chapter 2 discusses the methods used to assess the baseline information and to develop the integrated hydraulic and sediment transport model, which was used to run various simulations of landscape restoration interventions. It further discusses how suitable landscape restoration interventions were identified, how cost and benefits were assessed, and how ecosystem services were estimated.

Chapter 3 shows the results from the baseline assessment, including catchment characterization, geochemical tracing, climate change impacts and sediment budget, the selection of interventions, the cost-benefit analysis, and the economic valuation of the provisioning and regulating ecosystem services that may be influenced by implementing these interventions.

Chapter 4 presents the conclusions and key recommendations, which include suggestions for further work to build on the assessments conducted in this study.

The main conclusion is that landscape restoration/nature-based solutions/green infrastructures significantly benefit local, catchment, and global stakeholders. By increasing land productivity and supplying livelihood opportunities, reducing sedimentation, decreasing downstream impacts of floods and siltation, and improving carbon sequestration, landscape restoration increases the resilience of people, ecosystems, and infrastructures.

EXECUTIVE SUMMARY

CONTEXT

Millions of people in the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan depend on the freshwater supply of the Vakhsh River system (Gulakhmadov et al. 2020). Sustainable access to water resources underpins energy generation, agriculture, forestry, livelihoods, economic growth, and broader ecosystem services both nationally and regionally.

In Tajikistan, 90 percent of the nation's electric power generation capacity is produced by hydroelectric dams along the Vakhsh River (Xenarios, Laldjebaev, and Shenhav 2021). This cascade of dams includes the world's second tallest dam, Nurek Dam, with the future addition of the Rogun Dam upstream, expected to be the world's highest when completed (Britannica 2019).

Approximately 75 percent of Tajikistan's population reside in rural areas, and an estimated 49 percent of the rural population live below the poverty line. The country's agricultural sector contributes to 22 percent of the gross domestic product (GDP) (World Bank 2022c) while employing 43 percent of the population.[5] Despite this, Tajikistan depends on imports to cover 75 percent of its food needs (World Bank 2022c).

THE PROBLEM

Erosion processes occurring throughout the Vakhsh River Basin are threatening hydropower services and the reliability of irrigation and water supply systems, due to reservoir sedimentation. Mass wasting processes, including shallow and deep landslides, debris flows that directly enter channels, and deep gully erosion, are the dominant sediment sources of the Vakhsh River and its tributaries (Jones, Manconi, and Strom 2021; Lohr 2018; Safarov et al. 2015). Erosion processes have been further fueled by deforestation, unsustainable grazing, and poor agriculture management practices (World Bank 2020a), all contributing to added reservoir sedimentation and depletion of storage capacity.

Land degradation comes at a high economic cost to Tajikistan. Conservative estimates based on 2019 data range from US$574 million to US$950 million annually, equivalent to 8.1 percent to 13.4 percent of Tajikistan's GDP, due to productivity losses of croplands and pastures (World Bank 2020a). Moreover, Tajikistan is highly volatile to climate change in all sectors, ranked 100 out of 182 in terms of climate vulnerability (World Bank 2021).

Unsustainable land management and associated land degradation also affected livelihoods and caused damage to villages, roads, and farmland (Caritas 2019; World Bank 2012). Furthermore, degraded landscapes are more vulnerable to natural disasters and extreme weather conditions, including droughts, heavy rainfall, floods, and landslides—phenomena likely to become increasingly prevalent in this region in the coming decades because of climate change. The actual alterations in temperature and precipitation, however, remain highly uncertain (Gulakhmadov et al. 2020)

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[5] World Bank 2021 data, https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=TJ

Climate change is altering the distribution of freshwater resources and influencing the hydrological processes in different river systems in Central Asia. This is critical, as in 2015, only 74 percent of Tajikistan's population was estimated to have access to at least a basic level of water supply (World Bank 2021). The projected climate change scenarios in the Vakhsh River Basin point to an increasing tendency of annual streamflow and high-flow events (Kure et al. 2013). Moreover, models from the World Bank suggest that the annual probability of meteorological drought in Tajikistan will rise from 3 percent to over 25 percent under all emissions pathways by the 2050s (World Bank 2021).

THE CASE FOR LANDSCAPE RESTORATION/ NATURE-BASED SOLUTIONS/GREEN INFRASTRUCTURE[6]

Landscape restoration, intended as a mosaic of targeted interventions to reverse the impacts of land degradation, presents many environmental and socioeconomic benefits. It may enhance rural livelihoods and forest and agriculture productivity, hydrological provisioning and regulation of ecosystem services, climate change mitigation and adaptation, disaster risk and sediment management, and reservoir storage capacity.

As argued in this study, there is a compelling case for supporting economic development through investments into productive agricultural, pastoral, and forest landscapes within the Vakhsh River Basin, simultaneously serving as green infrastructure to protect the region's water, energy, and food security.

There are many approaches to using landscape restoration to derive its maximum benefits. The choice of any landscape restoration approach and combinations thereof depends on the context and the local circumstances, including land use types and the restoration aims (Mansourian, Lamb, and Gilmour 2005).

STUDY OBJECTIVES

The study's aim is to prioritize landscape restoration interventions in the catchment of the Vakhsh River, aiming to reduce soil erosion's impacts on the hydropower scheme, increase productivity and improve livelihoods, and inform potential future investments. The report highlights the need to integrate landscape/ watershed approaches into hydropower's design, implementation, and operation phases. In addition, this study's findings provide information for the World Bank's 'Technical Assistance for Financing Framework for Rogun Hydropower Project',[7] particularly concerning the application of the World Bank's Environmental and Social Framework (ESF).[8]

The intended audiences for the report are local, national, and regional decision makers, including government officers, financiers, and policy makers, and technical staff, such as landscape restoration practitioners and experts from the energy, agriculture, and water sectors.

The study identifies interventions and policy recommendations that hold relevance for the hydropower cascade in the Vakhsh River Basin. The findings and methodology hold relevance at a national, regional, and global level.

The following six steps have been undertaken in conducting this study: (a) catchment characterization and identification of sediment sources and loadings in the Vakhsh River

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[6] The three terms are used interchangeably for the purpose of this report.

[7] https://www.worldbank.org/en/news/press-release/2023/01/12/tajikistan-to-improve-the-rogun-hydropower-project-implementation-with-world-bank-technical-assistance.

[8] For more information on the World Bank's ESF, see https://www.worldbank.org/en/projects-operations/environmental-and-social-framework.

Basin, including field tests and the innovative use of geochemical tracing, undertaken by the University of Central Asia (UCA) and Griffith University, respectively; (b) integrated sediment and hydrology modeling; (c) identification of possible interventions, in consultation with local stakeholders; (d) cost-benefit analysis (CBA); (e) Ecosystem service valuation; and (f) prioritization of interventions. This report presents the findings and conclusions from these steps, recommends how the different beneficiaries and recipients can use the results, and outlines future work to improve the data and technical basis of the estimates.

METHODOLOGY

The study used a systematic valuation approach, anchored in stakeholder consultation with local stakeholders and nongovernmental organization s (NGOs), to define promising and possible landscape restoration interventions and identify where they may be upscaled, what ecosystem services they deliver, and where and to whom within the Vakhsh River Basin.

The most promising landscape restoration interventions were identified with stakeholders' consultations. Considered aspects included what ecosystem service the interventions would deliver and the criteria for their establishment, suitable altitudes and slope angles (for orchards and grazing), and pre-existing land uses (for example, sustainable pasture management interventions are assumed to be found on land that is already classified as pasture).

The net economic benefits of selected investments, orchards, woodlots, and rotational grazing, are evaluated individually, as well as in a large-scale restoration scenario that combines all interventions in a landscape mosaic across all possible locations within the Vakhsh watershed.

Ecosystem service benefits that were analyzed include the following:

- **On-site benefits to local land users due to more productive land.** Market value from enhanced timber supplies, livestock forage, fruits, nuts, and fuelwood were assessed against the investment and management costs (MCs) necessary to obtain them.
- **Downstream benefits to energy and water sectors in Tajikistan from reduced reservoir siltation and the regeneration of fragmented hydrological and carbon cycles were assessed from different angles:** avoided dredging and reservoir restoration costs from reduced reservoir siltation and value of enhanced water availability from reservoir storage, when used for downstream irrigation, and enhanced water fluxes, from soil moisture, lateral return flow, and groundwater infiltration, as well as value from marketable carbon credits from enhanced carbon sequestration.
- **Global benefits.** Avoided global damage costs and marketable carbon credits from enhanced carbon sequestration.

The method used to assess the sediment sources included geochemical tracing. The research, undertaken by Griffith University, consisted of collecting sediment samples from the Vakhsh catchment and analyzing them for particle size and geochemistry using ICP-MS[9] for 52 elements. Mixing modeling was then undertaken to find the proportional contributions of tributaries at critical junctions.

The method used to assess restoration interventions included the Soil and Water

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[9] Inductively coupled plasma time-of-flight mass spectrometry (ICP-MS) is used for multielement screening because of its ultra-high sensitivity and selectivity, high-throughput multi-element measuring capability, accurate absolute quantification in complex matrices, easy combination with chromatographic separation methods, complementarity with organic mass spectrometry, and isotope measuring ability.

Assessment Tool (SWAT)[10] **and the economic valuation process, which were run sequentially.** The model was used to set up the baseline for sediment and hydrological flows and to estimate those resulting from landscape restoration interventions. Monetarized ecosystem service benefits were used in a cost-benefit analysis to estimate the net benefit of intervening in distinct landscape restoration options relative to the opportunity cost of continuing land uses under business-as-usual (BAU) practices.

This study's models and economic analysis do not include climate change impacts. However, the research and recommendations considered the expected effects of climate change on the Vakhsh River Basin, which were assessed as part of the catchment characterization. The proposed landscape restoration interventions are intended to mitigate these impacts and supply a means of climate adaptation.

The study's models and economic analysis also did not include the impacts of soil erosion and sedimentation on water quality. While the study focused on water quantity, as well as the effects of soil erosion and land degradation on hydrological flows, it recognizes the importance of including this aspect in future work, especially with the escalation of climate change.

RESULTS

A CBA was assessed over a 30-year period (2022–2052) to make the economic case for landscape restoration. Following World Bank guidelines, discounted into present value terms using 6 percent, results are robust to different key parameter assumptions (more importantly, reducing the benefits years span, changes to the discount rate, and increasing cost of capital, among others). The primary beneficiaries are the rural communities and land users themselves. Net benefits to these stakeholders are presented first, followed by the catchment-wide co-benefits to the broader Tajikistan society.

Economic Net Benefits to Rural Communities and Land Users

- **Benefits from rotational grazing.** Using nonconservative implementation costs (ICs), rotational grazing generates US$2.1 of benefits for every US$1 invested and a net present value (NPV) of US$45 per ha, equivalent to an annual net benefit of US$1.5 per year per ha in present value terms. Assuming modest investment costs, pasture users enjoy US$8.4 for every US$1 invested. This is not an unrealistic outcome, considering ongoing innovation in virtual and mobile fencing (Wooten 2020).
- **Benefits from woodlots.** Accounting for the marketable value of fuelwood, timber, and non-timber forest products (NTFPs), as well as the establishment, maintenance, harvesting, and transportation costs, woodlots generate US$3.3 of benefits per US$1 invested and an NPV of US$31,690 per ha, equivalent to an annual net benefit of US$1,060 per ha in a 30-year rotation.
- **Benefits from orchards.** The highest net benefit may be enjoyed from the establishment of orchards. Preferred species for orchard development include apples, walnuts, pears, peaches, and apricots. Considering a mixed apple and walnut orchard, orchards generate US$4.2 in benefits for every dollar invested and an NPV of US$61,240 per ha, equivalent to an annual net benefit of US$2,040 per ha in present value terms.
- **Livelihood benefits for rural communities.**

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[10] SWAT is globally used to simulate the quality and quantity of surface water and groundwater and to predict the environmental impact of land use, land management practices, and climate change. It is also used in assessing soil erosion prevention and control, nonpoint source pollution control, and regional management in watersheds. For more information, see https://swat.tamu.edu/.

Since half of the estimated population in the Vakhsh River Basin (about 530,000 people[11]) are engaged in agriculture (ADB 2021a), it can be expected that land restoration will directly benefit at least 265,000 people, or 45,000 households based on an average household size of 5.9 in Tajikistan (GDL 2022). The potential benefit to rural livelihoods is, therefore, impressive. However, inferring how those benefits are distributed among the different districts and population segments is out of the scope of this study. This will also depend on prevailing benefit-sharing arrangements between public and private stakeholders, including farmers, pasture users, and the associated producers' associations.

Catchment-Wide Co-Benefits to Tajikistan Society

- **Sediment reductions.** Maximum overall erosion and sediment reduction are achieved under the mosaic landscape restoration scenario covering 1 million ha of land within the Vakhsh catchment (including approximately 32,300 ha of orchards, 183,000 ha of woodlots, and 751,000 ha of rangeland). In this scenario, erosion is reduced by 6.7 percent compared to the 'BAU' state of degraded land. This is equivalent to a present value benefit of US$15 per year per ha, via woodland reforestation, in terms of avoided dredging costs.[12] Sediment reduction can be attributed to the decline in gully erosion. Upstream of Rogun, erosion and sediment transport decreased by 4.4 m^3 of sediment per ha per year over 30 years,[13] ranging from 3.7 m^3 per ha of restored pastureland[14] to 15.1 m^3 per ha for woodlot establishment. In terms of the avoided reservoir construction cost, reduced erosion from mosaic restoration translates into a present value benefit of US$27 per ha of restored land over 30 years. Alternatively, considering avoided dredging costs, current value benefits are US$162 per ha of restored landscape.
- **Hydrological flows.** Landscape restoration also affects the water balance. The SWAT analysis shows that the regeneration of soil health in the mosaic landscape restoration scenario leads to an average annual increase in freshwater availability (soil water retention, lateral flow, runoff, and groundwater infiltration) of approximately 28 m^3 of water per ha restored per year.[15] The total economic cost of water, which considers the use and opportunity cost of the resource for irrigation, was then estimated. Using the total cost of irrigation water of US$0.1 per m^3, the present value benefit of enhanced water availability is US$1.4 per year per ha under the mosaic landscape restoration scenario or US$43 per ha over 30 years.
- **Combining all the benefits of sustainable landscape management,** the value of reservoir capacity for irrigation water, enhanced water availability, improved pasture

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[11] Based on 2020 WorldPop data.

[12] Based on information available, it was not possible to confirm whether Rogun will have sufficient dead storage available, when completed, to avoid any impingement on live storage due to ongoing sedimentation, and hence whether the reservoir will need any sediment dredging activities. There was no information also regarding the potential need for future dredging to reduce the risk of any operational or dam safety issues caused by sediment build-up. Nevertheless, the study revealed that even after potential completion of Rogun, proposed landscape restoration measures would still provide benefits for Rogun itself as well as for the rest of the hydro assets downstream of it, all of which will still receive sediments (passing through Rogun, during operational and sediment-removal activities, as well as via soil erosion that will continue to occur downstream of Rogun).

[13] Full restoration benefits kick in after 6 years for grazing land and 15 years for orchards and woodlots. At this moment, sediment reduction benefits range from 3.7 m^3 per ha of sustainably managed grazing land to 15.1 m^3 per ha for woodlots establishment.

[14] When full soil regeneration potential is met, 6 years after the implementation.

[15] The interventions are expected to alter the microclimate toward more moist conditions, and therefore, a possible increase in evapotranspiration due to the interventions has been neglected here (see also Filoso et al. 2017; Smith et al. 2023).

and land productivity, timber and NTFP, and sale of carbon credits, the Tajikistan society stands to enjoy an NPV benefit of US$284 per ha of land restored of which land users themselves can expect an average annual additional income of US$269 per ha, from NTFPs, timber, and enhanced pasture biomass. These are conservative benefit estimates, however. Considering the avoided climate-related damage costs,[16] the global societal NPV benefit is US$390 per year per ha restored.

- **Scaling up these interventions to their maximum intervention potential across 966,600 ha of land within the Vakhsh catchment** (including 32,350 ha of orchards, 182,900 ha of woodlots, and 751,350 ha of rangeland) provides an estimated US$8.3 billion in present value net benefits to the Tajikistan society over a 30-year time horizon and a 6 percent discount rate, including land user benefits and conservative values of regulating ecosystem services benefits.
- **The benefit-cost ratio (BCR) to the Tajik society is 3.6,** consistent with other studies on the benefits of green infrastructure. It is important to highlight that the added benefits of landscape restoration measures include enhanced climate change adaptation capabilities and reduced ecosystem-based disaster risks (Beetz and Rinehart 2010; Sayre 2001). Climate adaptation and risk management are significant in the Vakhsh catchment in the context of projected increases in temperatures, droughts and floods, fires, landslides and other mass movements; increased soil erosion; and reduced glaciers and snow cover, all of which could lead to losses of lives, livelihoods, and biodiversity and dam and reservoir safety issues (GIZ 2020; Gulakhmadov et al. 2020; Kure et al. 2013).

CONCLUSIONS AND RECOMMENDATIONS

- **Landscape restoration significantly benefits local, catchment, and global stakeholders.** By increasing land productivity and supplying livelihood opportunities, reducing downstream impacts of floods and siltation, and improving carbon sequestration, landscape restoration increases resilience of people, ecosystems, and infrastructures.
- **While each restoration possibility—orchards, woodlots, and rotational grazing—have distinct economic returns to society, no landscape restoration intervention can be classified as better compared to another.** What type of restoration intervention may be favored in one area depends on the suitability of the land, the institutions governing that land, and the preferences of affected stakeholders, for example, Is the land already used as pastureland? Is there a well-managed pasture users union (PUU) that can implement sustainable grazing measures? Or are there irrigation facilities nearby for orchard establishment? The interventions may therefore be viewed as complementary and can allow for regenerating land use productivity, stabilize soils, and enhance hydrological processes on at least 31 percent of the land surface within the Vakhsh catchment.[17]
- **Benefits to hydropower from reduced erosion upstream of Rogun.** For every hectare of land restored in mosaic landscape restoration, erosion is reduced by an average

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[16] Using a midpoint for the social cost of carbon (SCC), which increases from a minimum US$40/$tCO_2$ to a maximum US$80/$tCO_2$ in 2020 to US$78–156/$tCO_2$ by 2050.

[17] Approximately 966,616 ha, out of a total watershed area of 3.1 million ha.

of 4.4 m3 per year upstream of Rogun. The interventions also offer enhanced climate resilience by increasing soil moisture—a form of passive irrigation—reducing runoff and increasing lateral return flow to rivers, thereby securing water availability and inflow to the cascade of dams on the Vakhsh River. For capital-constrained farmers, payoff periods for woodlots and orchards may be high (6–8 years, under a 6 percent discount rate). Moreover, implementing successful rotational grazing schemes hinges on certain land management rights and established PUUs.

- **In terms of securing future production of hydropower energy, sustainable sediment management is necessary for the Vakhsh River Basin to serve the people of Tajikistan for a century from now and avoid significant cost burden on future generations.** In this sense, any efforts to reduce sediment inflow and mitigate and adapt to climate change cannot start soon enough.
- **Therefore, a targeted effort, financial resources, and favorable land use legislation are required to scale these landscape interventions.** For example, given the multiple functions of trees in building and protecting soils, supporting water and nutrient cycles, and supplying a buffer against climate extremes,[18] planting trees should be incentivized in Tajikistan.
- **Furthermore, existing market and policy distortions can be repurposed to mobilize financial resources.** For example, use of irrigation water could become more efficient by increasing tariffs. Excessive irrigation leads to soil salinization, water logging, and water productivity. Water use conservation efforts would significantly reduce costs to the farmer and the public treasury, which is heavily subsidizing electricity for pump stations. The free financial resources could be used in innovative financing mechanisms, for example, payments for ecosystem services (PESs) systems and blended finance solutions.

Policy Recommendations

- **Develop a strategy to address landscape restoration along the Vakhsh River Basin.** Developing a strategy will aid with land management in the Vakhsh River Basin while also serving as a basis for future strategies for other projects. Such a strategy should include a wider developmental vision for the areas surrounding the Vakhsh River Basin while also addressing policies, economic measures, data, and technical capabilities needed for land restoration to succeed.
- **Mainstream and implement sustainable grazing and landscape restoration measures into respective policies and legislation, at a local and national level.** Examples at the national level are design manuals for non-rotational grazing; requirements for compensation measures; requirements for consideration of erosion prevention measures; and broader aspects such as no-grazing buffering zones along riverbanks, active natural hazard zones, and roads.
- **Establish closer coordination and planning with local authorities and farmers to identify what land restoration intervention will work best for their communities.** Through discussions with local stakeholders, this report has identified several landscape restoration options and has highlighted their economic benefits. The choice of landscape restoration is dependent on the local context,

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[18] Winds, heat stress, and flooding.

and more cooperation between central and local governments is therefore key. Examples of such coordination mechanisms could include councils, commissions, and inter-local administration cooperatives for coordinating landscape restoration activities across communities.

- **Landscape restoration and sustainable sediment monitoring and management approach should be integrated into the design, implementation, and operation phases of the Tajikistan hydropower sector.** Using this report and the Vakhsh River Basin as a best practice, these aspects should be integrated and implemented into the growing and crucial hydropower sector in Tajikistan to sustainably manage water resources.
- **Identify the fiscal policies and green finance needed to implement the proposed restoration interventions and to scale up restoration finance for future projects.** Considering the significant payoff period, especially for farmers, co-financing arrangements such as public-private partnerships (PPPs) may be necessary to scale up restoration efforts and attract public and private capital into restoration.
- **PES schemes should be designed and implemented to protect and restore the upper part of the Vakhsh River Basin,** control the stock and flow of sediment more effectively, and ultimately regulate the quantity of eroded sediment reaching the stream network and the catchment's water quality and quantity.
- **Repurpose existing inefficient policies and subsidies within agriculture and irrigation toward incentives for landscape restoration, green infrastructure, and nature-based solutions.** Reshaping inefficient subsidies in water irrigation and agriculture can open opportunities for investments in landscape restoration to increase the resilience of infrastructure, people, and ecosystems in the Vakhsh River Basin.

Technical Recommendations

- **It is recommended to set up a bathymetric survey program for the reservoirs in the Vakhsh River Basin, to regularly measure sediment build-up and monitor trends against first predictions.** The rate of sedimentation is a critical information for the entire life cycle of hydropower and water storage reservoirs, from design to decommissioning. While sediment models can be useful to undertake projections and simulation scenarios, real data are essential for planning any type of interventions.
- **A climate change impact assessment for the Vakhsh River Basin and hydropower cascade is recommended in the future.** The assessment, which can further underpin the values of green infrastructure for increasing climate resilience and sectoral adaptation, should include an assessment of the impacts of climate change on soil erosion and reservoir sedimentation rates. As climate change affects the hydrological and ecological system in a complex spatio-temporal cause-effect chain, particularly in snow and glacier-dominated regions, quantitative causes of the changes cannot be drawn without a detailed climate change impact assessment.
- **It is recommended to prepare catchment-scale strategic environmental and social assessment of the Vakhsh River Basin.** The results of this study supply useful information for the environment and social assessment processes for the Rogun Dam construction as part of the implementation of the World Bank's ESF.
- **It is recommended to include in future work**

the assessment of the potential adverse impacts of soil erosion and sedimentation on water quality for the Vakhsh River Basin, using a combination of global studies and tools (that is, WaterWorld tool[19]) and field measures to estimate upstream-downstream links and surface water and groundwater quality impacts. This work would allow to revise the CBA, and prioritization of restoration interventions also informs the environmental and social assessment of the Vakhsh River Basin and Rogun.

- **It is recommended that any efforts to regenerate landscapes are accompanied with capacity building in climate change adaptation strategies among water user associations, PUUs, and forest user groups (FUGs),** to emphasize the importance of landscape restoration as an adaptive measure and prepare the communities for the expected future conditions.

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[19] https://www.policysupport.org/waterworld.

1. INTRODUCTION

1.1 ENVIRONMENTAL AND SOCIOECONOMIC CONTEXT

Tajikistan is a mountainous and landlocked country with a population of 10 million in 2022 and is the poorest country in Central Asia (Borgen 2020; USAID 2022; World Bank 2023b). Recovery has been slowed by uneven economic reforms, weak governance, high external debt, and seasonal electric power shortages (USAID 2022). About 26.3 percent of the population lived below the national poverty line in 2019, and 75 percent live in rural areas (ADB 2022). The country has a per capita gross domestic product (GDP) of US$822 and a narrow economic base reliant on a few products (for example, cotton and aluminum) and remittances. In 2020, remittances formed 27 percent of GDP and agriculture formed 20 percent. Agriculture, however, accounts for 43 percent of the country's total employment,[20] and poverty stays concentrated in rural communities dependent on natural resources—particularly poverty in terms of access to land, water resources, and agriculture (UNDP 2012).

The total arable land area in the country is limited to just 6 percent of the total land area, corresponding to 0.09 ha of arable land per capita.[21] The main production areas include valleys and foothills in temperate climatic zones (GEF 2016). However, the value of output produced per cubic meter of irrigation water is still exceptionally low, resulting in food insecurity and stressed water resources for many rural communities (World Bank 2020c).

Land degradation and unsustainable use of natural resources pose considerable constraints for rural development in Tajikistan (World Bank 2020a). Conservative estimates of the total economic cost of land degradation in Tajikistan are between US$574 million and US$950 million, equivalent to 8.1 percent to 13.4 percent of GDP (World Bank 2020a). The significant economic cost is related to yield losses in croplands.

As a result, Tajikistan tops malnutrition among the former Soviet republics (WFP 2016). About 530,000 people are living within the Vakhsh River Basin,[22] 51 percent of the population is engaged in farming, and household data from the Yovon district in the Vakhsh catchment (covering 40,355 ha) suggest that the average farm size is in the order of 5.2 has (ADB 2021b).

Tajikistan, on the other hand, is the world's highest per capita hydroelectric power producer. Characterized by its mountainous terrain with peaks of 6,000 m, the country has taken advantage of its geomorphology to build a significant amount of installed hydropower capacity and has become a net hydropower exporter in Central Asia.

About 90 percent of the nation's electric power generation capacity is from hydroelectric dams along the Vakhsh River (Xenarios et al. 2021).

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[20] World Bank 2020 data, https://data.worldbank.org/indicator/SL.AGR.EMPL.ZS?locations=TJ.

[21] World Bank 2020 data, https://data.worldbank.org/indicator/AG.LND.ARBL.ZS.

[22] Based on 2020 WorldPop data.

The Vakhsh River Basin is in the western Pamir mountains in Tajikistan. The river drains into the Panj, which then forms the Amu Darya River. The hydrological regime of the Vakhsh River is glacier and snow dominated, where the highest streamflow occurs during the summer snowmelt period ranging from April to October, with the peak in July or August. The incised riverbed in the mountainous terrain, the presence of bedrock, and the reliable river flows led to the development of a series of hydropower dams and reservoirs along the Vakhsh River. This hydropower cascade includes the world's second tallest dam, Nurek Dam, with the future addition of the Rogun Dam upstream, which will become the world's tallest dam once it is completed (Britannica 2019).

The Nurek hydropower plant (HPP), with an installed capacity of over 3,000 MW, generates about 50 percent of the total annual energy demand in Tajikistan. It recently initiated a rehabilitation project to refurbish its over 40 years old turbines. The completion of the first turbine, which extends the economic life by 35 years and increases the installed capacity by 40 MW to 375 MW, was a major milestone.[23]

The Rogun HPP Project, currently under construction, has the potential to generate significant economic, social, and environmental benefits for Tajikistan and other countries in the Central Asia region if it develops in a financially, environmentally, and socially sustainable manner. Once completed, it will be critical in helping Tajikistan to meet its domestic energy demands, especially during wintertime, and to support neighboring countries through the export of surplus electricity. In addition, as a reliable source of clean and affordable electricity, the Rogun HPP Project can contribute to decarbonization of the Central Asia region.[24]

Tajikistan's sustainable hydropower potential was recently showcased by having the world's first project to be certified against the Hydropower Sustainability Standard.[25] The standard, developed by the International Hydropower Association in collaboration with partners including the World Bank and the first global certification system of its kind in the renewables sector, outlines sustainability expectations for hydropower projects around the world in alignment with the safeguards of key lenders. The outstanding result of Sebzor HPP, an 11 MW hydropower project located along the Shokhandra River, has set the bar for the industry to follow and demonstrates that, in the words of the 2021 San José Declaration: "going forward, the only acceptable hydropower is sustainable hydropower."[26]

1.2 THE PROBLEM

Erosion and land degradation negatively affect Tajikistan's hydropower generating capacity and the broader economy (World Bank 2020a). Sedimentation is steadily depleting reservoir storage capacity worldwide. The estimated loss of reservoir storage capacity ranges between 0.5 and 1 percent per year compared to the installed capacity (Basson 2009; Mahmood 1987; Palmieri et al. 2003). While excessive sediment inflow is one of many factors that can reduce the efficiency of HPPs, it is of particular concern in the Central Asian belt, given the geomorphology of these mountains and the land degradation and deforestation they have suffered. Rivers transport sediment, made up of sand, gravel, silt

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[23] https://www.worldbank.org/en/news/press-release/2022/10/24/tajikistan-inaugurates-the-first-unit-of-the-nurek-hydropower-plant.

[24] https://www.worldbank.org/en/news/press-release/2023/01/12/tajikistan-to-improve-the-rogun-hydropower-project-implementation-with-world-bank-technical-assistance.

[25] https://www.hydropower.org/sustainability-standard.

[26] https://www.hydropower.org/publications/2023-world-hydropower-outlook.

and clay, and other fine particles, which tend to be deposited when water reaches a reservoir. Over time, sediment transport changes the overall geomorphology of the river. It affects the reservoir and the downstream environment that is deprived of sediment essential for channel form and aquatic habitats (Kondolf et al. 2014). Reservoir storage function can be reduced, depending upon the volume of sediment the river carries. Furthermore, excessive sedimentation can lead to dam safety hazards (California State Coastal Conservancy 2007; U.S. Bureau of Reclamation 2006) and damages to the turbines and other parts of the plant (Wang and Kondolf 2014).

Due to the steep gradients, little vegetative cover, erodible and shallow soils, and the hydrologic regime with intense snowmelt, the Vakhsh River Basin is highly vulnerable to erosion. Sheet, rill, and gully erosion; screes; and landslides are widespread in the Vakhsh catchment. The losses and threats from these erosion processes are manifold, ranging from agricultural and forest productivity losses, casualties due to landslides, and potentially blocked rivers through landslides damming the river flow path. In addition, the river carries high sediment loads into the reservoirs, with an estimated long-term input of around 93 million tons per year into the Nurek Reservoir (HRW 2015), which reduces the reservoir's storage capacities and its useful life.

The main drivers of land degradation in Tajikistan are natural mass wasting processes and anthropogenic poor land use practices, including agriculture, irrigation, deforestation, and grazing. Unsustainable land management and conversion contribute to sheet and rill erosion and severe gully erosion (Amare et al. 2019; Li et al. 2021). Other causes of decline include using steep hillsides to grow cereal crops, vertical plowing, and removing tree canopies on croplands (Caritas 2019; World Bank 2012).

Currently, the country's forest area covers only 2–3 percent of Tajikistan's territory compared to 16–18 percent a century ago. Over the last decade, there has been a noticeable increase in livestock numbers, accelerating the degradation of pastures, especially village pastures (Philipona et al. 2019). Unregulated transhumance and elevated levels of forest grazing are particularly damaging to forest health (Mislimshoeva, Herbst, and Koellner 2016).

Land degradation comes at a high economic cost estimated at US$574 to US$950 million per year, equivalent to 8.1 percent to 13.4 percent of Tajikistan's current GDP. The significant cost is related to yield losses on croplands and pastures, loss of croplands (to abandonment or fallow), and health problems (World Bank 2020a). In addition, land degradation affects the hydropower sector, resulting in loss of efficiency and reservoir storage, along with other hydrological impacts and risks.

Climate change exacerbates land degradation processes. As the planet warms, extreme weather events, including more prolonged and more intense droughts, heavier rainfall leading to floods and landslides, and more frequent and intense tropical storms, worsen land degradation. Forests, cropland, and rangeland in Tajikistan are expected to be affected by climate change through extreme weather events, affecting erosion and sediment transport and increasing the vulnerability of livelihoods and biodiversity (Kirilenko and Sedjo 2007).

At the same time, land degradation accelerates climate change and its consequences. The latest report from the Intergovernmental Panel on Climate Change (IPPC) indicates that in 2019, approximately 22 percent (13 $GtCO_2$-eq[27]) of the

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[27] The amount of carbon dioxide (CO_2) emission that would cause the same integrated radiative forcing or temperature change, over a given time horizon, as an emitted amount of a greenhouse gas (GHG) or a mixture of GHGs. (IPCC 2018, Annex I: Glossary)

net global greenhouse gas (GHG) emissions came from agriculture, forestry, and other land use (AFOLU) (IPCC 2023). About half of the total net AFOLU emissions are from CO_2 LULUCF (emissions from land use, land use change, and forestry), predominantly from deforestation. In addition to being a net carbon sink and a source of GHG emissions, land plays an essential role in climate through albedo effects, evapotranspiration, and aerosol loading via emissions of volatile organic compounds (IPCC 2023).

The Amu Darya, which flows through Afghanistan, the Kyrgyz Republic, Tajikistan, Turkmenistan, and Uzbekistan, supplies water for drinking, agriculture, and hydropower and sustains the Aral Sea (Glantz 2005). The river basin is home to about 80 million people (Babow and Meisen 2012).

Over 60 percent of all freshwater resources in Central Asia are formed within the borders of the Republic of Tajikistan (MFA 2020). The Vakhsh River is a headwater tributary to the Amu Darya. However, climate variability and anthropogenic actions have significantly altered water availability within the Vakhsh River (Prakash et al. 2014). Snow- and glacier-melted water contributes more to river discharge, particularly with peak flow in summer (June–September) (Jalilov et al. 2016).

Further glacier retreat is projected, which will hurt the region's water availability. At the same time, the annual water demand in the basin could increase by 3.8–5.0 percent by 2050 (Hagg et al. 2013). The area of irrigated land in the Vakhsh River system is about 172,200 ha (ICWC 2019). It is also a significant source for the generation of green energy in Central Asia, with the Nurek Reservoir being the largest in this region (according to the original water storage volume of 10.5 km^3) (Gulakhmadov et al. 2020). In this context, the sustainable management of the water and land resources of the Vakhsh River Basin cannot be compromised.

About 49 percent of Tajikistan's rural population are living below the poverty line, and therefore, combating land degradation and poverty is particularly important. Approximately 73.6 percent of the country's population of 8.6 million live in rural areas, and Tajikistan depends on imports to cover 75 percent of its food needs (World Bank 2022c) due to insufficient domestic food production (OSCE 2018). It is particularly vulnerable to international food market shocks and would significantly benefit from improved agricultural practices, which enhance food, water, and energy security while supplying an added green and inclusive growth source.

1.3 THE CASE FOR LANDSCAPE RESTORATION

Landscape restoration, intended as a mosaic of interventions to restore land degradation, presents many benefits including improved livelihood, forest and agriculture productivity, infrastructure protection, and climate adaptation. It involves the use of green infrastructures, natural-based solutions, and sustainable land management practices, including tree planting for forest restoration, reforestation, and afforestation; assisted natural regeneration; agroforestry and silvopasture; adaptive grazing; terracing for slope correction (Pye-Smit 2013; Reij and Garrity 2016); and various sustainable land management practices, including planting hedgerows and cover crops, using crop residues and mulches, trenching, and bunding. There is no single approach for using landscape restoration to supply green infrastructure.

Targeted landscape restoration interventions can minimize the loss of soil and downstream sedimentation, the positive impact of which can be felt across many sectors of the economy, including energy, agriculture, and water, while **reviving farm household economies**, **mitigating climate change, and reducing disaster risks**

and biodiversity loss. Integrated catchment management can also allow the local communities to be part of benefit-sharing arrangements through payment for ecosystem services (PES) schemes and the sale of carbon credits on the voluntary carbon market.

Large-scale landscape restoration, however, requires significant investments and resource mobilization. Whether such investments can be justified remains one of many questions. Which sectors stand to enjoy the most significant share of the benefits, and in what proportion? Is landscape restoration sufficient as a sediment management strategy for supporting reservoir capacity? Presented below are the potential benefits of landscape restoration for the Vakhsh River Basin and the broader Tajikistan society.

1.3.1 Sediment Management and Hydropower Generation

Hydropower is central to the energy security of Tajikistan and Central Asia. Tajikistan has more than 350 hydroelectric power plants that generate 95 percent of the country's electricity. According to its National Development Strategy, Tajikistan intends to increase its energy capacity to 10,000 MW by 2030 (MFA 2020). Such prospects could be hindered by excessive sedimentation that reduces reservoir storage. Abrasive sediments passing through turbines can damage the machines, increasing operation costs, reducing generation efficiency, and posing significant safety hazards (Wang and Kondolf 2014). As sedimentation continues, clogging of spillway tunnels or other conduits reduces spillway capacity, as already seen at Nurek HPP (AIIB 2017; D-Sediment 2022).

Landscape restoration and sustainable sediment management seek to balance sediment inflow and outflow, restoring sediment delivery to the downstream channel; maximizing long-term storage, hydropower, and other benefits; and minimizing environmental harm (Morris 2020). Management strategies focus on improving the sediment balance across reservoirs by reducing sediment yield from the watershed, routing sediment-laden flows around or through the reservoir, and removing sediment following deposition. Successful management will typically combine multiple strategies (Morris 2020).

Avoiding sediment deposition in the first place through landscape restoration is the first-best, most cost-effective choice (Randle and Boyd 2018). While the hydropower sector has begun to recognize the need for managing sediment production from landscapes as an integrated part of a sediment management strategy (Annandale, Morris, and Karki 2016), further evidence is needed to prove the benefits from reducing sediment inflow to reservoirs (Kondolf et al. 2014).

1.3.2 Hydrological Services

The Vakhsh River Basin supplies hydrological ecosystem services that are important to local communities and the water security of the entire region, besides hydropower generation. Landscape restoration contributes to regenerating soil health and is a sustainable measure to secure hydrological ecosystem services through increasing the soil's capacity to hold water (USDA-NRCS 2014). This improves groundwater infiltration, reduces surface runoff, regulates seasonal flows, reduces floods, and increases the availability of water for crops (USDA 2017). Rain-fed agriculture will benefit through higher soil water content and groundwater infiltration. Those dependent on run-of-river fed irrigation will also benefit from enhanced return flow[28] to rivers and reduced erosion and runoff.

Further hydrological benefits of landscape restoration are more balanced flows with

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[28] The portion of the streamflow that is sustained between precipitation events, fed to streams by delayed pathways, contrary to surface runoff.

smaller flood peaks, potentially reduced reservoir spills during peak events, and less water lost for hydropower production. Further, downstream irrigation schemes may benefit from a timelier water release. Other hydrological services associated with healthy soils and landscapes include water purification, flood reduction, habitat protection, and cultural and recreational ecosystem services.

1.3.3 Agriculture Productivity and Rural Development

With soils playing a pivotal role in carbon, nutrient, and water cycles, changes to vegetation cover and soil structure can translate into countless economic and societal benefits to rural communities of the Vakhsh River Basin, underpinning provisioning as well as regulating ecosystem services.

Improving the vegetation cover of soils and maintenance of living roots are the pillars of efforts to regenerate land productivity. Perennial tree crops, balanced rotational grazing schemes, reduced tillage, and crop rotations, among other practices, contribute to these 'soil health principles'. Living roots, in turn, improve nitrogen fixation, carbon sequestration, and prevention of soil erosion and soil nutrient losses, thereby improving crop and rangeland yields. Moreover, tree canopy lowers temperatures; serves as windbreaks; and supplies firewood, fodder, medicinal plants, fruits, and nuts that are important income sources to rural populations in Tajikistan (GIZ 2019).

1.3.4 Climate Change Adaptation

The size of future seasonal streamflow in the Vakhsh River Basin is still highly uncertain due to the probable alterations in temperature and precipitation (Gulakhmadov et al. 2020). In this light, efforts to attenuate siltation and fluctuations in overall water availability through landscape restoration and climate-resilient farming are well invested. Notably, landscape restoration allows for enhancing overall water quality and quantity, including soil water retention and reduction of runoff. Landscape restoration, along with other regenerative farming practices, offers a strategy for the Tajikistan farming sector to reduce its dependency on irrigated croplands as a source of income, with further positive effects in terms of more drought-resilient farming systems and the savings that are generated from running the irrigation and drainage network.

Despite an increase in the length of the growing season under future GHG emissions scenarios, agricultural productivity in Tajikistan is at risk due to rising temperatures, more frequent and intense heatwaves, as well as the risk of reduced irrigation water availability due to higher evaporation and glacier retreat (especially in late summer) (GIZ 2020). Climate change also affects livestock and rangelands, through increased livestock heat stress, soil erosion, nutrient runoff, and a reduction in forage quality and quantity. Restoration and the sustainable land management assessed in this report can help mitigate climate change and attenuate the impacts of climate change in the Vakhsh catchment. Rotational grazing, for example, is characterized by periodical movement of livestock to fresh paddocks to allow pastures time to regrow before they are grazed again.[29] When properly implemented, the management strategy helps improve land cover, animal nutrition, soil structure, biodiversity, and

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[29] Compared to continuous grazing, rotational grazing involves moving livestock through several smaller pastures, with one pasture being grazed at a time, and therefore provides time for defoliated grasses to recover and increases efficiency in grassland utilization. When the grazing area is divided into multiple pastures per herd, the grazing period will be shorter while recovery period for each pasture will be longer, thereby potentially allowing for greater stocking capacity and increased profitability (Wang 2020).

soil organic matter, thus reducing runoff, limiting soil erosion, and increasing pasture drought resilience (Beetz and Rinehart 2010; Sayre 2001; USDA 2023). Perennial components of orchard and agroforestry systems create microclimates that help crops and livestock (Dosskey, Brandle, and Bentrup 2017), serve as forest corridors in agricultural landscapes that enhance habitat connectivity (Schoeneberger, Bentrup, and Patel-Weynand 2017), and reduce water and wind erosion of soil while improving soil nutrients and moisture retention (Apuri et al. 2018).

Woodlot restoration and reforestation can also play a key role in decreasing vulnerabilities to climate change, conditional on good forest management (Duncker et al., 2012). Moreover, an increased supply of timber and non-timber forest products (NTFPs), such as fuelwood, nuts, fruits, and potential marketing of carbon credits, will contribute to more durable livelihood opportunities, improved food security, and longer-term development goals. Overall, a catchment with a restored and healthy vegetative cover is significantly more resilient against frequent and more severe extreme events such as floods and droughts. Hence, climate change amplifies the benefits evaluated under the baseline climatic conditions.

1.3.5 Other Co-Benefits

By building and keeping natural capital, landscape restoration catalyzes action that can directly deliver on national sustainable development priorities, **in tandem with the Sustainable Development Goals** (SDGs) (IUCN 2019). Through the diversification of rural livelihood options, increased farm household incomes, biodiversity protection, and water purification services, landscape restoration contributes to ending poverty (SDG 1), improving food security (SDG 2), good health (SGD 3), clean water and sanitation (SDG 6), affordable and clean energy (SDG 7), economic growth and decent work for rural populations (SDG 8), and climate action (SDG 13). At an international level, implemented landscape restoration supports the United Nations Convention to Combat Desertification and the Land Degradation Neutrality goal, the United Nations Framework Convention on Climate Change (UNFCCC) and the Paris Agreement, and the Convention on Biological Diversity and the Aichi Biodiversity Targets.

1.4 PURPOSE OF THIS STUDY

This study aims to (a) identify sediment loads and sources at the hydropower dams along the Vakhsh River of Tajikistan; **(b) identify promising landscape restoration interventions** and possible sites; **(c) analyze these landscape restoration interventions' contribution** to reducing erosion and reservoir sedimentation and improve hydrological ecosystem services, carbon sequestration, forest and agricultural productivity, livelihoods, and farm-related income; **and (d**) **assess the monetary benefits and costs** of the ecosystem services delivered through the different landscape restoration interventions. The restoration interventions should be complementary, allowing for maximum upscaling of landscape restoration efforts across private and public ranges, forests, and cropland.

The cost-benefit analysis (CBA) is developed to show the economic case for landscape restoration intervention and how farmers and the broader society (climate, water, and energy-related sectors) benefit from the landscape restoration interventions. Based on the critical financial parameters, the economic feasibility of implementing different landscape restoration interventions and conditions for success are highlighted. The investment criteria can help practitioners target landscape restoration interventions that match their goals of livelihood improvement and the provisioning of broader ecosystem service benefits. In addition to project-specific ‘per hectare’ estimates, the report also highlights the significant economic returns which can be enjoyed from large-scale landscape restoration within the Vakhsh River Basin.

Another aim of the study is to supply information for the environmental and social assessment processes for the Rogun Dam construction and the World Bank’s environmental and social framework (ESF). The report could also inform the World Bank’s ‘Policy Guidance Note on Sediment Management for Sustainable Development of Dams, Reservoirs, and Hydropower Facilities’ (World Bank 2023a) and highlights the need to integrate landscape/watershed approaches into the design, implementation, and operation phases.

The intended recipients of the report are local, national, and regional decision makers, including government officers, financiers, and policy makers, and technical staff, such as landscape restoration practitioners and experts from the energy, agriculture, and water sectors. The study is intended to inform other sectors relying on the catchment, including health, human development, and education, particularly universities and rural schools, which have the potential to become hubs for building environment and climate awareness and resilience in communities, as highlighted in a recent study (World Bank 2022a).

2. METHODOLOGY

2.1 IDENTIFICATION OF BASELINE INFORMATION

This study included research to assess the characteristics of the Vakhsh River Basin and the sediment loads and sources at the hydropower dams along the Vakhsh River. The methodologies for undertaking these activities and using the results are presented in the next chapter.

Due to the high uncertainties and nonlinear relationship between climate, erosion, and sediment transport processes, climate change impacts have yet to be included in this study's models and economic analysis. However, the expected impacts of climate change on the Vakhsh River Basin were assessed, as presented in the next chapter, and the results were used to inform the main study and selection of measures. Thus, the proposed landscape restoration interventions are also intended to mitigate these impacts and supply a means of climate adaptation.

2.2 INTEGRATED HYDRAULIC AND SEDIMENT MODEL

A comprehensive hydraulic and sediment transport model was developed, which supplied the physical boundary conditions for the ecosystem services' assessment. The model considers the geophysical and meteorological catchment characteristics to calculate hydrological and erosion processes. The model sets up the baseline for sediment and hydrological flows (see Integrated Model, Figure 1).

The sediment budget of the Vakhsh River Basin, upstream of the Baipasa Reservoir, is estimated using a coupled modeling procedure, using the Soil and Water Assessment Tool (SWAT).[30] The SWAT model, preferred over other open-source tools as it allows for combined modeling of hydrology and the spatio-temporal distribution of soil moisture and surface runoff-driven erosion processes (Neitsch et al. 2011), was coupled to a custom-built landslide, gulley erosion, and scree model to capture all important mass wasting mechanisms and the respective sediment sources.

SWAT is an open-source hydrological model that is used worldwide for a wide range of tasks, including successful applications in the Vakhsh River and glaciers (Omani et al. 2017a, 2017b). It can simulate sheet and rill erosion. In the mountainous region of the Vakhsh River Basin, mass erosion occurs in addition and delivers substantial amounts of sediment to the streams. The model, which supplied the physical boundary conditions for the ecosystem services' assessment, considers the geophysical and meteorological catchment characteristics to calculate hydrological and erosion processes.

Sheet and rill erosion, which occurs on agricultural fields, degraded pastures, bare areas, and gentle slopes, is simulated in SWAT with the use of the Modified Universal Soil Loss Equation (MUSLE)[31] (Williams 1995). The use of SWAT was preferred over other available open-source tools as it has more process-based

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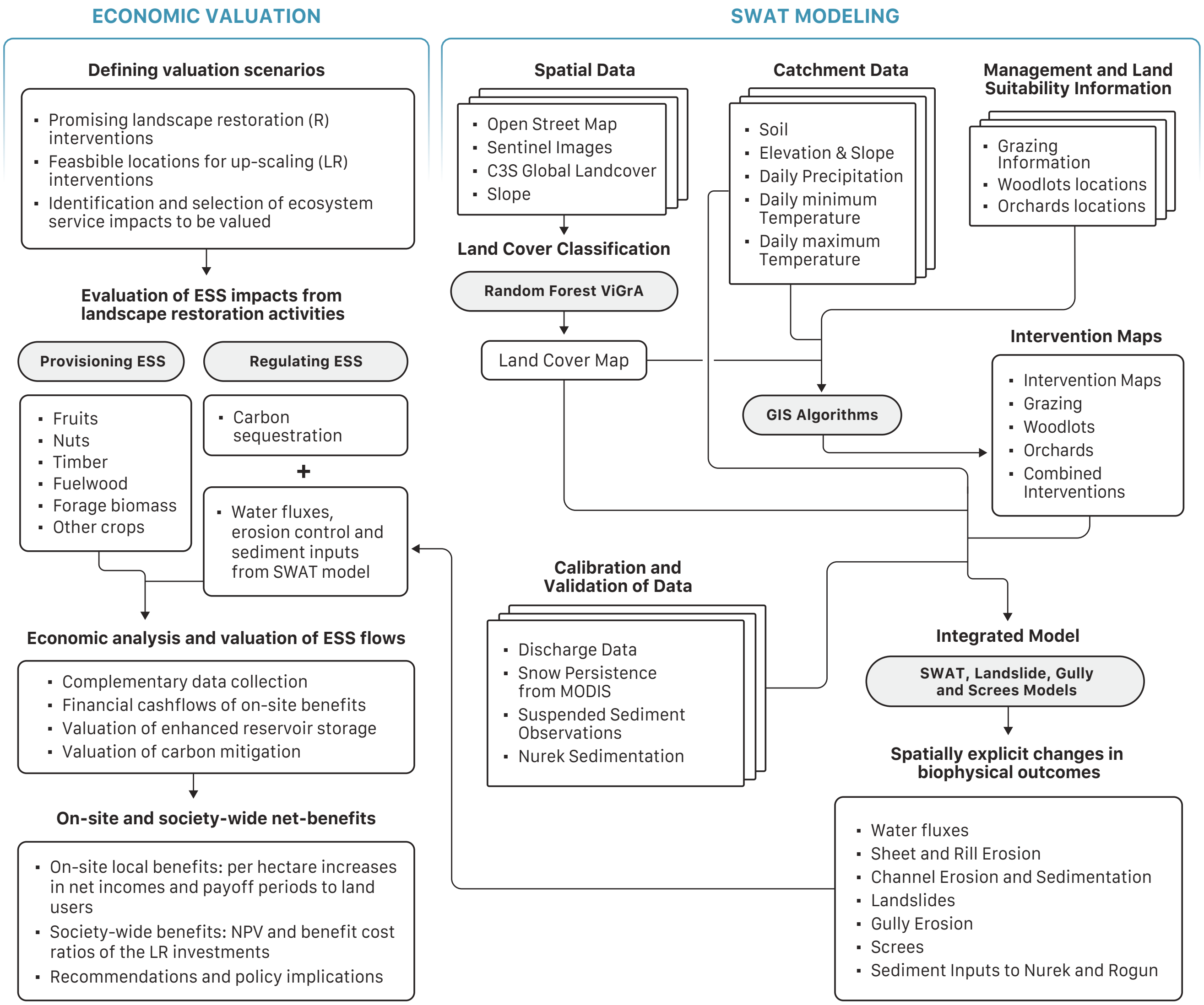
[30] https://swat.tamu.edu/. Version used: SWAT 2012, rev. 681 from 2020. https://bitbucket.org/blacklandgrasslandmodels/swat_development/src/master/.

[31] https://www.sciencedirect.com/topics/earth-and-planetary-sciences/universal-soil-loss-equation.

algorithms about erosion and in-stream sediment transport, and it has hydrology interlinked. The MUSLE approach considers surface runoff, such as snowmelt and glacier melt, as the main erosive force, instead of rainfall as for the original Universal/Revised Universal Soil Loss Equation (USLE/RUSLE[32]) approach used in other models (that is, in Integrated Valuation of Ecosystem Services and Tradeoffs [InVEST][33]). SWAT also allows for estimating changes in soil erosion associated with landscape restoration interventions and land use change overall.

Figure 1: Workflow to Evaluate Landscape Restoration Interventions and to Quantify and Value Their Impacts



Source: Original elaboration for this publication.
Note: C3 = Copernicus Climate Change Service; GIS = Geographic information system; NPV = Net present value; ViGrA = Vision with Generic Algorithms.

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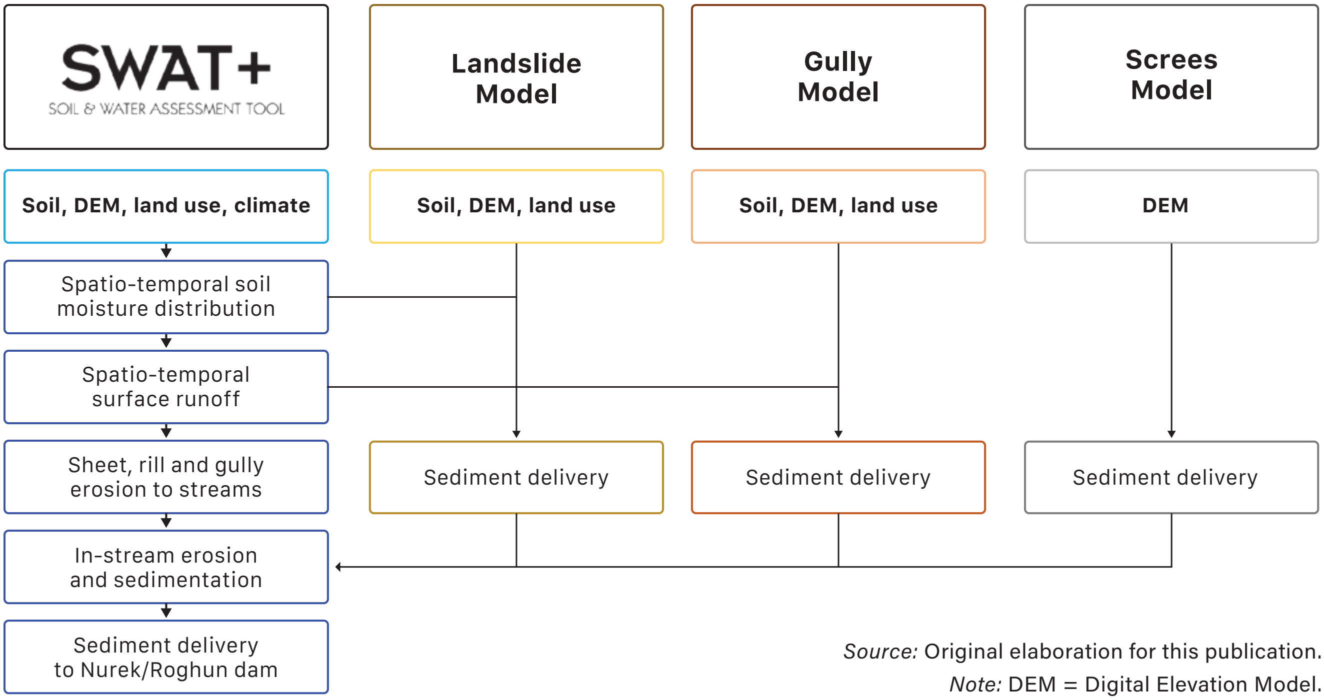
[32] https://www.ars.usda.gov/midwest-area/west-lafayette-in/national-soil-erosion-research/docs/rusle/.

[33] https://naturalcapitalproject.stanford.edu/software/invest.

SWAT/MUSLE is not capable of simulating erosion processes such as landslides, gullies, and screes (this is also the case for InVEST/RUSLE). Therefore, separate models, which all use the same input data as SWAT, were developed and implemented in the Python programming language. The models supply the location and spatial sediment delivery to the SWAT stream network for the different erosion types. SWAT's stream sediment routing algorithms are used to calculate the in-stream sediment transport processes and then, finally, the amount of sediment reaching the largest and most upstream dam along the Vakhsh River, the Rogun Dam. The linked model can be used to simulate the baseline conditions and scenario interventions. A brief description of how each of the erosion processes—sheet and rill, gully, and scree—are modelled, and how the four erosion processes affect sediment transport in river and fluvial erosion, is detailed in Annex 1, including details on models, processes, and assumptions.

Figure 2: Implemented Model Approach



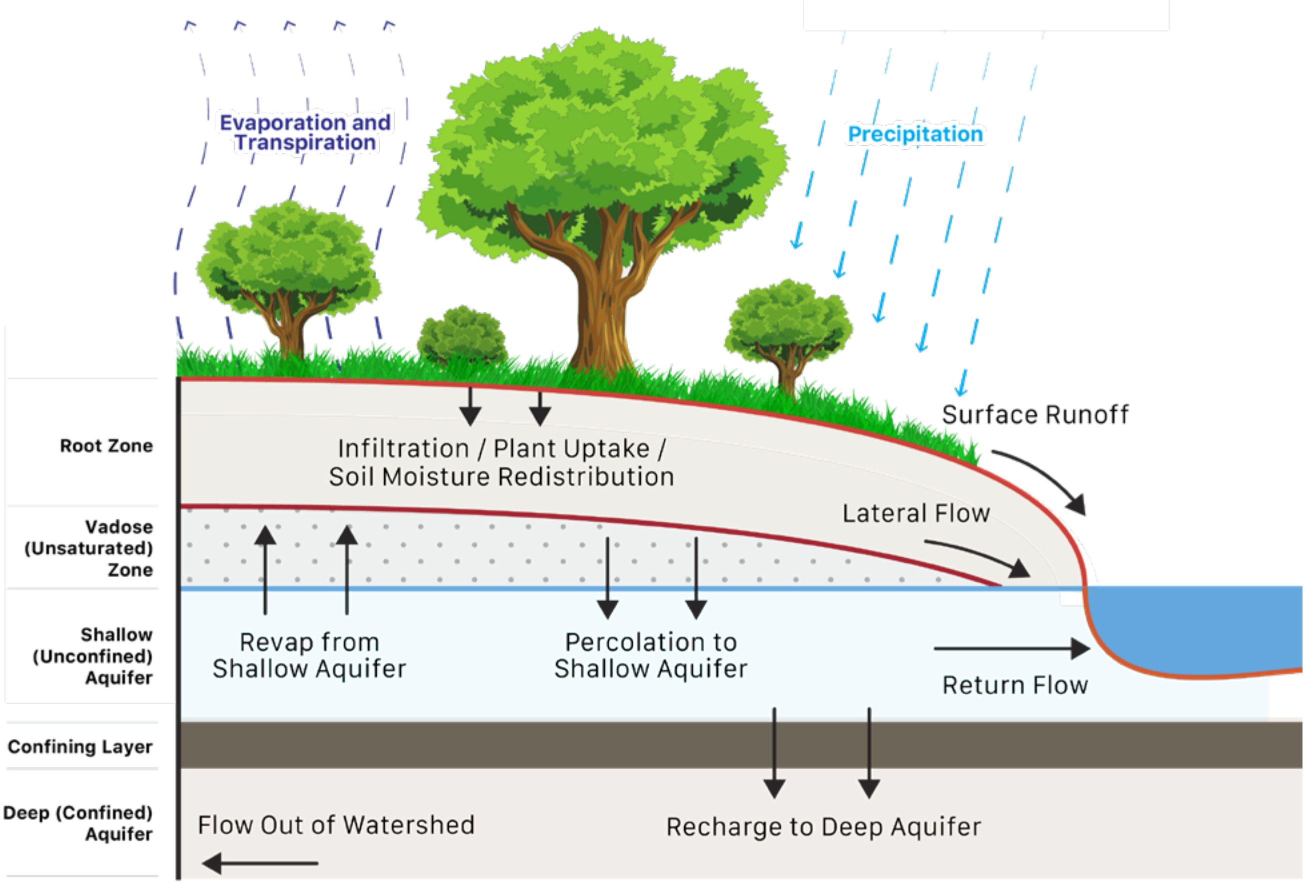
Source: Original elaboration for this publication.
Note: DEM = Digital Elevation Model.

Erosion from gullies is considered a significant sediment source in the Vakhsh (Sidle et al. 2019), but SWAT is not capable of simulating the gully erosion process. Therefore, a gully erosion model was implemented that is based on Allen et al. (2017). To calculate sediment input into the streams from gullies in this study, the locations of gullies are estimated according to a simple relationship developed by Meliho, Khattabi, and Mhammdi (2018) who found that barren and sparse vegetation with slope gradients above 50 percent were very susceptible to gully erosion. The SWAT computational units that match these conditions are selected as prone to gully erosion. The gully model is linked to SWAT, and surface runoff calculated at each hydrological response unit drives gully headcut advancement.

A landslide model was implemented into the integrated model since SWAT does not supply landslide simulations. The approach used for the application in the Vakhsh is based on World Bank (2019) and Wu and Sidle (1995), which describe a model of connected hillslope stability in detail. The models use typical equations that are often used to assess hillslope stability and are considered well suited to depict landslide processes in the Vakhsh. The model calculates the landslide processes on a 30 m by 30 m grid. First, soil properties and slope are used to find cells that can potentially reach failure and therefore can trigger a landslide. These cells are further processed by grouping those to landslide objects according to their spatial connection. All cells within the connected landslide are then evaluated if they fail under certain soil moisture conditions—the 'threshold moisture', which is obtained from the SWAT model. For each landslide object, the runout length is calculated and the part of sediment reaching the streams (the delivery ratio) is calculated.

The SWAT model is also used to simulate changes in the hydrological cycle. Landscape restoration and the associated regeneration of soil health affect surface runoff, groundwater aquifer recharge, and lateral return flow to rivers. The schematic representation of the hydrologic cycle within the SWAT model is illustrated in Figure 3 following Neitsch et al. (2011).

Figure 3: Schematic Representation of the Hydrologic Cycle in the SWAT Model



Source: Neitsch et al. 2011.

2.3 IDENTIFICATION OF LANDSCAPE RESTORATION INTERVENTIONS

Practical and promising landscape restoration interventions were defined in consultation with local stakeholders and nongovernmental organizations (NGOs) and based on earlier experiences of the World Bank. The engagement of various stakeholders was paramount to the study's success. The list of the stakeholders that helped with data acquisition, thereby making this study possible, and the list of the stakeholders consulted for the CBA are provided in Annex 3.

Feasible locations for these landscape restoration interventions were also shown based on physical land use criteria (elevation level, distance to roads, and land use classification), as shown in Table A2.2 in Annex 2. Data for key parameters, such as biomass productivity and suitable tree species, were also collected. The baseline and future (with landscape restoration) land use maps, and biophysical data were then used—see dotted line in Figure 1—to inform the Integrated Model and estimate how landscape restoration affects soil erosion and hydrological flows.

The consultation process also included the identification of the ecosystem service most likely affected by these interventions and an estimate of the intervention costs. Numerous organizations, NGOs, development finance institutions (DFIs), and government departments are working to combat land degradation and improve rural livelihoods in Tajikistan. The activities, sustained by these efforts, supplied an insight into unique landscape restoration interventions that stand out in terms of their feasibility for upscaling from the perspective of their ability to generate income for rural communities, enhance disaster risks, and reduce erosion processes. The identification of these restoration options served as a starting point for the assessment.

The identified interventions include forest landscape restoration, through the use of orchards and woodlots, and sustainable pasture management, through the use of rotational grazing. To find suitable areas for the landscape restoration interventions within the Vakhsh River Basin and ecosystem service benefits, the assessment drew on basic land zoning regulations and natural and technical constraints, such as distance to roads for irrigation, elevation, and land cover classification. These decisions were informed by satellite imagery, literature, and key informant interviews. Furthermore, data were collected, and assumptions were tested and confirmed based on a field study in the municipality of Tojikobod, a region with all significant land uses—range, forest, and croplands within the Vakhsh catchment—and vulnerable to land degradation disaster risks, such as landslides and gully erosion. On this basis, three distinct restoration scenarios were elaborated.

A fourth scenario, which combined a mosaic of all three restoration intervention scenarios, covering 1 million ha of land within the Vakhsh catchment (which presents an area of 3,125,291 ha), was also conceived. Discussions with relevant stakeholders, including farmers in Tojikobod and restoration practitioners, such as Caritas field staff, were also used to identify the most relevant benefits provided by the respective landscape restoration options.

The data were then fed into a comprehensive CBA and ecosystem services valuation. More details on the criteria used to define suitable locations for the three proposed interventions and for the mosaic scenario are presented in Chapter 3.

2.4 CBA AND ECOSYSTEM SERVICES VALUATION

This section describes the methodology for undertaking the CBA and how benefits and costs are retrieved to calculate on-site provisioning

and regulating ecosystem services resulting from the landscape restoration interventions. The study employs a mixture of valuation methodologies to assess ecosystem service net benefits for each intervention, including avoided damage and replacement, as well as opportunity and market costs. Where possible, prices are obtained from actual local markets to ensure that the financial cash flows of the orchard, woodlot, and rotational grazing enterprises are grounded in realistic assumptions reflecting what can be earned.

Opportunity costs were considered for each intervention, considering how the land is used under business-as-usual (BAU) scenario and the value of the BAU alternative. It was not possible however to account for the value of all the possible uses of land in the BAU—especially since earth observations supply broad land use classes (scrubland, herbaceous cover, mosaic cropland, mosaic natural vegetation, and so on).

In parallel, extensive data were collected to inform the cash flow and financial feasibility of the landscape restoration interventions and the carbon sequestration potential of the interventions. Changes in ecosystem service flows were finally used in the CBA to translate biophysical changes to monetary private and societal net benefits. The full flow of provisioning ecosystem service benefits to land users and regulating ecosystem service benefits to society were then merged in a comprehensive CBA.

Ecosystem service valuation was performed based on the CBA over a 30-year time horizon, 2022–2052, to demonstrate the economic case for landscape restoration intervention and show how local land users and the wider society stand to benefit from the landscape restoration interventions, in terms of improved livelihoods, regeneration of soils, enhanced land productivity, and sediment reduction.

Evaluation of potential impacts of landscape restoration activities. The impacts of activities on ecosystem services were evaluated using the SWAT model for simulating erosion and hydrological processes. Individual effects on sheet, rill, scree, and gully erosion and landslides were assessed for each type of landscape restoration process. Carbon sequestration was evaluated using the EX-Ante Carbon-balance Tool (EX-ACT) of the Food and Agriculture Organization (FAO) of the United Nations, while the production of timber and fuelwood, fruits, and nuts, under orchards and woodlot establishments, and forage, under the rotational grazing scheme, was evaluated through interviews with practitioners, farmers, and experts in forest and rangeland management.

The economic value to local and society-wide beneficiaries. A combination of valuation methodologies, including market price, avoided costs, opportunity costs, and productivity change approaches were used to value changes to provisioning and regulating ecosystem services. As stated, critical data inputs were obtained from practitioners, literature reviews, and consultation with local farmers and pasture users, and visits to the local farmer market supplied up-to-date farm gate market prices.

The cost of implementing and managing the individual landscape restoration interventions was also carefully noted. Yields, prices, and input costs were fed into detailed 20- and 30-year financial cash flows for each landscape restoration intervention. The results (expected increases in per-hectare incomes) were further confirmed with on-ground actors. The total flow of provisioning ecosystem service benefits to land users and regulating ecosystem service benefits to society are then merged in a comprehensive CBA, and the results are reported in Chapter 3.

The flow of benefits and costs from landscape restoration was assessed over a 30-year time

horizon for all interventions and ecosystem service impacts considered to prioritize the interventions.[34] Net benefits to these stakeholders are presented first, followed by an insight into the broader societal benefits generated from landscape restoration as a source of green infrastructure. The economic assessment of the provisioning ecosystem services focuses on changes in per hectare net incomes following the adoption of sustainable range and forest landscape management, independent of who manages or owns the land.

Maximum overall erosion and sediment reduction are achieved under a mosaic landscape restoration scenario covering 1 million ha of land within the Vakhsh catchment. Considering the importance of woodlots in reducing erosion, especially on steep hills, a higher sediment reduction could be achieved if suitable rangeland sites were subject to reforestation.

The target beneficiaries for the restoration interventions are (a) the rural communities that depend on land use activities for their income (including individual, family, or collective Dekhan farmers—growing crops and managing livestock—state forest enterprises or pasture users unions (PUUs), forest user groups (FUGs), and groups of farmers that form common interest groups); **(b) the population within the Vakhsh River Basin** living upstream and downstream of Rogun; **(c) the hydropower and irrigation sectors**, including dams, reservoirs, and power stations located along the Vakhsh River, and the irrigation network directly feeding from the reservoirs; **(d) the Tajikistan society**; and the **(e) regional and global community as a whole**, benefitting from improved water security, erosion control, and climate change mitigation. The beneficiaries and valuation approaches are presented in Table 1.

Table 1: Ecosystem Benefits, Main Beneficiaries, and Valuation Approaches

Objective	Beneficiary	Valuation approach
Land user benefits - woodlots	Local land users (FUGs, forest state enterprises, and rural communities)	Productivity change and market prices
Land user benefits - orchards	Local land users (Individual and Dekhan farmers, common interest groups, and rural communities more broadly)	Productivity change, market prices, and opportunity costs
Land user benefits - pastureland	Pasture users and PUUs	Productivity change, market prices, and avoided forage purchase cost
Erosion	Nurek and Rogun HPPs, Government of Tajikistan	(a) Value of enhanced storage capacity when used for irrigation (b) Avoided water storage recovery cost (c) Avoided dredging cost.
Enhanced water balance	Farmers, common interest groups, and broader Tajikistan society	Shadow price of water using the full economic cost of water
Enhanced carbon sequestration	(a) Land users and rural communities	(a) Voluntary market prices (voluntary carbon market)
	(b) Global	(b) Avoided damage cost, using the social cost of carbon (SCC, 2022–2052 pricing)

Source: Original elaboration for this publication.

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[34] Using a 6% discount rate. Interventions included a combination of orchard establishments, woodlot restorations, and rotational grazing throughout the study area.

With a total population of 530,000 living within the Vakhsh River Basin, it is expected that landscape restoration will directly benefit at least 265,000 people within the Vakhsh catchment (GDL 2022). Data from the Yovon district of 40,355 ha in the Vakhsh River Basin suggest that the average farm size is 5.2 ha (ADB 2021b). However, the landscape restoration interventions considered in this study fall outside the classical boundaries of individual farms, including state-owned forests and rangeland. Since available maps and earth observations do not allow for inferring who owns or manages the land under consideration, the CBA analysis changes in per hectare net incomes following the adoption of sustainable range and forest landscape management, independent of who manages or owns the land.

The study's models and economic analysis also did not include the impacts of soil erosion and sedimentation on water quality. While the study focused on water quantity about the effects of soil erosion and land degradation on hydrological flows, it recognizes the importance of including this aspect in future work, especially with escalating climate changes. The rationale for focusing on water flow and not water quality lies in the fact that only a limited number of factors could be included in the sediment, hydrological, and economic models. Therefore, the ecosystem service valuations were prioritized according to scope work and consultations. The details of the parameters used for the CBA, including the time horizon, the discount rate, and the sensitivity analysis, and of the valuation of enhanced land use productivity are presented below.

Parameters Used for the CBA

Time period. The period used in the economic analysis of projects should reflect reasonable estimates of the full duration of costs and benefits associated with the project. Joint forest management (JFM) lease contracts, and typical rotation lengths for woodlots and orchards, are usually 20 years. However, as highlighted in Fernández-Moya et al. (2019), mixed tree-farming plantations in Italy, France, and North America use very short rotations of 5–7 years when they are optimized for firewood production; short rotations of 8–12 years for peeler logs production, and medium-long rotation of 20–30 years for veneer production (for example, walnut and other valuable broadleaved species). It is also realistic to assume that woodlots and orchards can be subject to 30-year rotations. Using a time horizon of 30 years is considered a good compromise between capturing the main benefits of landscape restoration and minimizing uncertainties (climate change, prices, and so on) introduced over more extended times.

Discount rate. A social discount rate was used to calculate the NPV of the landscape restoration and catchment management intervention scenarios, according to standard World Bank practices (World Bank 2016).[35] Within World Bank client countries, per capita growth has averaged 3 percent per year, which yields a social discount rate of 6 percent, assuming an elasticity of marginal utility of consumption of two (World Bank 2016). At the same time, Tajikistan's GDP per capita growth has averaged 4 percent since 2015[36] (ranging from 2.1 percent in 2020 to 5 percent in 2018). In 2023, Tajikistan's economic growth is expected to decelerate to 5 percent as the

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[35] It is assumed that the marginal value of an additional dollar of net benefits is smaller when the recipients of those benefits are richer (the Ramsey formula is used). Therefore, if growth is expected to be positive over the life of the project, future benefits should be valued less than those that occur in the present when recipients are less well-off. With an elasticity of marginal utility of consumption of between 1 and 2, if a beneficiary is x percent richer, the marginal value of an additional dollar of benefits is lower by between x percent and 2x percent. Similarly, if per capita growth is expected to be y percent over the life of the project, the annual discount rate should be between y percent and $2y$ percent per year.

[36] https://www.adb.org/countries/tajikistan/economy.

2022 positive shock subsides and remittance inflows diminish, which is expected to result in a contraction in private consumption (World Bank 2023c). A 6 percent social discount rate is therefore considered reasonable.

Sensitivity analysis. For the sensitivity analysis, the descriptive approach to setting the interest rate is also used. It considers the opportunity cost of drawing funds from the real economy using the real interest rate (the nominal lending rate adjusted for inflation). Tajikistan's real interest rate has hovered around 20 percent since 2015 (World Bank 2022b). The descriptive approach needs to capture specific policy goals (for example, eradication of poverty or climate change adaptation). Still, the real interest rate remains a good indicator of the possible reality that landowners face if they look to raise capital to finance the landscape restoration activities analyzed here. The sensitivity analysis also incorporates a 3 percent discount rate to reflect the cost of capital, where landowners benefit from philanthropic grants, official development assistance grants, or 'below-market-rate return' impact investments. Additionally, upper- and lower-bound estimates of the financial return of the individual interventions are also estimated, assuming a pessimistic scenario with lower-than-anticipated yields and an excessive cost of capital (20 percent), as well as an optimistic scenario, considering lower implementation costs (ICs) and management costs (MCs) (from economies of scale) and a minimal fee of capital (3 percent).

Valuation of enhanced land use productivity. The benefit of the implementation of the integrated (landscape restoration) scenario is valued concerning the expected increase in forage, wood, fruit, and nut production (Q) over and above the BAU scenario without the interventions. The ICs and MCs are also deducted to estimate the change in per hectare net incomes for every year over a 30-year time horizon, according to Equation 1[37]. The flow of net benefits is discounted into NPV terms, using r, the social discount rate of 6 percent, and 20 percent for sensitivity analysis.

Net present value

$$^{\text{-ha}}\ \text{BAU} \rightarrow \text{LR} = \sum_{t}^{T} \frac{P \times (Q_{LRt} - Q_{BAUt}) - IC_t - MC_t}{(1+r)^t} \quad \text{(eq 1)}$$

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[37] It is assumed that the share of output of orchard, woodlot produce and pasture produce, is not sufficiently big to affect market prices via equilibrium effects.

3. ANALYSIS AND FINDINGS

3.1 BASELINE CONDITIONS

The first step consisted of assessing the baseline information for the study area, the Vakhsh River Basin. This included a catchment characterization, to gather and evaluate the characteristics of the catchment area; a geochemical tracing, to assess the sediment sources entering the hydropower reservoirs along the Vakhsh River; and a review of the possible impacts of climate change on the Vakhsh River Basin. The results from these activities are presented below.

3.1.1 Catchment Characterization

The analysis and characteristics of the catchment area have been provided by the Mountain Societies Research Institute from the University of Central Asia (UCA). The study included field data collection of sediment samples from the Vakhsh River Basin and tributaries, an assessment of suspended sediment concentrations in collected water samples, and the combined use of field investigations and remote sensing methods to assess how geomorphology and land use of the catchment may affect sediment supplies and transport. What follows is an extract from the study 'Catchment characterization in the Vakhsh River Basin Upstream of Nurek Reservoir, Tajikistan' (UCA 2022).

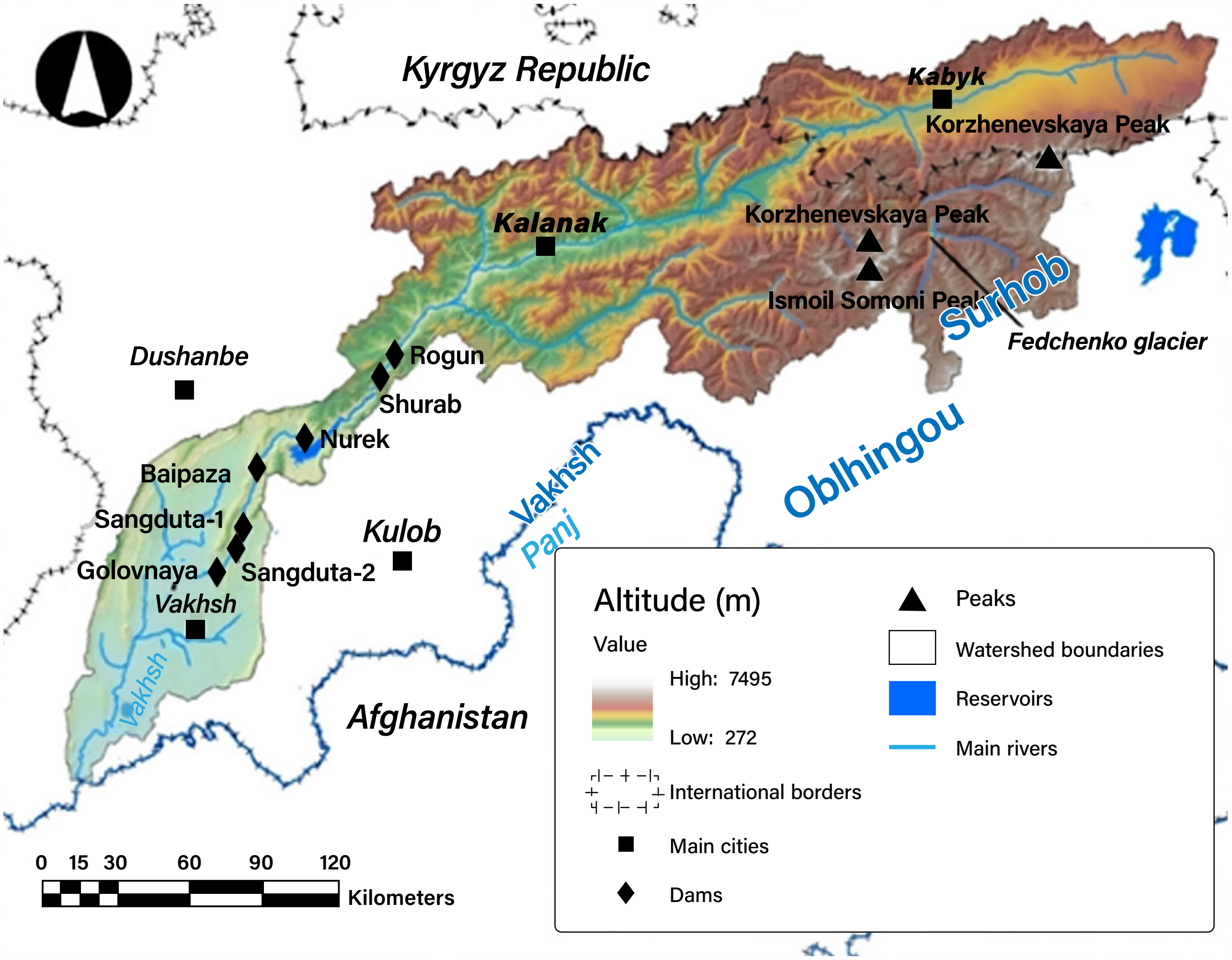
Topography

To understand the environmental conditions contributing to sediment transport from the landscape to the Nurek and Rogun hydropower reservoirs, it is essential to examine the catchment's geologic, geomorphic, and surface conditions. The drainage area upstream of the Nurek HPP estimated at the Vakhsh River gauging station (no longer operational) at Tutkaul Kishlak is 31,200 km^2 (Figure 4). Because of the narrow contributing area between Nurek Dam and the Rogun HPP, the catchment area upstream of Rogun reduces by less than 1,000 km^2—to about 30,390 km2. The total drainage area of the Vakhsh River is 39,160 km^2, of which 79.8 percent is in Tajikistan and 20.2 percent in the Kyrgyz Republic. Approximately 30 percent of this drainage area is above 4,000 m.a.s.l. and has thousands of glaciers, most of which are in the eastern part of the basin. The largest glacier is the 72 km long Fedchenko Glacier, with elevations ranging from 2,900 m at the base to 5,400 m at the summit (Lambrecht et al. 2014). Over a recent period of 80 years, the Fedchenko Glacier lost approximately 3 percent of its ice mass, a trend clear in many of the smaller glaciers in Tajikistan (Lambrecht et al. 2014).

The timing of water and sediment releases from these glaciers affects downstream sediment transport. Increasing flows in the main tributaries of the Vakhsh River (Surkhob and Obikhingou Rivers) have been measured since the late 1980s (Normatov, Markaev, and Normatov 2017). These trends reflect climate warming cycles and are expected to change in the future when tipping points are reached—that is, when glacier melt declines as the ice mass disappears and glaciers become disconnected from receiving streams and river systems. Given the high elevation of much of this basin, snow accumulation and melting also play significant roles in runoff and sediment transport. Snow cover and water content throughout much of mountainous Tajikistan are reported to be highly variable from year to year, with little insight into predictable patterns.

Within the Vakhsh River Basin, three iconic peaks above 7,000 m exist: Ismoil Somoni Peak (7,495 m.a.s.l.) in southeastern Tajikistan in the Academy of Sciences Range, part of the northern fringe of the Pamirs (located about 40 km northwest of the Fedchenko Glacier); Lenin Peak (7,134 m.a.s.l.) in the far eastern portion of the basin; and Korzhenevskaya Peak (7,105 m.a.s.l.) located about 13 km north of Ismoil Somoni Peak. All these peaks and surrounding high mountains are associated with extensive glacial processes that contribute seasonal runoff and sediment to tributaries of the Vakhsh River. While there are many glaciers, most are smaller than the Fedchenko Glacier.

Figure 4: The Vakhsh Catchment Topography and Current HPPs



Source: Original elaboration for this publication.

Hydrology

Tajikistan has abundant freshwater resources in its rivers, lakes, and glaciers, with an annual carbon sequestration of 7,649 m^3 per capita (ADB 2021b). The Vakhsh River Basin, the northeast tributary of the Amu Darya River, drains most of eastern and southern Tajikistan. It contributes about 29 percent of the total flow of the Amu Darya. The Vakhsh catchment is situated between 37.10° and 39.74° N and 68.31° and 73.70° E and has a total length of 524 km with a drainage area of about 39,008 km^2. The elevation in the basin ranges from 302 to 7,050 m.a.s.l. The temperature decreases with the increase in height, while precipitation has different patterns at different altitudes and aspects. A significant increase in the annual average temperature by the end of the twenty-first century is projected (Gulakhmadov et al. 2020), ranging from 2.25 to 4.40°C under RCP4.5 and a decreasing tendency of annual average precipitation (from -1.7 percent to -16.0 percent under RCP4.5[38]).

The Vakhsh River flows through a narrow valley, in places turning into impassable gorges 8–10 m wide, and in some areas, it expands up to 1.5 km (Gulakhmadov et al. 2020). Hydropower supplies 99 percent of Tajikistan's electricity, and 90 percent comes from eight hydropower dams on the Vakhsh River. Irrigation withdrawals are about 85 percent of the national water resource use (ADB 2021a). Millions of people in Uzbekistan, Turkmenistan, Tajikistan, and the Kyrgyz Republic depend on the freshwater supply from the Vakhsh River system. The total annual flow of the Vakhsh River is 20.22 km^3 per year, and the area of irrigated land in this river system is about 172,200 ha (ICWC 2019).

Climate

The Pamirs–Tien Shan also occupies the crossroads of Central Asia's most influential climate systems: the Westerlies and the Monsoon. Along with the Tibetan Plateau, these ranges are orographic barriers that shield and thus keep the continental-interior deserts. The topographic evolution of the Pamir-Tibet plateau, the development of orographic barriers, ice-sheet evolutions, and land-bridge and sea-surface temperature changes have been attributed to the poorly understood pattern of intensification and reduction of the Westerlies and the Monsoon in many studies of Central Asia (Chen et al. 2008).

The seasonal monsoon climate has been in southern Asia for the last 12.8 million years (Quade, Cerling, and Bowman 1989). In the early to middle Holocene, the northeastern Pamir Plateau was characterized by moister conditions (Heinecke et al. 2017). However, in contrast to the Himalayas, most of the precipitation in the northern Pamirs falls in winter and spring. This precipitation is provided by the Westerlies (Pohl et al. 2015). According to the global scale analysis, Westerlies' location depends on the position of the Siberian anticyclonic circulation (Aizen 2011). Such dependence can block the humid western air masses and can cause aridity in Central Asia. Therefore, precipitation decreases from west to east, and present-day rainfall is highly seasonal.

Sediment Transport

The Vakhsh River has the highest suspended sediment load of any river in Tajikistan, and it transports large amounts of sediment to the lowlands, where coarser sediments mostly deposit in the Nurek Reservoir affecting its water holding capacity. According to Glantz (2005), the height of sand accumulation in the

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[38] From 4.40 to 6.60°C under RCP8.5 and reduced precipitation from -3.4 percent to -29.8 percent under RCP8.5.

Nurek Reservoir reaches up to 50 m.

The assessment of suspended sediment concentrations in collected water samples indicates that the highest concentrations of sediment in the river water occur in August. This month is the driest but not the warmest in the season, and it correlates with the highest river water discharge (July–August) fed by higher elevation snow and glacier melt. Most sediments larger than 2 m appear to accumulate in the Nurek Reservoir as shown by the sharp decrease in suspended sediment concentration downstream of the Nurek Dam.

Overall, suspended sediment concentrations decline from the upper portion of the basin to the lowlands, likely due to sedimentation in the gentler reaches of the river. The water samples collected below the Nurek Dam had algae, which affected the results. Likely, the algae live in the still waters of the Nurek. Figures 5–7 present an overview of the erosion processes along the Vakhsh River.

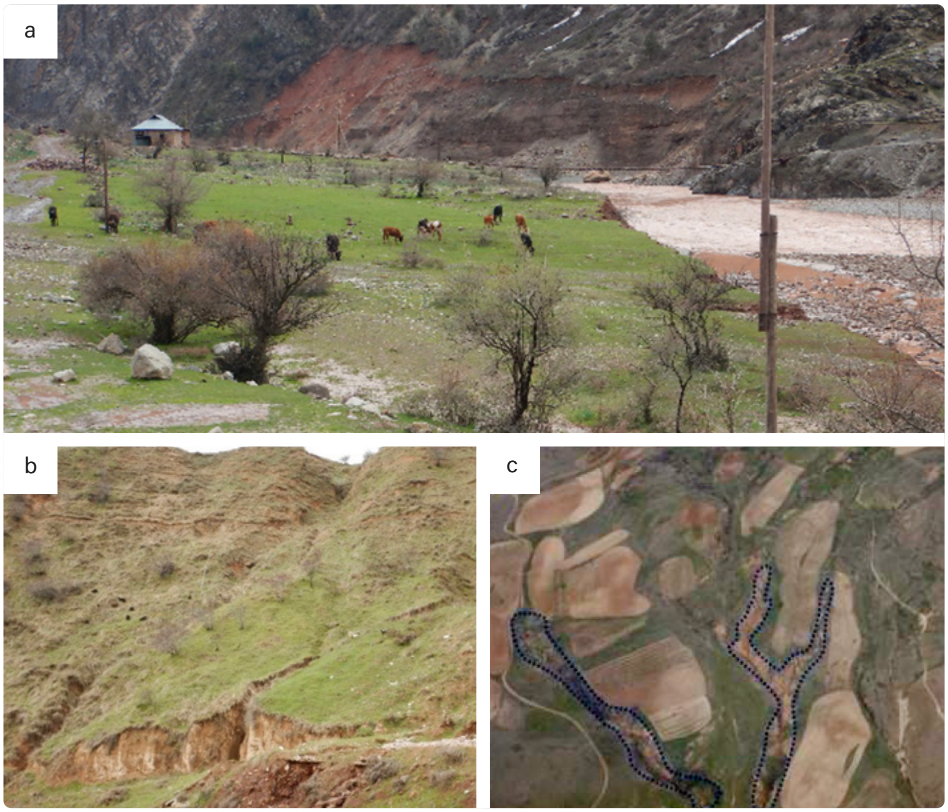
Figure 5: Streambank Erosion along a Vakhsh River Tributary Transporting High Sediment Load, Following a Low-Intensity Storm

Source: UCA.

Figure 6: Active Rockfall Contributing Substantial Amounts of Coarse Sediment to a Vakhsh River Tributary

Source: UCA.

Figure 7: Agricultural Influences on Sediment in the Catchment



Source: UCA.

Panel a - heavy grazing pressures contributing to streambank erosion.

Panel b - gully initiation and headcutting.

Panel c - cultivated lands in silty soils that have instigated gullies; these gullies now connect to the fluvial system efficiently delivering sediment.

3.1.2 The Impacts of Climate Change

Presented below is an overview of the potential impacts of climate change on the country and, in particular, the Vakhsh River Basin that were identified and assessed as part of this study. The proposed landscape restoration interventions aim at providing a means of adaptation for these identified climate challenges.

Due to political, geographic, and social factors, Tajikistan is recognized as vulnerable to climate change impacts, ranked 100 out of 182 countries in the 2020 ND-GAIN Index.[39] The ND-GAIN Index ranks 182 countries using a score that calculates their vulnerability to climate change and other global challenges and their readiness to improve resilience. The more vulnerable a country is, the lower its ND-GAIN score, while the more ready a country is to strengthen its resilience, the higher its ND-GAIN score (World Bank 2021).

Tajikistan is projected to experience temperature rises significantly above the global average. Under the highest emissions pathway (RCP8.5), warming could reach 5.5°C by the 2090s, compared with the 1986–2005 baseline. Warming trends are projected to lead to even stronger maximum and minimum temperatures, which could set back human livelihoods and ecosystems. There is a high likelihood that temperatures in Tajikistan will more regularly surpass 40°C, particularly in lowland regions. This will increase risks to human health and the severity of the consequences. Increased temperatures, paired with higher likelihoods for aridity and drought incidence, are likely to expand arid lands in some regions, and consequently reduce agricultural yields (World Bank 2021).

By the end of the twenty-first century, a significant increase in average annual temperatures is expected, ranging from 2.25 to 4.40°C under RCP4.5 and 4.40 to 6.60°C under RCP8.5 (Gulakhmadov et al. 2020). The probability of heatwave conditions (a period of 3 or more days where the daily temperature is above the long-term 95th percentile of the daily mean temperature) is projected to increase dramatically under all emissions pathways, reaching 7–23 percent by the 2090s. This is primarily a result of continued rising of temperatures, which shifts the average ambient temperature away from that of the baseline period (1986–2005) and increases the likelihood of heatwaves (World Bank 2021).

By the end of the century, glacier mass loss is projected at 50–70 percent over the Central Asian region, dependent on the emissions pathway. By comparison, in the middle of the twentieth century, around 6 percent of Tajikistan’s surface area was covered by glaciers. By the early twenty-first century, this was believed to have declined to 5 percent. The ongoing melting of glaciers is already delivering slightly increased runoff (typically less than 10 percent) in many of Tajikistan’s rivers. However, large uncertainty in precipitation and snowfall projections surrounds future runoff trends. (World Bank 2021). Qualitatively, based on higher intensity rainfall and the respective erosion, the projected climate change scenarios on the streamflow point to an increasing tendency of average annual streamflow and high-flow events (Kure et al. 2013).

Between 1940 and 2012, there has been an increase in the average annual precipitation by 5-10 percent, **as highlighted in Tajikistan’s Third National Communication to the UNFCCC**, submitted in 2014. However, this increase is associated with higher intensity of extreme precipitation events, and in some areas, the frequency of days with precipitation has declined.

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[39] University of Notre Dame (2020). Notre Dame Global Adaptation Initiative. https://gain.nd.edu/our-work/country-index/

This has led to some recent arid years: notably 2000, 2001, and 2008 when rainfall was 30–50 percent below average. One study finds a general drying trend over Central Asia's arid regions linked strongly to El Niño-Southern Oscillation trends (Hu et al. 2019). Climate data (over 60–80 years) from three stations within the Vakhsh River Basin show highly variable patterns of average annual temperature, with very weak increasing trends. Yearly precipitation is also highly variable, with growing trends in the catchment drained by the Kyzylsu River; the other catchments showed no significant trends (Normatov, Markaev, and Normatov 2017).

Eventually, the continuous decrease in the country's mountain glaciers is going to reduce the regularity and volume of water flows and may affect the energy, agriculture, and water sectors. One study has suggested that the increase in runoff due to accelerated melting could peak by around 2040. As smaller glaciers disappear entirely, the runoff of smaller tributary rivers can fall dramatically. The cumulative effects of glacier loss are likely to grow over the longer-term future, dependent on global emissions reductions, potentially leading to significant declines in the runoff (World Bank 2021). By about 2060, it is expected that increasing temperatures and associated further retreating of the snowline and loss of glacial mass will start affecting water storage and hydropower generation (Kure et al. 2013). This is critical, as in 2015, only 74 percent of Tajikistan's population was estimated to have access to at least a basic level of water supply (World Bank 2021).

Simultaneous flooding issues and associated hazards such as landslides and mudslides are also expected to intensify, affecting lives and livelihoods. Without adaptation efforts and disaster risk reduction preparedness and planning, climate change's effects, particularly heat and drought, may result in severe economic loss and damage in Tajikistan (World Bank 2021).

Up to 36 percent of Tajikistan's land area may be at risk of landslides, and climate changes are projected to compound this risk. A similar proportion of the nation faces a substantial risk of mudflows, which is also projected to increase because of land degradation and climate change. By 2035–2044, the number of people annually affected by an extreme river flood is projected to increase by around 6,000–7,000. By comparison, as of 2010, assuming protection target for up to a 1-in-25-year event, the population annually affected by river flooding in Tajikistan is estimated at 20,000 people, and the expected annual impact on GDP at US$39 million (World Bank 2021).

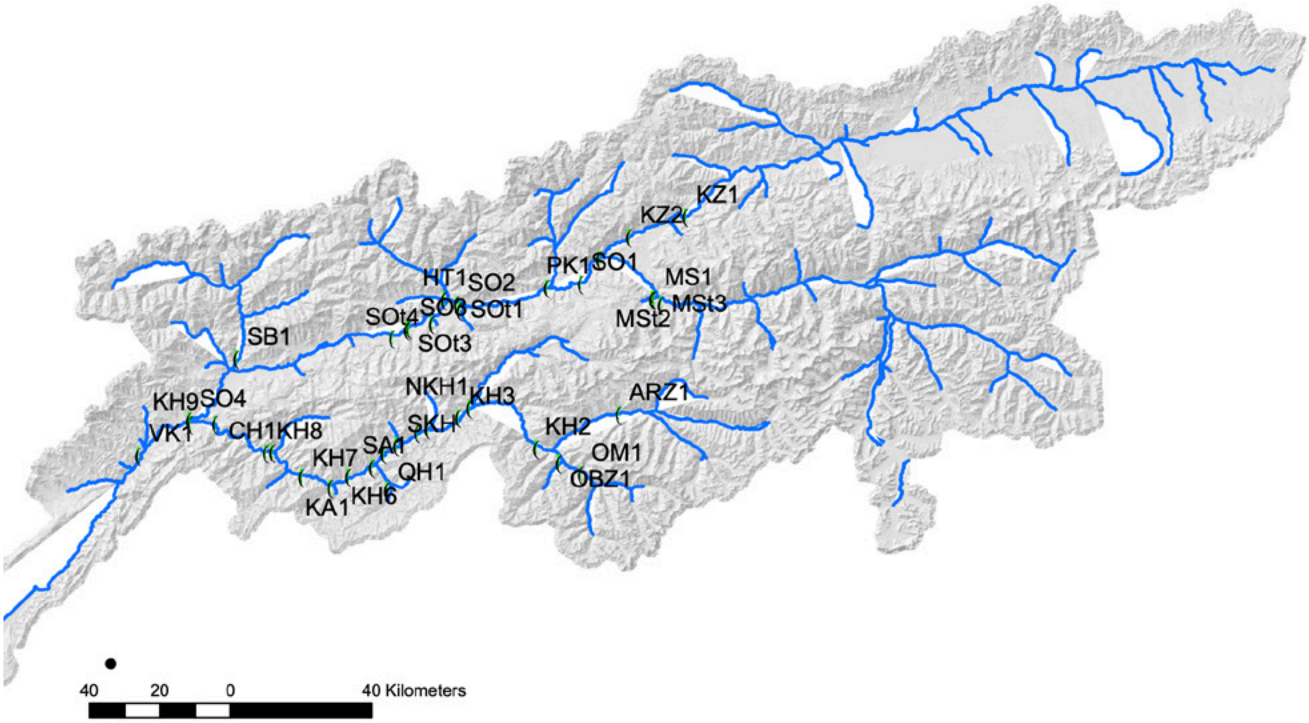
Issues such as the projected increase in the erosive capacity of rain, and its impact on soil quality, will increase the pressure on essential ecosystem functions. These changes, in combination with issues such as glacial melt and drought, will result in significant shifts in species' viable ranges (both in natural ecosystems and for agricultural purposes) (World Bank 2021).

3.1.3 Geochemical Tracing

To complement this study, Griffith University from Australia conducted a parallel study, 'Sediment tracing in the Vakhsh River Basin Upstream of Nurek Reservoir, Tajikistan'. The resulting report describes a geochemical investigation into sediments of the Surkhob and Obikhingob sub-catchments of the Vakhsh River (Griffith University 2022). What follows are essential extracts from that study.

This research consisted of a pilot study based on 37 samples from the Vakhsh catchment analyzed for geochemistry and particle size. Mixing modeling was undertaken to decide the proportional contributions of tributaries at key junctions. Each sample was analyzed for 52 elements (Figure 8). Site-to-site variation in elemental concentrations was found to be surprisingly consistent, complicating the unmixing modeling. The collected samples also had consistent particle sizes, with no spatial patterns or basic relationships seen.

Figure 8: Map of the Study Area Showing Sampling Locations



Source: Original elaboration for this publication.

The most notable finding was that the Surkhob catchment is contributing 65 percent of the deposited bedload of the Vakhsh River, with the Obikhingob contributing the remaining 35 percent. Elsewhere it was found that the Upper Surkhob catchment is dominated by sediments originating in the MS1 sub-catchment, consistent with the MS1 catchment having the more significant proportion of its catchment glaciated.

By far, the dominant sources of sediment to tributaries and the main stem of the Vakhsh River are derived from mass wasting, including landslides (both shallow and deep), debris flows that directly enter channels, and gully erosion. The latter (gully erosion) consists of very deep features (sometimes greater than 100 m deep) in which mass wasting along the flanks contributes far more sediment than surface erosion processes.

Other findings include the remarkable consistency in elemental ratios across tributary junctions in general, resulting in poor discriminatory power regarding the identification of sediment sources. This unfortunate occurrence has hampered the attempt to trace the sources of sediments with any spatial precision. One group of small sub-catchments did have distinct vanadium, titanium, and chromium assemblages as a function of them being almost wholly within a singular geological unit (the Cretaceous), with this enabling discrimination of them as a group from sediments collected in the main channel. However, these four sub-catchments represented just 1 percent of the total catchment area; hence, no influence of these catchments could be detected downstream.

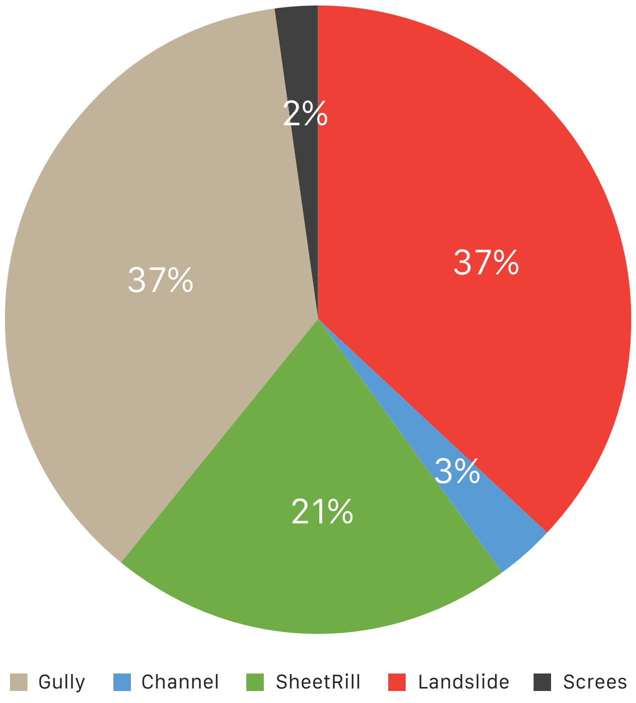
Finally, it was found that some elemental concentrations change with downstream patterns. No mechanism for this is clear; however, examination of these patterns may supply an alternative approach for future tracing.

3.1.4 Sediment Budget

The SWAT model was first used to set up the baseline for sediment flows for the Vakhsh River Basin, as presented below. Then, the integrated sediment and hydraulic model was used to estimate the benefits resulting from landscape restoration interventions, as described in the following sections.

The sediment that enters the stream network from the different inputs is deposited or transported further downstream. Once the sediment has entered the channel, it is not possible to trace the sources in SWAT. Therefore, the sediment budget is set up based on the assumption that the share between the different erosion types stays constant within the in-stream phase. Figure 9 illustrates the long-term average sediment budget simulated from the various sources. Unfortunately, little information exists to verify these results. The amounts of sheet and rill erosion (13 percent) and of gullies (35 percent) generally agree with the estimate of Safarov et al. (2015) for a small catchment in Faizabad district; however, it must be noted that efforts should be made to gain knowledge on the sediment sources so that such modeling efforts could be verified in the future.

Figure 9: Sediment Balance (2012–2021) Upstream of Rogun from Different Erosion Types



Source: Original elaboration for this publication.

Channel erosion and screes show the lowest variability and remain relatively constant over the years, while landslides and gully erosion show the highest variability, as shown in Table 2. The total loads per year vary between 65 and 120 million tons. This shows that climate variability significantly affects sediment processes. Average sediment load upstream of Rogun Reservoir over the 10 years is 92.7 million tons per year, which matches well with the observations summarized by HRW (2015) for Nurek.

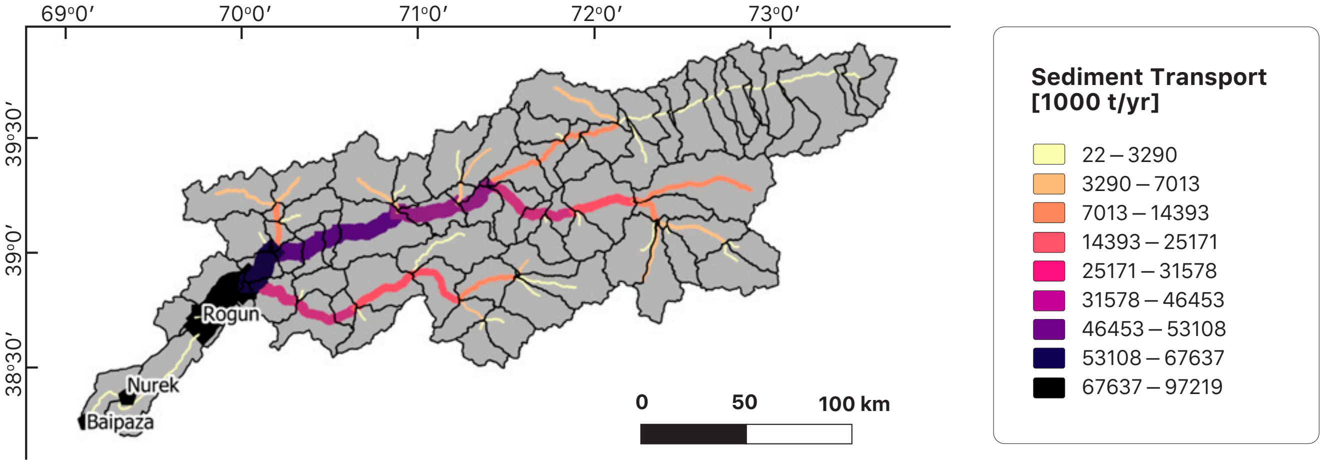
Table 2: Annual Contribution of Sediment for the Different Erosion Types Upstream of Rogun (million tons per year)

Year	Sheet and Rill	Landslide	Screes	Gully	Channel	Mosaic
2012	21.3	69.5	3.4	35.3	3.5	131.7
2013	14.4	28.8	1.4	23.5	2.6	70.7
2014	23.0	30.1	1.6	43.0	2.4	99.7
2015	28.7	41.2	2.3	44.0	2.8	118.7
2016	20.3	33.3	1.8	38.7	2.6	96.3
2017	16.5	26.9	1.5	34.9	2.2	81.8
2018	14.9	22.3	1.2	28.7	1.9	68.8
2019	23.9	45.2	2.5	37.5	2.5	111.2
2020	16.6	25.9	1.4	28.7	2.0	74.4
2021	14.6	21.2	1.1	32.6	1.3	70.6
Average	**19.4**	**34.4**	**1.8**	**34.7**	**2.4**	**92.4**

Source: Original elaboration for this publication.
Note: The values for 2021 are simulated only until July 31 and are extrapolated linearly to the full year.

The highest erosion inputs occur along the middle reaches of the Surhob and Oblhingou, as shown in Figure 10 that visualizes the 10-year average sediment transport along the Vakhsh River network that results from the input of all erosion types. The steepest and highest areas of the catchment are mostly covered by snow and ice and therefore do not contribute significant amounts. After the confluence of both rivers, the Vakhsh has the highest sediment load which then ends at the Rogun Dam.

Figure 10: Spatially Distributed Average Annual Sediment Transport in Vakhsh River and Tributaries



Source: Original elaboration for this publication.

3.2 IDENTIFICATION OF LANDSCAPE RESTORATION INTERVENTIONS

The sedimentation assessment from Griffith University suggests there is no one single dominant spatial source of sediment, so landscape restoration efforts can be implemented on any possible land use type within the Vakhsh catchment. Eventual decisions on the locations of these restoration interventions should therefore be based on other considerations such as social acceptability, enabling land governance arrangements, and access to finance. Most of these are factors that cannot be seen using 'remote sensing'.

For this reason, areas with restoration potential were physically identified based on context assessment, review of existing initiatives, discussions with local stakeholders, and land zoning regulations, as well as natural and technical constraints, such as required maximum distance to infrastructure, elevation, and land cover classifications. These decisions were informed by satellite imagery; literature; and key interviews with country director for Caritas-Tajikistan (Kassam 2022), the natural resource and disaster risk reduction specialist in Tajikistan (Davlatov 2022b), and an International Fund for Agriculture Development (IFAD) consultant engaged in the Livestock and Pasture Development Project in Kulob. Assumptions were furthermore tested and confirmed based on a field study in the municipality of Tojikobod by Davlatbeg Davlatov (Davlatov 2022a).

As a result, the most promising landscape restoration interventions that can be scaled in time and space within the Vakhsh catchment were identified, presented below. Potentially suitable locations for these interventions were also identified, along with an estimate of the most affected ecosystem services and intervention costs. The data are fed into the comprehensive CBA presented in the following section.

3.2.1 Context Assessment

The agricultural sector employs 50 percent of the labor force and contributes approximately 20 percent to GDP in Tajikistan (World Bank 2023c). Crop production, including cotton and wheat, accounts for approximately two-thirds of the total production value, and livestock husbandry accounts for another one-third (CIA 2020). Livestock is also a strategic store of wealth and can be sold in time of need. Moreover, manure is used for both fertilizer and heating fuel (Philipona et al. 2019). Over the last decade, there has been a noticeable increase in livestock numbers. This is due to a combination of factors, including a decline in remittances from family members working abroad, lack of trust in the formal banking sector and declining cropland productivity, limited employment opportunities within rural areas, and weak markets for agricultural produce (Caritas 2020; Philopona et al. 2019). Tajikistan has a total of 3.8 million ha of pasturelands (World Bank 2020a), approximately 868,000 ha of which are in the Vakhsh River Basin (23 percent of the total).

Forests also play a key role in the lives of Tajikistan's rural population (FAO 2007; Pilkington et al. 2020). Firewood, fodder, medicinal plants, fruits, and nuts are an important source of income (GIZ 2019). Today, however, the country's forest area only covers some 2–3 percent of Tajikistan's territory, against 16–18 percent a century ago. The mountain ecosystems of southern and southeastern Tajikistan were the major regions for the conservation of wild-growing fruits (apples, pears, apricots, mulberries, cherry plums, and plums, among others), nuts (walnuts and almonds), grapes, and berries (World Bank 2012). Forests were cleared for agriculture and mining during the Soviet period. Since 2000, the pace of forest degradation has accelerated due to uncontrolled tree cutting and increased livestock numbers (Thevs 2018) and a spike in demand for fuelwood, after the fall of the Soviet Union. Unregulated transhumance and elevated levels of forest grazing are particularly damaging to forest health (Mislimshoeva, Herbst, and Koellner 2016). These factors, combined with unsustainable NTFP extraction, present significant challenges for the Tajikistan forestry department. The ongoing decline in forest resources is seen in increased travel times to locations for fuelwood harvesting (FAO 2007; Pilkington et al. 2020). For 70 percent of the population, fuelwood is the primary energy source due to an inconsistent energy supply (World Bank 2018).

Land degradation is also affecting Tajikistan's pastures and cropland. The use of steep hillsides to grow cereal crops, vertical plowing, and removal of tree canopy on sloped croplands (Caritas 2019; World Bank 2012) has led to mudslides (ruining villages, roads and farmland, irrigation, and water systems), soil erosion, and silting of waterways used for drinking water and irrigation (World Bank 2012). The rising livestock numbers place increasing pressure on the already degraded pasturelands (Philipona et al. 2019). Degradation of summer and winter mountain pastures persists (Jenet 2005). It is estimated that Tajikistan is losing about 2,243,166 tons of hay yearly due to pasturelands degradation, for an estimated value of US$109 million, equivalent to 1.5 percent of the country's GDP (World Bank 2020a). For alpine pastures in Muminabad, Jenet (2005) has estimated that grazing areas produce dry matter (DM) of 500 kg per ha compared to a maximum of 1,600 kg per ha for winter pastures and 2,000 kg per ha for summer pastures. In contrast, local pasture experts in World Bank (2020a) estimate the total amount of hay that can be harvested from undegraded pastureland to be about 1,100 kg per ha per year.

Degradation of mountain pastures, together with deforestation and unsustainable agricultural land use management practices, compromise livelihoods and increase the vulnerability of rural communities to natural hazards (Golubeva 2018; World Bank 2020a). Restoration and the sustainable management of crop, forest, and rangelands, on the other hand, can help mitigate climate change and attenuate disaster risks by reducing the likelihood and intensity of expected hazards, via soil stabilization, reduced erosion, flood protection, drought control while increasing the resilience of local communities (Harari, Gavilano, and Liniger 2017; IPCC 2019; World Bank 2019).

3.2.2 Existing Initiatives

In the light of the problems of land degradation, many organizations, NGOs, and DFIs, such as the World Bank, the IFAD, and Caritas, are working to improve the situation. As argued in the following, certain forest landscape interventions, notably orchards and woodlots as well as sustainable rangeland management, stand out in terms of their feasibility and suitability for upscaling.

Woodlots are typically implemented using JFM contracts. These are contracts between local tenants and the local state forest enterprise that grants the land use rights to the local forest tenants over a leasing period of up to 20 years, with the possibility for prolongation (GIZ 2019). In addition to the contract, management and annual plans serve as tools for forest management planning and for the monitoring of activities and results (GIZ 2019). Between 2015 and 2019, German investments, coordinated by Caritas with the state at the district-level authorities, covered close to 10,000 ha of public forest. The 20-year lease agreements—between farmers and state forest agencies—were part of a larger forest management plan and commodity-sharing mechanism. The JFM enables the local population to be involved in forest management and to support the rehabilitation of degraded natural forests over the long term. The sustainability of this approach is grounded in active involvement of farm households in forest protection, afforestation, and rehabilitation. There are also economic incentives for the state forest enterprises, in that these contracts reduced the need to undertake forest management initiatives, and a negotiated share of the commodities produced (in the order of 50 percent) are convertible through commercial sales for cash for local and state budgets (Caritas 2020). The primary products produced and harvested include hay and fodder, fruits and nuts, firewood, and timber. Based on discussion among experts of the consulting team (G. Petersen, J. Kiesel, and A. J. Van Schalkwyk), woodlots were also considered the most promising intervention, from the perspective of reducing gully erosion and landslides.

For more than two decades, the World Bank has actively supported forest landscape management activities in Tajikistan (through the Environmental Land Management and Rural Livelihoods project[40] and now RESILAND CA+[41]), including woodlot establishment, orchards, assisted natural regeneration, forest protection and pasture management, JFM, FUGs, and spatial and integrated landscape management planning (World Bank 2020b). This commitment is aligned with Tajikistan's national strategies and targets. For example, in 2018, Tajikistan signed the Astana Resolution for about 48,000 ha of degraded forest landscapes in Tajikistan by 2030 (World Bank 2020b). Tajikistan's 'Forest Sector Development Strategy' aims, by 2030, to plant new forests on 15,000 ha, rehabilitate 30,000 ha of existing forests, and carry out measures that support natural forest regeneration on 120,000 ha (Thevs 2018).

Ecosystem-based adaptation. With limited ministerial and district budgets to support needed agricultural, environmental, and water-related initiatives, there is a case for building disaster risk resilience using ecosystem-based approaches (so-called ecosystem-based disaster risk resilience [ECO-DRR]). Caritas' experience is that willingness of communities to invest in ECO-DRR measures is still high. While for investments in physical mitigation, infrastructure-leveraged community contributions are in the order of 20 percent of the financing needed, for ECO-DRR measures, such as agroforestry plots and rotational grazing, community contributions can reach 45 percent (in the Muminabad district between 2010 and 2026[42]) (Caritas 2020). In a feasibility study on the ecosystem-based adaptation methods for soil erosion control (Redmann and Mislimshoeva, 2017), afforestation was also found to offer the greatest potential for upscaling, due to economies of scale that could be realized in terms of program management and cost reduction. Orchard establishment with legumes, such as lucerne, esparcet, and safflower, planted in between the rows is an excellent way to restore degraded soils. Horticulture also ranks high in terms of its soil protection and carbon sequestration potential. A key recommendation from the World Bank's carbon balance assessment undertaken during the Environmental Land Management and Rural Livelihoods project (Golubeva 2018) is to prevent erosion on slopes by afforestation, and where possible, to implement horticulture projects on eroded slopes of varying degrees of degradation, also on lowlands.

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[40] https://documents1.worldbank.org/curated/en/624581558014153035/pdf/Tajikistan-Env-Land-Mgt-and-Rural-Livelihoods-GEF.pdf.

[41] https://documents.worldbank.org/en/publication/documents-reports/documentdetail/099520211222125066/environmental00n0project000p171524.

[42] Undertaken jointly with district governments and communities.

Sustainable pasture management. Efforts to improve pastures and livestock productivity in Tajikistan—led by, for example, IFAD, the World Bank, and Caritas—are focused on various practices. This includes enhancing access to remote pastures, improving water supply and rotational grazing, rehabilitating pasture schemes and planning, growing forage crops, promoting livestock migration, and supporting the establishment of Livestock and Pasture Management Plans and PUUs (IFAD 2015). Legally registered PUUs are entitled to obtain land use certificates and long-term lease agreements from the state, thereby allowing activities on public pastures that relate to productivity improvement and protection (Philipona et al. 2019). As pasture management activities span large areas with uncertain boundaries (for example, the building of a pasture bridge supplying access to summer pastures) or involve activities where the planting of forage crops allows for relieving pressure on grazing land elsewhere, the assessment of benefits in per hectare terms can be subject to much uncertainty. The landscape restoration intervention considered for the CBA in this study, therefore, focuses on rotational grazing, as a popular rangeland restoration strategy, that can be implemented and assessed within a defined geographical boundary.

3.2.3 Orchards, Woodlots, and Sustainable Grazing Localities

Suitable locations for orchards and woodlots were found by excluding glacial terrain, barren land, water bodies, and grassland, using land use classifications developed under similar studies (Bandishoev et al. 2021). The land uses that were classified as possible for each landscape restoration intervention are shown in Table A2.2, Annex 2. As for other specific criteria, it was furthermore required that orchards be found within 1.5 km of a village, to allow for regular maintenance activities and irrigation. Easy access to woodlots is also needed for their establishment and maintenance. In designing future land use options, it was therefore 'imposed' that woodlots are planted within a 1.5 km reach of a road.

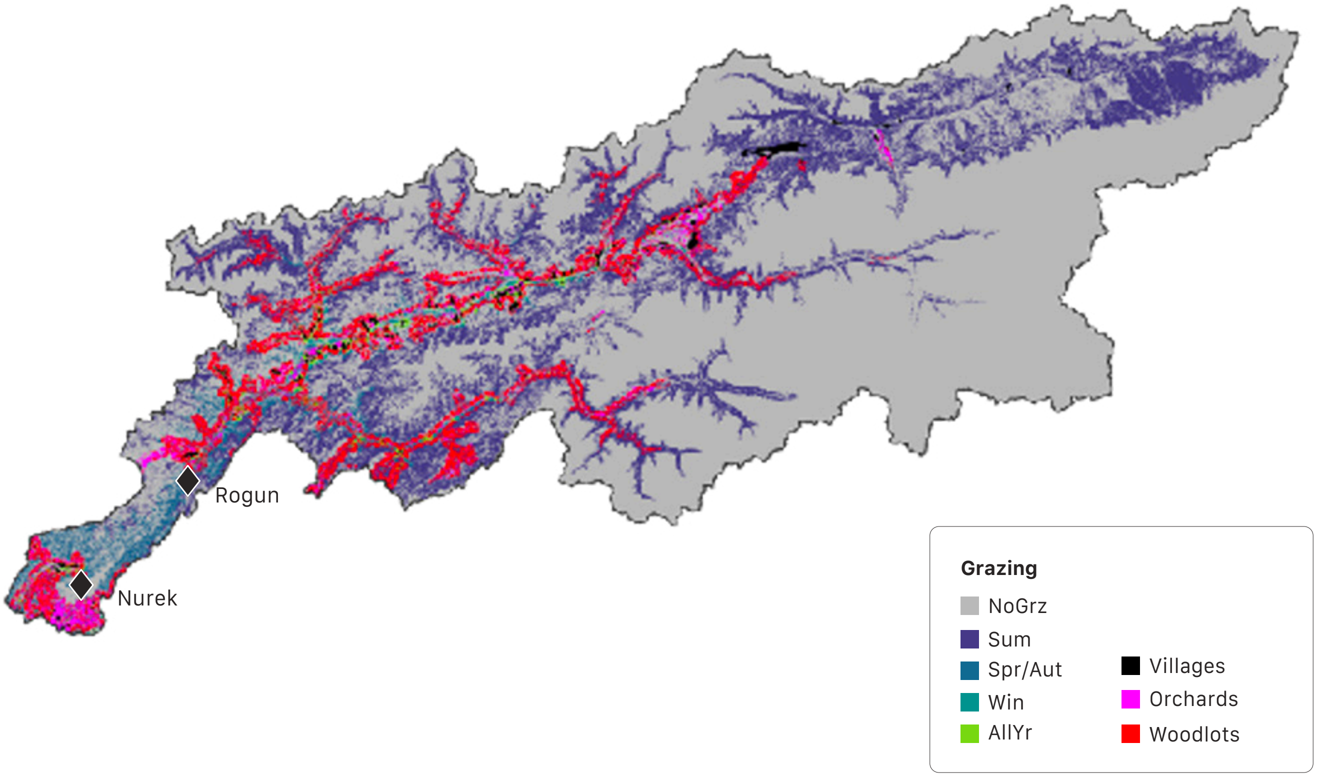
Orchards and woodlots need to be planted below the tree line, which is at 2,800 m (Davlatov 2022a). Since woodlots can help prevent gully erosion and landslides on steep slopes, it is assumed that they can be planted on any slope angle. Orchards, however, are typically proven on slopes between 0 and 30° angle. The area suitable for woodlots is therefore larger relative to that suitable for orchards. Typically, orchards are built on Dekhan farms and private land, while woodlots are found on Dekhan farms or land owned by the forestry commission. In principle, orchards and woodlots can also be set up on degraded pastures, but in this study, it is assumed that land currently used for pastures continue to be dedicated to (sustainably managed) pastures. Figure 11 shows the locations for the landscape restoration scenarios, including summer, spring, winter, and all-year-round grazing areas, that were used to produce the modeling results. The full range of criteria used for mapping the interventions within the Vakhsh River Basin is shown in Table A2.2 in Annex 2.

The mosaic scenario combines the possible intervention sites for orchards, woodlots, and rangelands. In some cases, a specific area (for example, with mosaic natural vegetation) may be simultaneously suitable for orchards, woodlots, and sustainable rangeland interventions. In that case, orchards were allowed to take priority, followed by woodlots. Grazing was given last priority because grassland areas are already significant—including the largest proportion of land uses—and it is assumed that they continue to be used for grazing in the landscape restoration scenario.

The mosaic landscape restoration scenario should be seen as an entry point for understanding how large-scale restoration could take place. This is because, in principle, reforestation initiatives can also expand over grasslands, supplying enabling conditions, such as infrastructure and ability to irrigate in the first years. However, the decision should come down to the individual use case. From the perspective of maximizing the benefits from reduced erosion and carbon sequestration, it is more efficient to regenerate forest landscapes over degraded pastures. But to enable such significant land use transitions, there needs to be both social willingness and capital availability. For this reason, the mosaic landscape restoration scenario adopts a more conservative approach, assuming all grassland areas are still grassland. Chapter 2 includes a detailed discussion on how land use criteria were defined for the valuation scenarios.

Assuming that all the possible restoration areas are subject to interventions, the maximum theoretical potential for implementing landscape restoration interventions is calculated at 966,616 ha within the Vakhsh River Basin, out of a total basin area of 3,125,291 ha, as shown in Table 3. The Table also shows the total area that is dedicated to each restoration intervention for the Vakhsh catchment, as well as upstream of Rogun and between Nurek and Rogun.

Figure 11: Location of Possible Landscape Restoration Interventions



Source: Original elaboration for this publication.

Table 3: Total Areas for Each Scenario, in ha

	Scenarios – Intervention Area			
Scenario	Between Rogun and Nurek	Intervention Upstream of Rogun	Whole Catchment	Ratio of the Intervention Area between Rogun and Nurek against the Intervention Area Upstream of Rogun (%)
Mosaic total	54,406	912,211	**966,616**	6
Mosaic - rotational grazing	37,207	714,153	751,360	5
Mosaic – woodlots	10,365	172,544	182,909	6
Mosaic – orchards	6,834	25,513	32,347	27
Rotational grazing	46,978	820,991	867,969	6
Woodlots	10,605	174,334	184,939	6
Orchards	6,834	25,513	32,347	27

Source: Original elaboration for this publication.
Note: Total catchment area is 3,125,291 ha.

3.3 IDENTIFICATION OF INTERVENTIONS TO IMPROVE ECOSYSTEM SERVICES: ORCHARDS AND WOODLOT ESTABLISHMENT AND SUSTAINABLE GRAZING

The aim of the CBA is to assess the costs and benefits of identified landscape restoration interventions. The results, presented below, were then used as input to calculate on-site provisioning and regulating ecosystem services resulting from implementing these interventions, as described in the following section.

Cost of Orchard Establishment

Fencing is often needed for woodlot and orchard establishment, especially in areas close to roads or livestock corridors where the number of livestock tends to be higher. Livestock eat young trees and can damage root systems. This hinders natural regrowth and reduces yields (GIZ 2019). In terms of irrigation needs, evidence from Uzbekistan suggests that orchards, which are irrigated with traditional furrow systems, require the digging of 14–16 m long wells. Facilities for drip irrigation, however, can be implemented at US$200 per ha (USAID 2020) based on a 15 ha orchard farm. Irrigation for small orchards can be secured through manual watering,[43] but this involves a significant investment of time (Davlatov 2022a). The cost of installing drip irrigation equipment (USAID 2020) is therefore considered for orchard establishment. Farmers further pay a flat fee to their water user association of US$17 per ha to access 8,000 m^3 of irrigation water for a 1 ha orchard (Davlatov 2022a). It is furthermore assumed that the opportunity costs of using land for orchards is considered negligible, as orchards are often implemented on degraded land, and the spacing density of trees allows farmers to grow hay and leguminous species in between the trees (for example, alfalfa, lucerne, or wheat), with an output value equivalent to what they were doing before orchards establishment (Kassam 2022).

Main orchard ICs thus relate to the installation and use of irrigation equipment (US$200 per ha),

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[43] A single tree irrigation can be managed by mulching and supplementary irrigation by bottles according to Rajabov in Davlatov (2022a).

purchase of seedlings (US$0.9 per seedling), wire and poles (US$2.7 per m) and 1 shrub per m (US$1.3 per shrub). As the hedgerow scrub grows—typically thick thorny bushes, such as buckthorn and rosehip—wire fencing equipment does not need to be replaced. According to a local farmer, labor costs for harvesting are in the order of US$12 per day (Davlatov 2022b). Departing from the example of a pure apple orchard, the harvesting season is approximately 2 months, resulting in an average annual harvesting cost of US$636 per ha. Transportation costs are estimated to be in the order of US$4.5 per metric tons of apples, resulting in an average transportation cost of about US$100 per ha, per year. The various costs of orchard establishment and MCs are summarized in Table A2.7, Annex 2.

Fruit, Nut, Fuelwood, and Timber Yield from Orchards

Orchards are found within Dekhan farms and are typically sized 1–2 ha. Rural communities value a range of products for orchard development. Preferred outputs include apples, walnuts, pears, peaches, and apricot. To value the benefits from orchard development, the returns from a 1 ha of mixed apple and walnut orchard are considered. The first yield is typically obtained 5 years after planting (grafted and non-grafted species) for nuts, and after 4 years for apples (Stark Bro's 2021). Walnuts are usually planted at 10 x 10 m distance (100 trees per ha) due to their wide canopy, and apples at 5 x 5 m (400 trees per ha) (Davlatov 2022a; Kassam 2022). Walnut trees and apple trees yield an average of 40 kg of nuts per tree and 100 kg of apples per tree at peak yield, respectively. It is assumed that apple yield increases linearly from the first year of harvest and peaks at year 10 (Mika, Chlebowska, and Kosmala 1981), after which it stabilizes until the end of a typical 20-year rotation, followed by a gradual decline to reach 43 kg/tree 30 years after planting. Walnut yields are assumed to peak at 15 years of age. At the end of the rotation, trees are cut down and can be used for fuelwood. However, not all the harvested produce is sold or consumed. According to an orchard farmer from Tojikobod, an estimated 20 percent of fruits and nuts are lost to diseases and are rotten, not sold, or not necessarily harvested at the right moment (Davlatov 2022b). This is accounted for in the CBA. In neighboring Uzbekistan, mixed maple-walnut and apple-walnut forests develop under poor site conditions on the southern slopes with shallow soils. A mature walnut tree reaches up to 60 m^3 volume of timber per ha (Botman 2009) and can be sold for an average of US$9.3 per m^3 (Davlatov 2022b). These assumptions are shown in Table A2.6 Annex 2.

Cost of Woodlot Establishment

While the density of trees is higher within woodlots compared to orchards, the proportion of species destined for NTFP is smaller. It is therefore assumed that annual maintenance and harvesting costs (NTFP harvesting, thinning, pruning, and pesticides) are half that of orchards. This was backed up by Davlatov (2022b), after consultation with the Head of Forest Department in Tojikobod. Woodlot establishment costs, irrigation costs, and fencing establishment, however, are like that of orchards (Kassam 2022). The hiring of a small excavator may also be necessary (GIZ 2015). This cost has been added to the ICs. In terms of forgone benefits, it is assumed that woodlots are regenerated on degraded land, used for marginal activities and occasional grazing. The opportunity cost is therefore considered equivalent to what can be enjoyed from a hectare of typical pasture under continuous grazing, that is, US$29 per ha (see Table A2.8 and Table A2.9 in Annex 2 for a breakdown of yields, costs, and opportunity costs related to woodlot establishment).

Fruit, Nut, and Timber Yields from Woodlots

Field visits in the district of Tojikobod, in early

February 2022, revealed that the creation of woodlots is a popular and prioritized intervention, notably to enhance incomes and reduce disaster risks (see Table A2.10 in Annex 2). According to the head of department of forestry in Tojikobod, woodlots include walnut, almond, apricot, acacia, cherry, pistachio, dog rose, and juniper tree species and other species that may be used for timber with a density of 400 trees per ha. For the economic analysis, it is assumed that half of the trees in the stand (200 trees per ha) supply NTFPs, including walnuts (100 trees per ha) and fruits (100 trees per ha). For simplicity, the economic returns from fruit yields are estimated with reference to apricots. A healthy mature apricot tree produces an average yield of around 40–70 kg of apricots per season, according to crowdfarming (undated) and wikifarmer (undated). This number may fluctuate a lot and depends on the cultivar, the age of the trees, plant density, and availability of water and nutrients. There are cases where farmers can reach 140 kg per tree (wikifarmer undated). This analysis uses a more conservative estimate of 30 kg/tree, referring to an orchard at year 10 from plantation, considering that the woodlots are not optimized for fruit production.

Fruits, such as apricots, sell at US$0.9/kg; in Tojikobod, approximately 100 m^3 of timber can be harvested from a woodlot after 14 years (Davlatov 2022a; World Bank 2020a).[44] Consulting the literature, a volume of 104 m^3 per ha was harvested in a pure 23-year-old walnut plantation in Italy (Pelleri et al. 2020). In Uzbekistan, the average stock of mature walnut trees mixed as maple-walnut and apple-walnut forests reaches up to 60 m^3 per ha (Botman 2009). Considering these estimates, it is stipulated in the cash flow that 150 m^3 of timber can be harvested after a 30-year rotation.

Cost of Sustainable Grazing

Provided an enabling environment with the presence of PUUs that can access and manage pasture lands, the implementation of rotational grazing is cost-effective (Kassam 2022). The main cost elements are associated with the acquisition of mobile fencing options (such as poly wire) or active use of herding (Westerberg et al. 2021). This latter possibility is more realistic in Tajikistan. In the literature ICs range from US$8.1 (Wang et al. 2018) to US$112 per ha, when integrating access to water resources (Undersander et al. 2002).

In Tajikistan, rotational grazing is practiced using fencing on village pastures. Traditional fencing had a cost of US$120 per ha in 2022 and should be replaced every 6 years. Many villages also use natural fencing from their own trees or bushes and supplement with purchased mesh wire and can already use existing fences (Davlatov 2022b). In that case, the IC is lower. On summer and winter pastures, rotational grazing is usually implemented using (existing) herders, who need basic training in rotational grazing management. Considering these elements, it is reasonable to assume that average per hectare (additional fencing) ICs are in the order of US$30 per ha for village pastures, with fencing to be replaced every 6 years, while rotational grazing schemes on more distant pastures are in the order of US$8.1 per ha (Wang et al. 2018) and up to a maximum of US$20 per ha—which covers training, capacity building, and the elaboration of grazing management plans. The upper-range costs are used in the final CBA and are summarized in Table A2.5 in Annex 2), providing conservative estimates of true net benefits from rotational grazing. Lower-bound costs are used for the sensitivity analysis.

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[44] Another candidate tree species is pistachio, as a drought-resistant and highly appreciated tree, that under normal circumstances has a hard time regenerating, partly because of intensive fruit harvesting and use as cattle pasture. Pistachio, along with juniper and riparian forests, needs urgent attention in Tajikistan (Thevs 2018).

The time to move livestock is negligible if paddock design is efficient and livestock are moved after milking. Rotational grazing may also decrease the need to make hay. Labor effort is therefore not accounted for. Indeed, personal discussions with the country director for Caritas in Tajikistan confirmed that the costs of rotational grazing are minimal and that the main constraint to the upscaling of rotational grazing system is the underlying land tenure situation in Tajikistan (Kassam 2022). That is why Caritas is now focusing its efforts on the reform of pasture legislation (Kassam 2022) instead of site-specific project implementation. The opportunity cost is assumed to be merely that which may be earned from a hectare of grazing land in its degraded state.

Sustainable Grazing and Forage Yield

The degradation of pastures is commonly addressed by balancing forage demand with forage production (Etzold and Neudert 2019; Pachzelt et al. 2013). A meta-analysis of 30 long-term grazing studies from various environments in North America showed that grazing at the carrying capacity of land led to a 23 percent higher biomass productivity relative to the heavily grazed areas.

To the extent that planting of forage crops, rotational grazing, and improved pasture access to remote areas allow for evening-out grazing pressure over a given area, it may be assumed that biomass productivity can increase by at least 20 percent because of these actions. This hypothesis was confirmed by field observations in Tojikobod, situated 35 km east of Kalanak (Figure 4), where the planting of esparcet and rotational grazing schemes has allowed to increase land productivity by more than 20 percent on spring/autumn pastures (Davlatov 2022b).

In the IFAD Livestock and Pasture Development Project, in the district of Kulob, farmers have seen biomass productivity improvements of about 50 percent within five years of the project life span on 'all year round' village pastures (Shuhratjon 2022). The pastures are around villages at an altitude from 500 to 1,200 m, with average distances of 0.5–2 to 3–4 km to village centers. The project measures included the implementation of rotational grazing, water supply, livestock migration, and interventions including access to summer pastures, formalized through Community Livestock and Pasture Management Plans by the participating PUUs.

Actual estimates of forage production in tons of DM per hectare were not available from Kulob or Tojikobod. However, World Bank (2020a) report benchmarks estimates for low, moderately, and severely degraded pastures in the province of Districts of Republican Subordination (DRS), an area which hosts a large part of the Vakhsh River Basin (World Bank 2020a). Consistent with literature and expert opinion (Davlatov 2022b; Kassam 2022), it is assumed that winter, spring, and fall pastures are moderately degraded; village pastures are severely degraded; and summer pastures are little degraded because they are remotely located. Using the above benchmark estimates from the World Bank (2020a), post-intervention forage production was estimated for different classes of pastures. According to IFAD's and Caritas' experiences, it was also assumed that biomass productivity can be increased by 50 percent on village pastures and 20 percent on remaining pastures (see Table A2.4 Annex 2 for details). Biomass estimates from Table A2.4 have been used to parameterize the hydrological SWAT model and to assess how improved pasture productivity contributes to reducing erosion and enhancing water yield.

A principal limitation of livestock productivity in Tajikistan is the quantitative and qualitative scarcity of feed (Jenet 2005; Cavatassi and Gemessa 2022). The most important food resources are pasture biomass, crop residues and hay. Additionally, farmers and pastoralists supplement with cultivated fodder (such as alfalfa and sainfoin) and concentrates of cottonseed oilcake (Jenet 2005; IFAD 2015). The benefit of improved pasture productivity may therefore be valued using the replacement cost method since an increase in forage production will reduce the need to buy hay (or other forage supplements[45]). The inflation-adjusted average price of hay in Tajikistan is US$52.4 per metric ton (World Bank 2020a). It is conservatively assumed that changes in pasture productivity are achieved within five years of implementing the sustainable pasture management measures, following IFAD's experience (Shuhratjon 2022).

3.4 IDENTIFICATION OF OFF-SITE REGULATING ECOSYSTEM SERVICE BENEFITS

Given the data availability, the list of ecosystem services was narrowed down to focus on those related to provisioning (such as forage, fruits, nuts, timber, and fuelwood) **and to co-benefits from regulating** (such as those pertaining to climate change mitigation and improvements to the hydrological cycle, including erosion control, water availability for plants, return flow to rivers, soil moisture, and reduced runoff).

Landscape restoration contributes to controlling soil erosion, reducing losses of water and nutrients, sequestering carbon, strengthening biogeochemical cycles, managing soil pH and salt balance, enhancing biocomplexity, and creating disease-suppressive soil (Lal 2016). Benefits will take some time to materialize. Expert deliberation within the consultant team suggests a period of 15 years would be needed before full benefits will kick in and the new equilibrium to be reached after woodlots and orchards reforestation. In terms of rotational grazing, field visits from Tojikobod and associated literature reviews suggest that it will take 6 years for pasture biomass to be regenerated (Davlatov 2022b; Li et al. 2018). It is assumed that other associated ecosystem service benefits, notably reduced erosion, water regeneration, and carbon sequestration, will follow the same path. Thus, to account for the continuous increase in ecosystem service benefits between 'now' and when the effects of the planned interventions are fully developed, a linear interpolation is undertaken from no reduction within the 1st year to 100 percent reduction in the 6th year (sustainable grazing) or 15th year (orchards and woodlots).

3.5 APPROACHES TO VALUE HYDROLOGICAL ECOSYSTEM SERVICES

About one-third (1.57 million ha) of the total 4.6 million ha of agricultural land in Tajikistan is potentially irrigable (Xenarios et al. 2021). The area currently irrigated is half its potential (753,083 ha), and only 201,370 ha of rain-fed arable land is cultivated (GOT 2016). The average yield of wheat crops in irrigated lands of valleys in Tajikistan (Khatlon, Sughd, and DRS) is 4–6 times higher than the wheat produced in rain-fed areas (OSCE 2018). As a result, almost 80 percent of the agricultural output in Tajikistan is cultivated in irrigated areas (Xenarios et al. 2021). More than 90 percent of Tajikistan's total annual runoff of freshwater and groundwater sources is diverted to agriculture (GOT 2015), and irrigated farming accounts for approximately 40 percent of groundwater exploitation (Chen et al. 2008). Freshwater is an inherently important input into the agricultural production in Tajikistan.

Landscape restoration positively affects hydrological services, including the recharge of groundwater aquifers, thus contributing to the increase of baseflows and streamflows during dry periods and to reduction of runoff

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[45] Such as cottonseed oilcake and grain by-products.

and flood risk (van Meerveld et al. 2021). This is confirmed by the results of the SWAT model. Reduced sedimentation also improves reservoir storage capacity. Therefore, in estimating the value of enhanced water supplies, the assessment accounts for (a) soil moisture, as a source of passive irrigation, (b) groundwater infiltration, and (c) enhanced reservoir storage of water. The value of that water is estimated, as explained in the next section.

While the study focuses on in-situ and extractive uses of water in farming, it should be acknowledged that water also supplies other important use and non-use values, for example, for industry, urban water supplies, recreation, and biodiversity maintenance (Turner et al. 2004). The latter, however, are not accounted for here.

Valuing Water

Since markets for water either typically do not exist or are highly imperfect, the task of valuing its economic contribution for different users is challenging. A broad range of methods have therefore been used to estimate the value of water. These methods include estimating demand curves and integrating areas under them, examining market-like transactions, estimating production functions, estimating the costs of supplying water if an existing source were not to be available, and asking willingness-to-pay questions on how much users value the resource (Arrow et al. 1993; Griffin et al. 1995). To value the benefits of supplying irrigation water, the World Commission on Dams recommends estimating the net value of the resulting increase in crop production (Aylward et al. 2001). As explained in Annex 2, this approach was not deemed suitable for this study due to insufficient data on input production costs and the heavy subsidization of irrigated water in Tajikistan, which leads to an inefficient use of water and potentially negative net benefits.

Historically, water has been undervalued in Tajikistan. Undervaluation leads to misuse and misallocation of water. All too often, it is used for purposes that do not maximize well-being and is regulated in ways that do not recognize scarcity or promote conservation (World Bank 2017a). An economically efficient use of water requires equalizing its marginal product in value across competing uses. This requires the consideration of the full economic cost, which requires an assessment of the use cost of water and the opportunity cost of the resource (Briscoe 1996). The use cost corresponds to the marginal financial cost of supplying the water to the user (that is, costs incurred in financing and running the abstraction, transmission, treatment, and distribution systems), and the opportunity cost reflects the value of water in its best alternative use, in farming, typically the gross benefits forgone by not irrigating a neighboring field or storing the water for use at a later time when it is of higher value. These elements are analyzed in detail in Annex 2, to attribute a shadow price to the enhanced water availability and improved reservoir storage capacity, resulting from landscape restoration.

Use Cost of Water

The supply of irrigation water in Tajikistan is challenged by the deteriorating conditions of pump stations, distribution networks, drainage, and canal systems, due to environmental factors and insufficient maintenance. Due to insufficient structures and inefficient drainage systems, there is a high volume of water losses from seepage throughout the distribution systems. These are causing topsoil salinization. The replacement and maintenance of deteriorating irrigation and drainage infrastructure is therefore of paramount importance to ensure sustained agricultural production (ALRI 2021). Moreover, in many cases, the river water level is at a lower elevation compared to the agricultural land, which makes it necessary for water to be lifted by large pumping stations into main canals (OSCE 2018). Pump irrigation and associated electricity absorbs 70 percent of the annual operation and maintenance (O&M) budget in neighboring Uzbekistan (World Bank 2022d). Given this, electricity costs for pumping are used as a (conservative) proxy for the use cost of water in irrigation.[46] Water abstraction use costs are furthermore corrected for artificially low electricity tariffs (as explained in Annex 2), yielding an economic use cost of irrigation of US$0.05 per m^3 of irrigation water (Table 4).

Table 4: Economic Cost of Water in Tajikistan

Use Cost of Irrigation Water	Unit	Value
Water abstraction use cost - subsidized (covering 70% of the true electricity cost)	US$/$m^3$	0.014
Water abstraction use cost - unsubsidized	**US$/$m^3$**	**0.048**

Source: Original elaboration for this publication.

Opportunity Cost of Water Used for Irrigation

While the financial sustainability of irrigation systems is important for O&M reasons, from the point of view of managing water as an economic resource, the key challenge is to ensure that users consider the opportunity costs of water. Opportunity costs vary depending on which alternative use comes into play. A typical situation in irrigated systems, including in Tajikistan, is one in which users are charged a small, subsidized amount for the 'use cost' and the opportunity cost is the value of the forgone output on 'another' (unirrigated) field. To approximate this value, Annex 2 Section A2.6 uses information on average irrigation volumes, water productivity for wheat in the Vakhsh River Basin, water efficiency, and the market prices. This generates a gross benefit of US$0.05 per m^3 of water used. Combining the use value and the opportunity cost yields an economic cost of US$0.1 per m^3 of irrigation water, a price that would ensure that users consider the full economic cost of water when using it.)

Table 5: Full-Cost Assessment of the Value of Water - Assumptions and Results

Parameter	Unit	Value
Yield of wheat (for a typical irrigation volume V)	kg/ha	1,837.5
Irrigation volume per hectare	m^3/ha	15,000
Average price of wheat grain in Tajikistan[a]	US$/kg	0.402
Water productivity in Vakhsh for wheat	kg/m^3	0.35
Water efficiency	%	35
Revenue per ha of added wheat	US$/ha	739.1
Gross benefit/opportunity cost of irrigation	**US$/$m^3$**	**0.05**
Full economic cost of water (use cost + opportunity cost)	**US$/$m^3$**	**0.1**

Source: Original elaboration for this publication.
Note: a. From World Bank (2020a).

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[46] While this may be an overestimate of the use cost for irrigation systems that rely on gravitation, overall, this is counteracted as we have not been able to incorporate replacement, repair, and damage costs of infrastructure in the use cost.

3.6 APPROACHES TO VALUING SEDIMENT REDUCTION

Sustainable sediment management seeks to achieve a balance between sediment inflow and outflow and to restore sediment delivery to the downstream channel, thereby maximizing long-term storage, hydropower, and other benefits while minimizing environmental harm (Morris 2020). Management strategies focus on improving the sediment balance across reservoirs by reducing sediment yield from the catchment. For example, through the kind of landscape restoration interventions analyzed here, routing sediment-laden flows around or through the storage pool, or removing sediment through flushing, or with various dredging options, including continuous sediment transfer. The benefit of reducing sedimentation through landscape restoration can be assessed in terms of the benefits of keeping reservoir storage, energy production, and discharge capability. This maximizes long-term storage for hydropower and irrigation and other benefits compared to the BAU scenario of continued sediment build-up.

Sedimentation also affects the safety and flood attenuation capabilities. As sedimentation progresses, the reservoir becomes a delta-filled valley that takes a meandering course, such that a flood wave does not spread out to allow flood routing.[47] Sediments will often block low-level outlets designed to allow for reservoir drawdown. As sedimentation continues, clogging of spillway tunnels or other conduits reduces spillway capacity, as seen in Nurek (AIIB 2017). The two outer dam gates of Nurek were already inoperable, in 2014, due to sedimentation (D-Sediment 2014).

Sediment also creates a wide range of environmental impacts (such as CH4 production from anoxic sediments), **increases loads on the dam and gates, and damages mechanical turbines and other mechanical equipment.** Damage to equipment happens through erosion of the oxide coating on the blades, leading to surface irregularities and eventually to more serious material damage. Sustained erosion can lead to extended shutdown time for maintenance or replacement. Moreover, recent studies have highlighted the synergic effect of cavitation erosion and sediment erosion, showing that the combined effect of cavitation and sand erosion is stronger than the individual effects (Thapa, Dahlhaug, and Thapa 2015).

Moreover, it is unclear whether Nurek Dam was designed to deal with added sediment load once more sediment reaches the dam axis. Sedimentation load will add significant pressure toward the dam's upstream face. If not designed for this, it is a threat to the structural integrity of the dam (Detering 2018). There is thus a significant range of present and future costs and risks associated with unabated sediment accumulation, whether for Nurek or Rogun under construction. In elaborating this assessment, several approaches to valuing the impact of reduced erosion from landscape restoration were used, notably (a) the value of enhanced reservoir storage for irrigation (assessed in the earlier section), (b) the full-cost accounting and avoided reservoir rehabilitation costs, and (c) the value of avoided or reduced dredging costs.

Avoided Reservoir Rehabilitation Costs and the Case for Considering Dredging Costs

Full-cost accounting recognizes that the value of (restored) reservoir volume—when considering its productive services alone—is incomplete. Leaving out the value of dam safety and flood protection is not acceptable from an engineering

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[47] https://www.hydroreview.com/world-regions/dealing-with-sediment-effects-on-dams-and-hydropower-generation/#gref.

and safety standpoint. So, in that case, the full-cost approach involves assessing reservoir restoration cost—that is, the cost of replacing the storage that would be lost by new infrastructure. This is done by estimating the original reservoir construction cost (or that of Rogun) and then inflating them to obtain their present value. Alternatively, one may use the new-build cost for storage capacity. Rogun Dam was first scheduled for US$2 billion with a nominal active capacity of 10 km^3. Newer estimates suggest US$5 billion are needed for the construction of the Rogun powerplant (Asia Plus 2022), leading to a specific storage cost of only US$0.5 per m^3 leaving out sediment MCs and other environmental consequences. In comparison with Europe and West Asia, estimates are seen in the range between EUR 2 and 6 per m^3 (D-Sediment 2022; Myint and Westerberg 2015). Even the full-cost accounting approach therefore has its limitation, since in most cases, 'other effects' and the true costs of sedimentation (upstream aggradation, downstream degradation and decommissioning costs, and sediment MCs in general) are unaccounted for in the construction design (Randle and Boyd 2018). For this reason, it may be equally justified to consider the benefit of reduced sedimentation in terms of avoided dredging and sediment transfer costs, which embeds a wider range of benefits from reducing sedimentation.

Reduced Dredging Costs

Erosion affects the hydropower generation capacity of Nurek. However, as argued above, there are other benefits to reduced sedimentation—including more balanced reservoir operation, reduced flood risk, reduced damage to equipment, and minimized environmental harm. It is beyond the scope of the current study to quantify these 'co-benefits'. Taken together, however, they often justify expenditures on dredging and active sediment management of reservoirs. Consequently, the benefit of reduced erosion is also estimated in this study, in terms of averted dredging or sediment transfer costs.

It is also important to note that flushing is not an effective possibility for Nurek nor for Rogun (TEAS 2014). In the case of Nurek, the effect is limited to a tiny section of the reservoir, which is directly in front of the dam (D-Sediment 2014). Other sediment will remain in place, and flushing will come with a loss of valuable water. Dredging and sediment reuse or continuous sediment transfer could therefore offer promising options for managing sediment, in combination with the reduction of sediment from catchment—as a source of green infrastructure—the first-best choice to sediment management (Randle and Boyd 2018).

Continuous Sediment Transfer and Dredging Costs

Dredging refers to the excavation of material from beneath the water. There are broadly two types of dredging: (a) mechanical-lift dredging removes sediment by buckets such as a backhoe, clamshell, dragline, or bucket ladder, placing the excavated material into a barge or truck for transport; and (b) hydraulic dredging mixes sediment with water for transport in a slurry pipeline, reintroducing the sediment back to the river below the dam, or discharging to a containment area for dewatering. A critical limitation to dredging is its cost. This cost is reduced by discharging to the river below the dam instead of upland disposal sites, for example, using continuous sediment transfer (Detering 2014, 2018). This allows for restoring sediment transport along the fluvial system, through the reintroduction of sediment into the river below the dam. This strategy implies continuous sediment transfer as opposed to large dredging campaigns at intervals of decades (Morris 2020). Unfortunately, active reservoir sediment management is globally not a standard practice (Randle and Boyd 2018), and evidence suggests that this is the case for Nurek as well. At hydropower sites, costs can be reduced by using self-generated electrical energy for dredging.

The key cost drivers of dredging are shown in Annex 2. Interviews and literature research were used to obtain a ballpark estimate of ranges of potential dredging costs for Nurek and Rogun. Dredging price in East Asia region is in the order of US$4.67 per m^3 in India, based on seven inland river dredging projects, each removing over 1 million m^3 of sediment (Indian Infrastructure 2019), and US$3.46 per m^3 in Bangladesh (Dhaka Tribune 2020). In the United States, the most typical dredging price over the last decade has been US$3.5–5.8 per m^3 for hydraulic dredging into a nearby confined placement site. Higher-priced exceptions apply to projects where access was particularly difficult or the containment area required a significantly higher preparation (Western Dredging Association 2021, 44). Discussion with Royal IHC IDH suggests that dredging costs are in the order of US$1–4 per m^3, with the most critical parameters being the type of material, dredging depth, and pumping distance World Bank communications with Royal IHC IDH, 2022). Moreover, as mentioned above, costs are expected to be lower if reservoir sediments are delivered to the downstream channel and more natural sediment transport conditions are restored to the environment (Western Dredging Association 2021).

A continuous sediment transfer could come with a lower cost and higher environmental compliance than conventional dredging due to significantly smaller dimensions and 24/7 operation. In the case of Nurek, very roughly, D-Sediment estimates the implementation of a continuous sediment transfer option for Nurek to be in the order of US$2 per m^3 transferred (D-Sediment 2022). Water and power needs for continuous sediment transfer would be compensated by maintained reservoir capacity, avoiding power and water losses. In the light of this data, a conservative sediment removal cost of US$3 per m^3 is used to infer the value of reducing erosion through landscape restoration. A more detailed description of the approaches used to assess the value of sediment reduction is presented in Annex 2.

3.7 APPROACHES TO VALUE THE IMPACT OF LANDSCAPE RESTORATION ON THE CARBON BALANCE

Terrestrial carbon sequestration is the process of capture and long-term storage of atmospheric CO_2 by forests, grasslands, wetlands, and other terrestrial ecosystems. The carbon stock of an ecosystem is determined by the environmental conditions, land use, and regime of natural and anthropogenic disturbances (Keith et al. 2019). Rangeland and forest landscape restoration will therefore also alter the above- and below-ground carbon balance within the Vakhsh River Basin.

Changes in the carbon balance, resulting from woodlot and orchards establishment, as well as rotational pasture management, were estimated using FAO EX-ACT software. For woodlots, the results reported in the Environmental Land Management and Rural Livelihoods (ELMARL) project's carbon balance report were used (Golubeva 2018), which are likewise derived from the FAO EX-ACT software. These results are shown in Table 6. Negative values show that all the restoration interventions contribute to a net-sequestration of carbon.

Table 6: Changes in the Carbon Balance over a 30-Year Time Horizon

30 Years	GHG in tCO_2-eq per ha (30 years)	Per ha per Year
Orchards	-296.0	-9.9
Grazing	-34.5	-1.2
Woodlots (plantation)	-69.3	-2.3
Woodlots (natural)	-564.6	-18.8
Mixed (plantation and natural)	-317.1	-10.6

Source: Original elaboration for this publication.

The high variance in sequestration potential from woodlots is explained by the fact that the main characteristics (for example, the growth rate of trees and respective biomass quantities) **depend on the management regime.** A distinction should be made between intensively (for example, plantation forestry) and extensively (naturally regrowing stands with reduced or minimum human intervention) managed forests (Golubeva 2018). In the case of the woodlot intervention considered in the Vakhsh River Basin, these are not naturally regrown; however, only non-grafted species are allowed (Kassam 2022). For this reason, we use a midpoint estimate (between natural and planted) for the carbon sequestration potential of woodlots. For each year *t*, the average annual increase in the ecosystem carbon balance, in moving from the BAU scenario to the landscape restoration scenario, is estimated according to Equation 2:

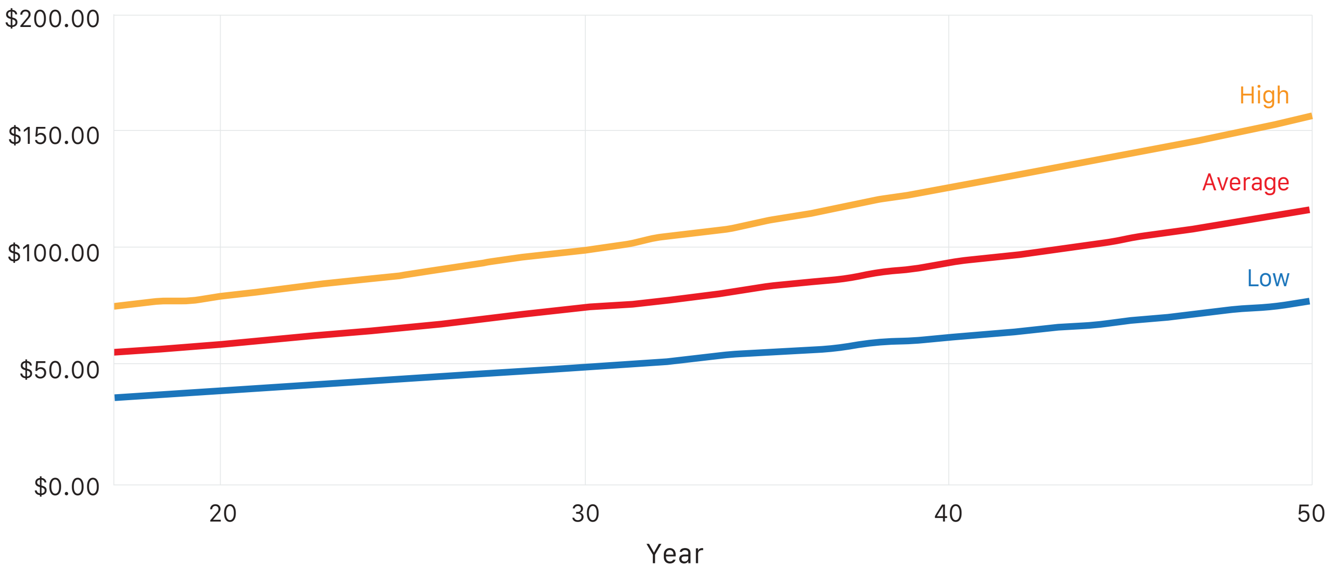
Net increase in the carbon balance BAUt→LRt =

$$GHG^{-ha}_{\text{degraded pasture} \rightarrow \text{restored pasture}} \; (x) \; AC_{pasture} + GHG^{-ha}_{\text{cropland} \rightarrow \text{orchards}} \; (x) \; AC_{cropland}$$
$$+ \; GHG^{-ha}_{\text{degraded land}} \; (x) \; AC_{woodlots} \quad (eq\ 2),$$

, where GHG are the sequestered GHG emissions, associated with landscape restoration, expressed in tCO_2-eq per year per hectare. AC refers to the area that is converted in year *t* from that land use type to the other.

The economic benefits of investing in integrated landscape management scenarios can be estimated using the SCC, which tries to capture the marginal global damage cost of an added unit of CO_2 emitted into the atmosphere. For this purpose, we draw on the recommendations produced by the High-Level Commission on Carbon Prices, led by Joseph Stiglitz and Nicholas Stern (Carbon Pricing Leadership Coalition 2017). The commission concluded that the explicit carbon price level consistent with achieving the Paris temperature target and keeping temperature rise below 2° is at least US\$40–80/tCO_2 in 2020, rising to US\$50–100/tCO_2 by 2030 and US\$78–156/tCO_2 by 2050 provided that a supportive policy environment is in place (World Bank 2017b). The trajectory of the recommended SCC is shown in Figure 12. The assessment uses the average/midrange of the SCC.

Figure 12: SCC (US$/$tCO_2$-eq), Shadow Price of Carbon by Year



Source: Original elaboration for this publication.

The avoided societal damage costs from enhanced carbons sequestration cannot be directly appropriated by communities, nor Tajikistan, since carbon sequestration is a global public good. The estimates nevertheless supply an important perspective on the societal-wide benefits of adopting landscape intervention scenarios within the Vakhsh River Basin.

Another way to estimate economic benefits is to provide carbon credits. Then, emission reductions are certified and verified and could be sold as carbon emission reductions credits in the voluntary carbon market. The voluntary carbon market is currently grabbing headlines with record transactions and soaring credit prices. The weighted average price per ton for credits from forestry and land use projects that reduce emissions or remove carbon from the atmosphere has been on a steady upward path, rising from US$4.3 per credit in 2019 to US$5.60 in 2020 (Ecosystem Services Marketplace 2021) with a spike to about US$7.5 per tCO_2-eq by end of 2022 for premier voluntary REDD+ credits (S&P Global 2022). This assessment uses an average price of US$5 per tCO_2=eq to infer the potential value of carbon emission reductions to local communities. Consequently, the present value of the avoided social damage cost or marketable benefits from enhanced carbon sequestration is estimated following Equation 3.

Present value of enhanced carbon sequestration =

$$\sum_t^T \frac{(SCC_t / P_t \times GHG_t)}{(1+r)^t} \quad \text{(eq 3),}$$

where P_t is the price of a unit tCO_2-eq emission reduction, sold on the voluntary carbon market in year *t*.

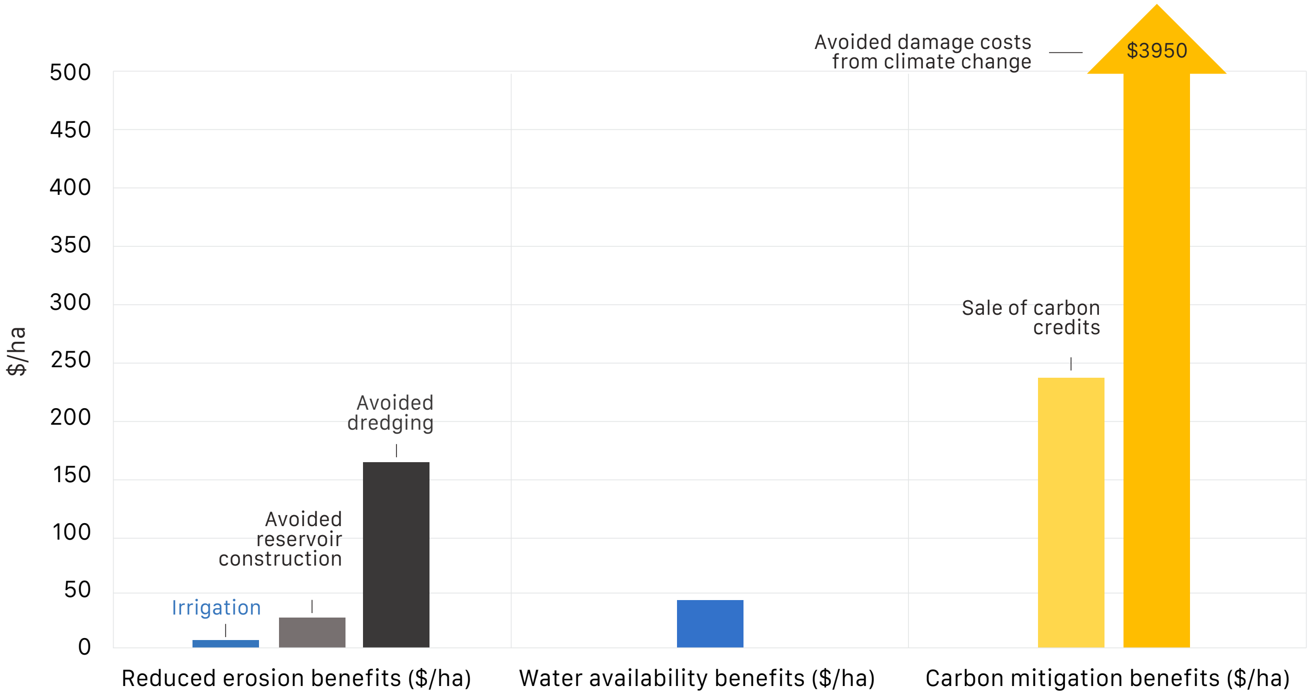
3.8 ECONOMIC VALUATION OF ALTERNATIVE INTERVENTIONS IN VAKHSH VALLEY - INTEGRATED ANALYSIS

Forest and rangeland restoration enhances nutrient, carbon, and water cycling, thus supplying important ecosystem services to

the wider society. The results from the previous analysis were used to assess the value of reduced erosion and runoff and enhanced groundwater, soil moisture, and carbon sequestration, from orchards, woodlots, or rotational grazing, individually and when combined as part of a landscape mosaic. The interventions also enhance the availability of marketable produce to local communities. The monetary net benefits of these ecosystem services to land users and the wider society alike are presented below.

As the earlier sections have shown, landscape restoration provides a range of benefits with values that vary according to the perspective taken. As an example, Figure 13 shows the range of benefits generated per hectare of land restored under mosaic restoration. Further, the report discusses economic benefits from improvement in ecosystem services associated with different landscape restoration interventions in the Vakhsh River Basin.

Figure 13: Regulating Ecosystem Service Benefits from Reduced Erosion, Carbon Sequestration, and Enhanced Water Availability, per ha Land Restored



Source: Original elaboration for this publication.
Note: T = 30 years, r = 6 percent.

Economic Value of Erosion Reduction and Avoided Dredging from Landscape Restoration Interventions

A summary of the sediment input to Rogun Dam for the different source types is provided in Table 7 for the baseline and the four scenario interventions, averaged over the 10-year simulation period. It must be kept in mind that the interventions are assumed to have been completely developed, that is, 5–6 years for the rotational grazing and 15 years for the woodlots and orchards. After that time, maximum overall reduction is the highest for the scenario where all interventions are carried out (S1 - mosaic) and reaches 6.7 percent reduction, followed by the rotational grazing (S2, 4.2 percent) and woodlots (S3, 3.5 percent) scenario. The reductions can mainly be attributed to the reduction in gully erosion. The detailed spatial intervention results are provided in Annex 1.

Table 7: Sediment Budget at Rogun Dam, in Million Tons per Year

	Sheet and Rill	Landslide	Scree	Gully	Channel	All	Reduction (%)
Baseline	**19.4**	**34.4**	**1.8**	**34.7**	**2.4**	**92.4**	**—**
S1 - Mosaic	18.3	34.4	1.8	29.6	2.4	86.2	6.7
S2 - Rotational grazing	18.8	34.4	1.8	31.4	2.4	88.5	4.2
S3 - Woodlot reforestation	18.8	34.4	1.8	32.0	2.4	89.1	3.5
S4 - Orchards establishment	19.4	34.4	1.8	34.5	2.4	92.2	0.2

Source: Original elaboration for this publication.

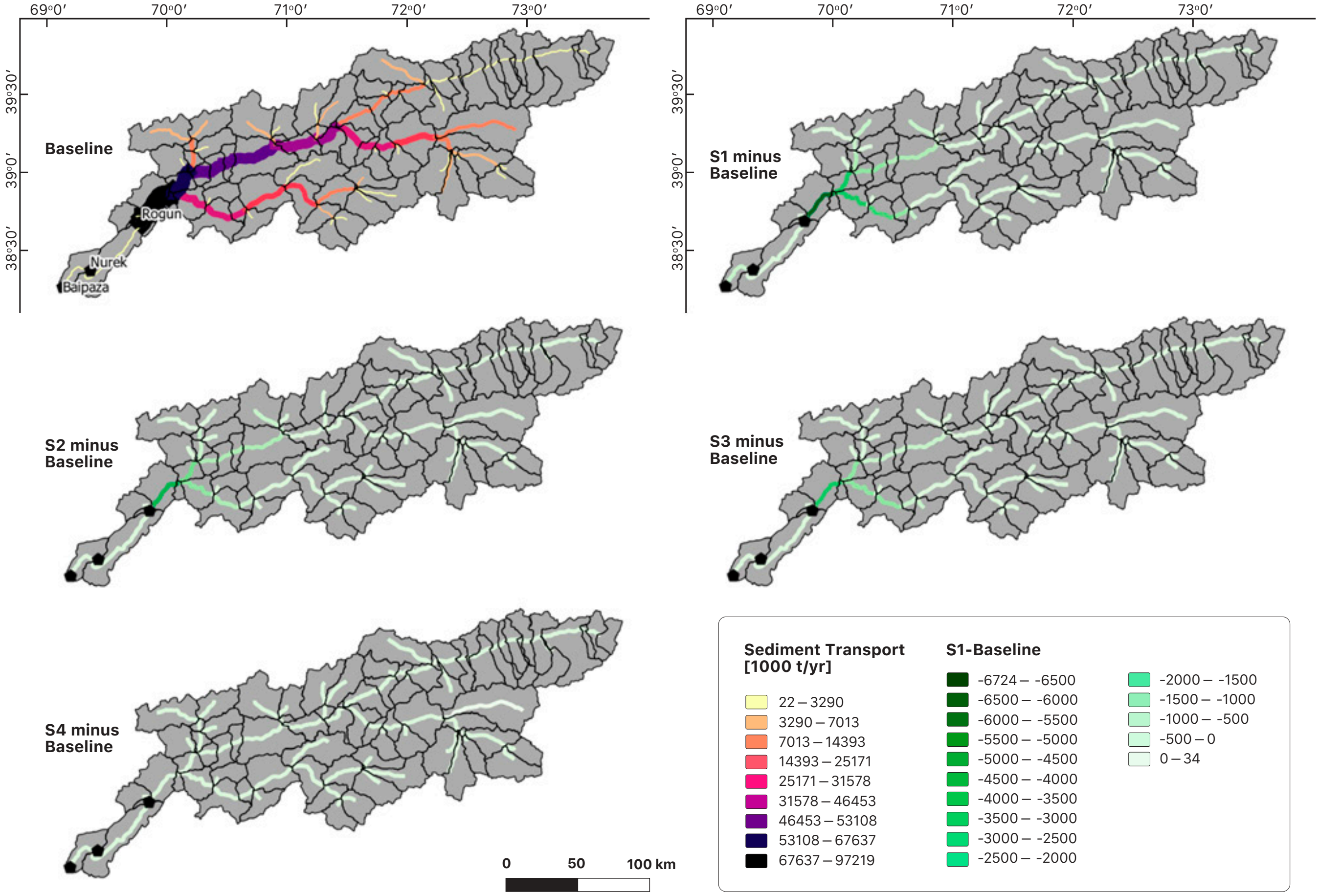
Figure 14 shows the spatial distribution of sediment transport in the river reaches of the Vakhsh River and its tributaries for the baseline and the four scenario interventions. Upstream and headwater catchments are affected the least while the reductions accumulate downstream and the highest absolute reductions are shown for the main stem of the Vakhsh River upstream of Rogun Dam, reaching 6.7 million tons, equivalent to 4.92 million m^3 sediments using a sediment bulk density of 1.3594 from TEAS (2014).

Impact of Landscape Restoration Interventions on Combined Sediment Transport for Nurek and Rogun

For the economic valuation, the sediment budget and observed changes have been converted into cubic meters, since the impact of landscape restoration on reservoir storage is evaluated in volumetric terms. The total sediment reduction upstream of Rogun, as well as between Rogun and Nurek, for each of the landscape restoration interventions is provided in Table 8.

The results prove that even after the construction of Rogun has been completed, there are significant benefits to be reaped from reducing erosion, especially channel and gully erosion, between Rogun and Nurek and upstream of Rogun (Annex 1). Upstream of Rogun, landscape restoration allows for reducing erosion and sediment transport by 3.7 m^3 per ha per year restored, through rotational grazing, and by 15.1 m^3 per ha woodlot reforested. The area between Nurek and Rogun covers 96,612 ha. Within this segment, the mosaic landscape restoration scenario covers 54,406 ha. Average annual sediment loads are reduced by 1.5 m^3 per ha restored under mosaic landscape restoration. The impact of landscape restoration on reduced erosion, from all sources, is of smaller magnitude in the Rogun–Nurek section, compared to upstream of Rogun. This is mostly attributed to steeper terrain, upstream of Rogun (Table 8).

Figure 14: Combined Sediment Transport and Reduction from the Interventions



Source: Original elaboration for this publication

Table 8: Total Sediment Reduction Upstream of Rogun and Between Nurek and Rogun, Including the Size of the Intervention Areas

	Unit	Baseline to Mosaic	Baseline to Rotational Grazing	Baseline to Woodlot	Baseline to Orchard
Upstream of Rogun					
Total reduction over 30 years	m^3	127,984,830	76,026,188	53,405,914	3,236,722
Annual sediment reduction[a]	m^3/ha/year	5.5	3.7	15.1	6.8
Total area	**ha**	**912,221**	**714,153**	**172,544**	**25,513**
Between Nurek and Rogun					
Annual sediment reduction[a]	m^3/ha/year	1.5	1.2	3.5	1.9
Total area	**ha**	**54,406**	**37,207**	**10,365**	**6,834**

Source: Original elaboration for this publication.
Note: a. When full restoration impact has been achieved (6 years for grazing and 15 years for orchards and woodlots).

Value of Reduced Erosion - Whole Catchment

The mosaic restoration scenario — which caters to the integration of sustainable pasture management, woodlots, and orchard establishment within the same landscape—will reduce erosion by an average of 132.4 m^3 per ha restored over a 30-year period, compared to the baseline scenario (Table 9). When valued in terms of the enhanced reservoir storage capacity using the full economic cost of irrigation water, the benefit is US$5.4 per ha restored.

Alternatively, when using the construction cost of Rogun as a benchmark for possible reservoir restoration costs, the value of that improved storage capacity amounts to US$27 per ha of land restored. As argued above, however, there are other costs associated with sediment build-up that are typically not accounted for in reservoir construction costs, including the damage caused by sediment to turbine equipment, increased risk of flooding, and eternity costs associated with dam decommissioning. In this sense, it may be argued that the avoided dredging cost is a more adequate reflection of the true benefits of reducing sedimentation.

Under mosaic restoration, the present value benefit is US$162 per ha in terms of avoided dredging cost (ranging from US$127 per ha of rotational grazing to US$449 per ha from woodlot establishment). Large-scale mosaic restoration of the Vakhsh catchment leads to savings of over US$26 million from avoided reservoir restoration costs, or US$156 million in terms of avoided dredging costs, over a 30-year time horizon.

Table 9: Present Value Benefits from Reduced Erosion, Whole Watershed

Discount Rate	m^3/ha/year	30-Year Total per ha (m^3/ha/30 years)			
	Mosaic (Average Annual over 30 Years)	Mosaic	Rotational Grazing	Woodlot	Orchard
Reduced erosion (m^3/ha)	**4.4 m^3/ha**	**132.4**	**87.6**	**288.8**	**100.1**
	US$/ha/year	**30-Year Total (US$/ha/30 years)**			
Enhanced storage for irrigation (US$/ha)	0.2	5.2	4.1	14.4	6.5
Reservoir restoration cost (US$/ha)	0.9	26.0	20.4	72.0	32.4
Avoided reservoir dredging cost (US$/ha)	5.2	156	123	432	194
		Total 30 Years, Whole Vakhsh River Basin			
Reservoir restoration cost		**25,115,217**	17,747,383	13,324,326	1,046,726
Avoided reservoir dredging cost		**150,691,299**	106,484,300	79,945,953	6,280,355
Total area (ha)		**966,616**	**751,360**	**182,909**	**32,347**

Source: Original elaboration for this publication.
Note: Increasing to maximum 5.2 m^3 per ha, 15 years after the restoration interventions; r = 6 percent.

Value of Reduced Erosion to Nurek HPP - Erosion Affecting Nurek

The 300 m tall Nurek Dam on the Vakhsh River is the largest HPP and the second largest regulation reservoir in the Amu Darya River basin (after Tyuyamuyun Reservoir in Uzbekistan).[48] Built during the 1960s when Tajikistan was part of the former Soviet Union, the dam impounds a 70 km long reservoir, with a design capacity of 10.5 km^3 that was reached in 1983 (D-Sediment 2022). The dam's nine turbines contribute some 3,015 MW of power, being the single largest point of generating capacity in the country (Taylor 2016). Nurek also has the seasonal purpose for irrigation of approximately 70,000 ha in the months (D-Sediment 2022). Since its construction, sedimentation has significantly reduced the reservoir's storage capacity. Between impoundment in 1972 and 2001, the reduction in storage capacity is estimated to be 2 km^3, some 20 percent of the reservoir's original volume (Taylor 2016). At peak storage levels, water depths in the reservoir vary from 158 m close to the dam, decreasing to 35 m at 30 km above, due to the sediment infill which has formed a 150 m thick sequence of delta deposits. These deposits have reduced the reservoirs storage capacity by 33.5 percent according to HRW (2016) (potentially up to 50 percent according to D-Sediment), with a 48.5 percent loss in the inactive storage volume but only a 13.8 percent loss in the reservoir's active storage volume. D-Sediment suggests storage loss may be up to 50 percent in 2013. Using a midpoint, we assume that Nurek had lost 42 percent of its storage capacity by 2016, resulting in a remaining storage capacity of 6.09 km^3 that year (D-Sediment 2022)

Rogun HPP is planned to rise to 1,100 m.a.s.l. by April 2024. Until then about 70 percent of the average annual sediment volume (of 92.7 million tons) arriving upstream of Rogun Reservoir is transferred downstream (Kochnakyan 2022). After 2024 and until 2030 (projected end of construction), this sediment volume is expected to decrease sharply by about 40–50 percent. The total amount of sediment passing downstream for 2020–2030 is thus expected to range between 400 and 450 million m^3 (Kochnakyan 2022). This is consistent with calculations in Table 10.

Table 10: Storage Loss of Nurek Reservoir over Time

	Original Storage of Nurek Reservoir	10.50 km^3
A	Storage loss to sediment (1983–2016)	42% (between 33% and 50%)
B	Total storage (2016)	6.09 km^3
C	Average annual sediment arriving at Rogun (converted from 92.4 million tons)	68,444,444 m^3
D	Average annual sediment load to Nurek (2016–2020) - 70% transferred	47,911,111 m^3
E	Average annual erosion between Nurek and Rogun (independent of Rogun)	442,309 m^3
F	Average annual sediment inflow to Nurek (up until 2020) (E + D)	48,353,420 m^3
G	40% of sediment after 2024 (average amount arriving to Nurek after 2024)	27,377,777 m^3
H	Sediment build-up for 2020–2030 (70% transferred until 2024 and 45% transferred after 2024)	411,667,534 m^3
I	Sediment build-up in Nurek by 2030	574,281,214 m^3

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[48] https://www.worldbank.org/content/dam/Worldbank/document/eca/central-asia/ESIA%20Vol%20I%20%20Final_eng.pdf.

Table 10

	Original Storage of Nurek Reservoir	10.50 km³
J	Remaining storage of Nurek (2030)	5.51 km³
K	Sediment build-up in Nurek (2030–2050), assuming 3% of sediment entering Rogun continues to be transferred + continued sediment from the Rogun–Nurek section	49,912,847 m³
L	Projected remaining storage of Nurek in 2050	5.46 km³

Source: Original elaboration for this publication.

However, there are erosion processes between Rogun and Nurek that lead to siltation levels that are equivalent to average annual quantity of 442,309 m³ per year (Table 10). By extrapolation, it implies that Nurek will have halved its storage capacity by 2030, after which sediment inflow will reduce to 3 percent of the sediment arriving upstream of Rogun, in addition to the continued erosion between the two dams. By 2050, therefore, Nurek will have lost an added 50 million m³ of storage capacity. This result is contrary to HRW (2016) report (where erosion between the two dams was neglected), which concludes that "in the best case of the highest Rogun Dam height alternative, there is no storage loss in Nurek until the end of the simulation period."[49]

Value of Reduced Erosion to Nurek HPP - Economic Value of Improved Sediment Reduction

Although Rogun is being constructed, the results presented here still make a case for minimizing catchment erosion upstream of Rogun and between Rogun and Nurek. When using a combination of restoration approaches, between Nurek and Rogun erosion levels are reduced by 43 m³ per ha restored, over a 30-year time horizon (Table 10). Landscape restoration upstream of Rogun will also lead to reduced sedimentation of Nurek, though to a lesser extent per hectare restored, since Rogun traps a significant amount of that sediment. Over a 30-year time horizon (2022–2052), large-scale landscape restoration within the Vakhsh River Basin would allow for reducing sediment inflow to Nurek by 10.9 million m³ by 2050 (Table 11) compared to the BAU scenario projecting 50 million m³ of lost storage capacity by 2050.

Based on the avoided reservoir rehabilitation cost (US$0.5 per m³), the present value benefit of large-scale landscape restoration in terms of avoided reservoir rehabilitation cost is in the order of US$3.2 million for the 2022–2052 time horizon. Focused restoration efforts within the Rogun–Nurek section alone (on the 54,000 ha of suitable land) can reduce sediment inflow to Nurek by 2.3 million m³. The greatest per hectare benefits come from woodlot restoration. Added benefits include climate proofing, notably, enhanced flood attenuation capacity, reduced risks to the structural integrity of the dam, and more balanced reservoir operation. It was outside the scope of this assessment to estimate these benefits.

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[49] According to HR Wallingford, the construction of the Rogun dam has three alternative full supply levels: 1,290 m (S-2.1). The model predicts that the decrease in storage volume due to the inflow of sediment from the catchment between Rogun and Nurek Dam (about 3 percent of the total catchment at the Nurek Dam) is approximately balanced by the increase in storage volume due to compaction of deposits. However, it is understood that the secondary data used for this study are not trusted and that the primary data were insufficient to confirm the results.

Table 11: Present Value Benefit of Avoided Erosion to Nurek HPP

Discount Rate		30-Year Total per ha			
r = 6.00%	Units	Mosaic	Rotational Grazing	Woodlot	Orchard
Reduced erosion between Rogun and Nurek	m^3/ha	43	33	85	47
Reduced erosion upstream of Rogun, passed to Nurek[a]	m^3/ha	9	8	26	12
Avoided reservoir restoration cost per hectare restored	**US$/ha**	**12**	**10**	**26**	**13**
		30-Year Total - Benefit to Nurek			
Reduced erosion, between Rogun and Nurek	m^3	2,314,925	1,531,246	900,135	321,487
Reduced erosion upstream of Rogun, passed to Nurek	m^3	8,661,385	6,822,763	4,589,942	301,701
Reduced erosion (total)	**m^3**	**10,976,310**	**8,354,009**	**5,490,077**	**623,188**
Avoided reservoir restoration cost (total)	**US$**	**3,222,652**	**2,595,805**	**1,633,426**	**160,820**

Source: Original elaboration for this publication.

Note: a. Based on the assumption that 70 percent of the sediment is transferred downstream of Rogun during 2022–2024, 40 percent is transferred during 2024–2030, and 3 percent is transferred after 2030.

Economic Value of Hydrological Ecosystem Services from Catchment Management in Vakhsh River Basin

Hydrological impacts from landscape restoration and resulting water availability could be evaluated using two alternative approaches, depending on how the water budgets are estimated. As shown in Table 12 and Table 13, water availability varies significantly depending on the assumptions made.

In the first approach, changes in water availability have been assessed considering a significant amount of water being taken out of the system for plant evapotranspiration/production of the newly established plants. This leads to a seriously negative water balance at the expense of the downstream area—and downstream users that are mainly evaluated. The results are shown in Table 12 with reduced water availability for all downstream users. This approach may anyhow be questionable as it does not consider changed microclimate so that there may be an increased return flow that could not be captured in our assessment (Filoso et al. 2017; Smith, Baker, and Spracklen 2023), and there are significant benefits in disaster risk reduction that are less tangible. Further, actual downstream water availability will also depend on reservoir storage capacity and operation as the reduced runoff may be available promptly and with reduced spill. Dam operation schedules would need to be available for a thorough assessment in this regard. Further, the water would contribute to GHG reduction through biomass build-up.

In a second approach, evapotranspiration is considered a neutral factor with the benefits as shown in Table 13 (Filoso et al. 2017; Smith, Baker, and Spracklen 2023). While surface runoff is reduced (specifically during high-flow events), there is a positive total water balance with increased lateral flow,[50] groundwater recharge, and soil moisture. This assumption has been used in this report.

As shown, the mosaic restoration scenario enhances water availability by 38.8 m^3/ha/year (when full restoration benefits have materialized), resulting in an added 1,164 m^3 of freshwater per ha restored over 30 years (Table 13). Reduced surface runoff ranges from an average annual reduction of 64 m^3 per ha under rotational grazing to 190 m3 per ha in the woodlot restoration scenario. The interventions, as a source of green infrastructure, supply benefits for:

- Upstream rain-fed agriculture, through higher soil water content and groundwater level;
- Upstream run-of-river fed irrigation agriculture, through more lateral return flow and reduced sediment flow;
- Increased flood retention through smaller flood peaks and more balanced annual reservoir operation, supplying further resilience to climate change impacts;
- Less potential spill in dam operation; and
- Better flow timing for irrigation system operation.

Table 12: Changes in Hydrological Flows as a Result of Landscape Restoration Interventions, in m^3/ha/year

Parameter	Baseline Mosaic		Baseline Rotational Grazing		Baseline Woodlot Establishment		Baseline Orchard Establishment	
	%	m^3/ha/year	%	m^3/ha/year	%	m^3/ha/year	%	m^3/ha/year
Groundwater infiltration	-4	-77	-3	-58	-26	-471	-57	-738
Lateral flow	-4	-89	-3	-65	-28	-522	-58	-135
Surface runoff	-77	-117	-69	-87	-91	-253	-91	-255
Soil moisture	-6	-14	-4	-11	-31	-68	-62	-111
Evapotranspiration	6	299	5	225	25	1,314	24	1,237
Total water balance (% change inflow to Rogun)	**-1.4**	**-297**	**-0.9**	**-221**	**-1.2**	**-1,315**	**-0.2**	**-1,239**
Total water balance – 30 years (m^3/ha)		**-8,905**		**-6,632**		**-39,442**		**-37,179**

Source: Original elaboration for this publication.
Note: Evapotranspiration is fully considered as 'lost' water.
Numbers may not add to 100%, due to aggregating numbers from the gridded GIS layer for the different components.

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[50] Lateral return flow is the portion of the streamflow that is sustained between precipitation events, fed to streams by delayed pathways, contrary to surface runoff.

Table 13: Changes in Hydrological Flows as a Result of Landscape restoration Interventions, in m^3/ha/year

Parameter	Unit	Baseline Mosaic	Baseline Rotational Grazing	Baseline Woodlot Establishment	Baseline Orchard Establishment
Groundwater infiltration	m^3/ha/year	66.0	49.0	132.0	182.0
Lateral flow	m^3/ha/year	49.0	39.0	106.0	24.0
Surface runoff	m^3/ha/year	-88.0	-64.0	-190.0	-165.0
Soil moisture	m^3/ha/year	11.1	9.3	22.0	32.5
Total water balance[a]	**m^3/ha/year**	**38.8**	**32.9**	**70.0**	**72.6**
Total water balance - 30 years	**m^3/ha**	**1,164**	**987.0**	**2,100**	**2,179**

Source: Original elaboration for this publication.
Note: a. When full benefits have kicked in after 15 years; Evapotranspiration is balanced out by the local microclimate. Numbers may not add to 100%, due to aggregating numbers from the gridded GIS layer for the different components.

The four landscape restoration interventions lead to changes in hydrological flows. On the one hand, surface runoff is reduced in all the interventions. On the other hand, lateral return flow to streams increases under all landscape restoration scenarios. The combined effect is a small reduction in actual water inflow into Rogun and Nurek (due to more water available and used by the plants). This effect, however, is compensated for by the diversion from surface runoff to increased ground recharge and soil moisture. Considering the full economic cost of water, when used for irrigation, the present value benefit of enhanced water availability for plants is in the order of US$43 per ha restored (or US$1.4 per ha per year) under mosaic restoration amounting to US$41.4 million in benefits over a 30-year time horizon under large-scale landscape restoration (Table 14). In principle, reduced runoff and enhanced lateral return flow will also allow for more balanced hydropower operation, but to assess how the timing of water inflow affects reservoir operation and flood risk was beyond the scope of this study.

Table 14: Present Value Benefit from Changes in Hydrological Flows

Discount Rate		Average per ha per Year	30-Year Total per ha			
r = 6.00%	**Units**	**Mosaic Restoration**	**Mosaic Restoration**	**Rotational Grazing**	**Woodlot**	**Orchard**
Enhanced plant water availability	m^3/ha	**28**	**853**	**599**	**1,540**	**1,598**
Value of enhanced water availability	US$/ha	1.4	43	39	58.6	60.8
			30-Year Total - Whole of Vakhsh Catchment			
Value of enhanced water availability	**US$/ha**		41,395,688	33,709,637	10,828,937	1,965,194

Source: Original elaboration for this publication.

Value of the Improved Carbon Balance in the Vakhsh River Basin

Landscape restoration is adopted by governments and practitioners across the globe to mitigate and adapt to climate change and restore ecological functions across degraded landscapes (Bernal et al. 2018). The carbon balance models developed for this assessment show that woodlots and orchards hold a significant carbon sequestration potential, allowing for the sequestering of an added 35–317 tCO_2-eq carbon emissions per ha over 30 years. The adoption of sustainable grazing can also enhance the carbon sequestration potential of soils, but the emission reductions are significantly smaller in per hectare terms. The present value benefit from emission reductions from an average hectare of the mosaic landscape restoration scenario is in the order of US$3,951 in terms of avoided global climate-related damage costs and US$235 when sold as verified credits on the voluntary carbon market (Table 15). Mosaic restoration across the whole Vakhsh River Basin will generate US$3.8 billion worth of avoided damage costs, or US$227 million of carbon credits, using a value of US$5 per tCO_2-eq.

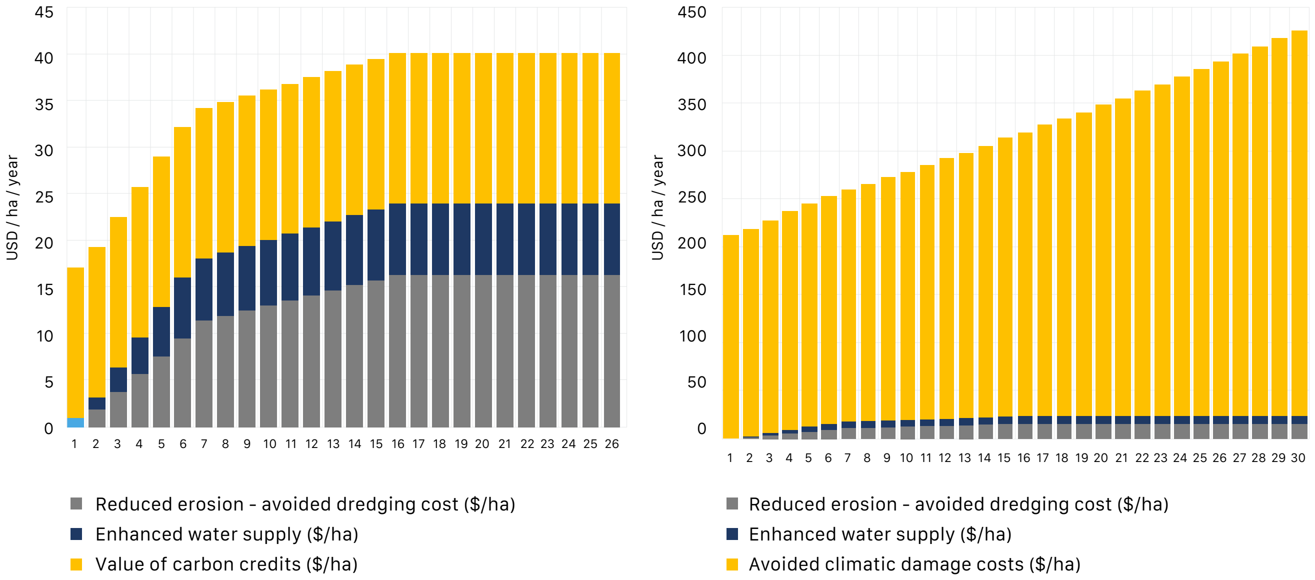
Table 15: Present Value Benefit from Enhanced Carbon Sequestration

Discount Rate		Per ha per Year	30-Year Total per ha			
r = 6.00%	Units	Mosaic	Mosaic	Rotational Grazing	Woodlot	Orchard
Enhanced carbon sequestration	tCO_2-eq/ha	**3.2**	97	35	317	296
Value of carbon credits	US$/ha	8	**235**	84	771	720
Avoided SCC	US$/ha	132	3,951	1,408	12,956	12,098
			30-Year Total - Whole Watershed			
Value of carbon credits	US$		227,318,138	72,756,359	142,610,312	23,291,518
Avoided SCC	US$		3,819,232,613	1,222,398,972	2,396,033,862	391,326,992

Source: Original elaboration for this publication.

Figure 15 (panel a) shows the flow of benefits, for the ecosystem service values that are considered to best reflect the benefits to the Tajik society, as well as the maximum potential (panel b), reflecting benefits to the global society. Estimations of economic benefits from reduced erosion and avoided dredging costs are presented in Section 3.9.

Figure 15: Economic Benefits from Reduced Erosion, Carbon Sequestration, and Enhanced Water Availability, per Year per ha under Mosaic Restoration



Source: Original elaboration for this publication.
Note: Non-discounted, r = 0 percent, for illustration.

3.9 ECONOMIC VALUE TO LAND USERS AND LOCAL COMMUNITIES - THE CASE FOR INVESTING IN LANDSCAPE RESTORATION

Net benefits to land users from woodlot and orchard establishment, as well as sustainable pasture management through rotational grazing, are shown in Table 16 through to Table 21, for a 30-year time horizon, using a discount rate of 6 percent.

The financial returns and benefit-cost ratios (BCRs) are within expected ranges for these kinds of landscape restoration interventions. Overall, the highest net benefit may be enjoyed from the establishment of orchards, providing US$4.2 in benefits for every dollar invested, with an NPV of US$61,000 per ha over a 30-year time horizon. The average annual net income from the orchard establishment amounts to approximately US$2,000 per ha. This compares well with the results found from orchard establishment by Caritas under the IWSM III project, where farmers were able to earn US$1,740 per ha after orchard establishment (a 190 percent increase) over a 6-year period. Tree planting alone generated income increases of 80 percent (increasing income to US$1,081 per ha) (Kassam 2022).

In terms of payoff, under a 6 percent discount rate, it takes more than 6 years to recover the expenses from orchard establishment (Table 16). From the perspective of a capital-constrained (poor) farmer, this is significant and may help explain why this otherwise profitable activity does not spontaneously take place across landscapes as extensively as one could expect[51] and needs to be encouraged through co-financing arrangements. The payoff period for woodlots is even longer (10 years). Overall, however, they would supply US$3.3 of benefits for every US$1 that is invested and an average annual discounted net income of US$1,056

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[51] As an example, within the district of Tojikobod, an additional 2–3 ha of orchards are planted every year.

per ha under a 30-year rotation. This figure is also aligned with the incomes from tree planting, under the Caritas Programme (Kassam 2022). State forest enterprises also stand to benefit from the woodlot establishment. Under JFM contracts, they usually obtain a negotiated share (usually 50 percent) of the commodities produced.

Table 16: Financial CBA Results of Woodlot and Orchard Establishment

Orchard and Woodlots. T = 30 Years, r = 6%	Orchards 30 Years	Woodlots 30 Years
Internal rate of return (%)	6.0	10
Internal rate of return (%)	41%	22%
BCR	4.2	3.3
NPV ‘20–30-year horizon’ (US$)	61,239	31,688
Average net benefit per year (US$/ha) ‘20–30-year horizon’	2,041	1,056

Source: Original elaboration for this publication.

Out of the three landscape restoration interventions, sustainable rangeland management generates the lowest financial returns with an NPV of US$45–78 per ha over a 30-year time horizon pending on assumptions around fencing and herding costs (as discussed in more detail in Annex 2). It should also be recalled that intervention areas are significantly larger (several hundred hectares of rangelands) than orchards and woodlots (a couple of hectares) and therefore the aggregate impact is more significant.[52] The BCR is 2.1 for a 30-year time horizon. This is aligned with rotational grazing benefits seen in other semiarid environments (Myint and Westerberg 2015). Where fencing costs are minimal, for example, because of active use of herding, in distant mountain pastures, Tajikistan pasture users stand to enjoy US$8.5 for every dollar invested and a BCR of 3 (Table 17).

Table 17: Financial CBA Results of Rotational Grazing Establishment - Probable Lower- and Upper-Range Costs

Rotational Grazing. T = 30, r = 6%	Upper-Range Costs	Lower-Range Costs
Payback period (years)	8.4	4.0
Internal rate of return (%)	19.0	0.5
BCR	2.1	10.5
NPV (US$)	45.0	78.0
Average net benefit per year (US$)	1.5	3.0

Source: Original elaboration for this publication.

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[52] Pasture productivity increases between 20 percent and 50 percent within 5 years (Davlatov 2022b; Kassam 2022; Shuhratjon 2022) resulting in an average increase from 0.55 t/ha in the baseline to 0.68 t/ha under the rotational grazing (across the village, summer, and winter pastures). This value is calculated assuming hay valued at US$52.3 per ton (2022 prices) and an average annual present value cost of approximately US$2. Grazing areas are usually very large, so even US$3 more in net benefits per ha will result in significant livelihood benefits/avoided expenses on forage costs (as well as nutritional and health-related benefits from more biodiversity-rich pasture biomass).

Economic Value to Land Users and Local Communities - Sensitivity Analysis

Lower- and upper-bound values of net incomes have also been estimated. Lower-bound estimates assume a cost of capital of 20 percent (aligned with the real interest rate) and 20 percent lower yields of timber, fuelwood, fruits, and nuts within orchards and woodlots—which could materialize because of adverse climate change impacts.

Considering new evidence on the benefits of rotational grazing in Tajikistan (Norton 2022), it is likely that enhanced forage productivity may kick in already as of the second year. It is also likely that investment costs will decrease over time, because of significant innovation with virtual and mobile fencing (Wooten 2020), alongside knowledge take-up and mainstreaming of rotational grazing. An assumption of low investment costs of US$8.1 per ha (Wang et al. 2018) is incorporated in the optimistic 'upper-bound' welfare estimates for rotational grazing.

Upper-bound estimates of the potential net benefits from woodlots and orchards are also estimated, assuming a cost of capital of 3 percent and reduced ICs and MCs. Reduced costs may materialize as result of the economies of scale that are generated when restoration interventions scale across thousands of hectares. A 3 percent discount rate is realistic, if interventions benefit from grant or philanthropical funding and social impact investments.

The estimated net income for all the interventions, summarized in Table 18 to Table 21, prove that even if communities were to bear all the costs themselves, their welfare stands to be improved across all the landscape restoration options, at a 6 percent discount rate. However, under the pessimistic scenario, only orchard establishment remains profitable. Rotational grazing is on the border line (generating a loss of US$0.1). Under optimistic assumptions, the interventions generate substantial returns with possible profits of US$3,390 per ha orchard established. Mosaic restoration generates an average annual added net income of US$535 per ha of land. The flow of per hectare revenues and costs to land users under mosaic restoration is illustrated in Figure 16 (non-discounted for illustration).

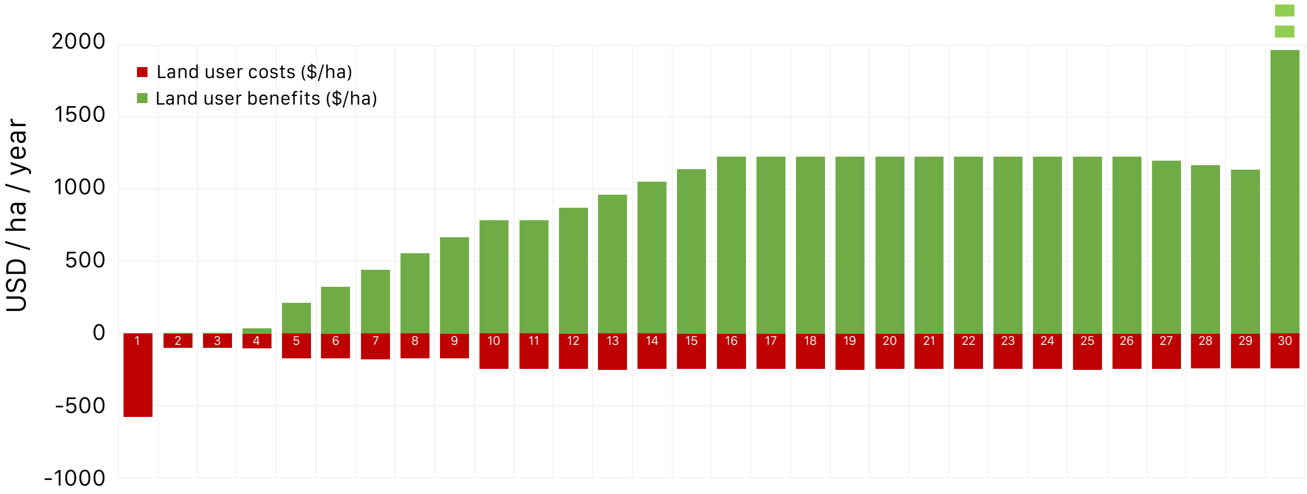
Table 18: Summary of Present Value Benefits - Harvestable Provisioning Ecosystem Services - 30 Years

	Units	Mosaic Restoration	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
NPV @ r = 6%	US$/ha	8,145	45	32,033	61,239
Average annual net benefit @ r = 6%	US$/ha/year	272	1.5	1,068	2,041
Average annual net benefit[a] Lower to upper bound*	US$/ha/year	5 to 535	-0.1 to 3.9	-12 to 2,207	233 to 3,339

Source: Original elaboration for this publication.

Note: a. From r = 3 percent to r = 20 percent and minimum and maximum ranges for possible ICs and yields.

Figure 16: Estimated Flow of Average per Hectare Revenues and Costs to Land Users under Mosaic Restoration



Source: Original elaboration for this publication.

Note: Non-discounted for illustration. Woodlots are cut for timber at the end of the 30-year rotations, leading to revenues of US$50,000 in future value terms (beyond what is illustrated on the graph).

3.10 CBA OF PROPOSED LANDSCAPE RESTORATION INTERVENTIONS

Considering first the business case for the landscape restoration options, the interventions generate a flow of income from timber, fuelwood, fruits, nuts, and forage biomass, which results in an NPV of approximately US$31,700 per ha woodlot, US$61,000 per ha of orchards, and US$45 per ha of sustainably grazed rangeland, over a 30-year time horizon (Table 19). For every dollar invested, land users stand to enjoy between US$2.1 and US$4.2 of benefits over a 30-year time horizon. If land users can capitalize on emission reductions, they could earn an average added US$8 per ha per year under mosaic landscape restoration, assuming a constant and modest carbon price of US$5 per tCO$_2$-eq sequestered (discounted at 6 percent).

The landscape restoration measures also alter wider ecosystem service flows within the catchment, specifically hydrological and erosion processes, of benefit to the Tajikistan society. Under mosaic restoration, estimated benefits from reducing erosion loads within the reservoirs range from US$0.2 per ha of land restored, when assessed in terms of enhanced water storage capacity for irrigation water, to US$0.9 from avoided reservoir restoration cost and up to US$5.4 per ha of land restored when assessed in terms of avoided dredging costs. In a similar sense, the benefits from enhanced carbon sequestration range from US$8 per ha in terms of the value of carbon credits that can be generated in the voluntary carbon market and up to US$132 per ha restored in terms of the avoided social damage cost from climate change.

Mosaic landscape restoration supplies co-benefits in the range of US$281 to US$4,388 per ha of land, pending on the perspective taken (Table 19).[53]

When accounting for these regulating

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[53] Of course, there is also underlying variation for each valuation parameter—with a range of possible dredging costs, carbon market prices, SCC estimates, shadow prices for water, as well as possible variations in output prices, input costs, and yields, that the farmer may experience. This assessment has used midrange and conservative estimates, to avoid any risks of overestimating net benefits.

ecosystem service co-benefits, in addition to land user benefits, the BCR to the Tajikistan society is in the order of 3.6 (US$3.6 of benefits provided for every US$1 invested) generating an NPV of US$8,582 per ha restored under mosaic landscape restoration. In this scenario, the sales value of carbon credits amounts to US$235 per ha, enhanced freshwater supplies are worth US$43 per ha, while the sediment retention benefit, in terms of avoided dredging costs[54] generates a benefit of US$162 per average ha of land restored.

The global society also stands to derive welfare benefits from climate change mitigation provided by mosaic restoration efforts in Tajikistan. Accounting for the avoided damage costs, NPV is in the order of US$12,534 per ha restored over 30 years, or US$418 per ha per year.

Comparing the different possible restoration interventions in terms of benefits and costs, sustainable pasture management supplies proportionally more benefits to the wider society (societal BCR of 8.1) **compared to the benefit that the pasture user enjoys himself** (private BCR of 2.1). This is attributable to the fact that the per hectare investment costs are significantly lower than those of orchards and woodlots, while regulating ecosystem services impacts are still of significant magnitude. Of course, were investment costs to be co-financed, the land user can expect a higher BCR than 2.1.

Table 19: NPV and BCR from Restoration Interventions and Individual Ecosystem Service Benefits

	Land Users Provisioning Ecosystem Service		Per Year per ha	Total per ha - 30 years			
	0%	Unit	Mosaic	Mosaic	Rotational Grazing	Woodlots	Orchards
NTFPs, timber, fuel, and forage	Land user benefits	US$/ha	**381.0**	11,426	86.0	45,853	80,182
	ICs and MCs	US$/ha	-109	-3,281	-41	-13,820	-18,943
	Co-benefits Regulating Ecosystem Service		**Per year per ha**	**Total per ha - 30 years**			
		Unit	Mosaic	Mosaic	Rotational grazing	Woodlots	Orchards
Reservoir and hydropower	**Reduced erosion**	**m^3/ha**	**4.4**	**132.4**	**87.6**	**288.8**	**100.1**
	Enhanced storage for irrigation	US$/ha	0.2	5.4	4.2	15.0	6.7
	Reservoir restoration cost	US$/ha	0.9	27.0	21.2	75.0	33.6
	Avoided reservoir dredging cost	US$/ha	5.4	162.0	127.0	449.0	202.0
Carbon and hydrological ecosystem service benefits	**Water availability (soil and ground water and river flow)**	**m^3/ha**	**35.0**	**1,051**	**779.0**	**1,968**	**1,963**
	Benefit of enhanced water availability	US$/ha	1.4	43.0	39.0	59.0	61.0

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[54] Based on the information available, it was impossible to confirm whether Rogun will have sufficient dead storage available when completed, to avoid any impingement on its live storage due to ongoing sedimentation, and hence whether the reservoir will need any sediment dredging activities during its lifespan. There was also no information regarding the potential need for future dredging to reduce the risk of any operational or dam safety issues caused by sediment build-up. Avoided dredging costs are arguably a better estimate of the true societal benefits of reduced erosion, in that the true cost of sedimentation (flood risks, risks to structural integrity, and balanced hydropower) are not reflected in reservoir restoration costs or the value of enhanced storage capacity.

Carbon and hydrological ecosystem service benefits	**Enhanced carbon sequestration**	**tCO_2-eq/ha**	**3.2**	**96.7**	**34.5**	**317. 1**	**296.1**
	Voluntary carbon market	US$/ha	8.0	235.0	84.0	771.0	720.0
	Avoided SCC	US$/ha	132.0	3,951	1,408	12,956	12,098
Present value benefits	Total: hydrological, sediment, and carbon **Min to Max**		9 to 146	281 to 4,388	128 to 1,559	826 to 13,772	801 to 13,094
	NPVs Society		**Per Year per ha**	**Total per ha - 30 Years**			
NPV	**Land user NPV**	**US$/ha**	269.0	8,080	45.0	31,690	61,240
BCR			**3.5**	3.5	2.1	3.3	4.2
NPV	Land users NPV lower- to upper-bound estimates	US$/ha	5 to 537	164 to 16,020	-2 to 117	-361 to 66,202	6,977 to 101,644
NPV	**Tajikistan society** - land user NPV + water + carbon credits and avoided dredging costs	US$/ha	**286**	**8,582**	**294**	**33,312**	**62,221**
BCR			3.6	3.6	8.1	3.4	4.3
NPV	**Global society -** land user NPV + Tajikistan society + avoided damage cost of carbon	**US$/ha**	418.0	12,537	1,702	46,268	74,319
BCR			4.8	4.8	42.4	4.3	4.9
NPV	**Global society lower to upper bound**		58 to 746	1,733 to 22,375	587 to 2,517	4,736 to 86,801	11,682 to 120,558

Source: Original elaboration for this publication.
Note: Using a social discount rate of r = 6 percent, unless otherwise stated.

Large-Scale Restoration across the Vakhsh Catchment

Scaling up these interventions across nearly 1 million ha of land within the Vakhsh catchment and summing up the full suite of benefits—from sediment reduction, water stewardship, climate mitigation, and enhanced rural incomes—the large-scale mosaic restoration scenario generates a total NPV benefit of US$7.9 billion over a 30-year time horizon to land users and US$8.3 billion to land users and the wider Tajikistan society (Table 20). This is arguably a conservative estimate of the true benefits of landscape restoration. Other outstanding benefits from landscape restoration that have not been part of this assessment include reduced landslide and flood risk, improved annual reservoir operation, reduced spills, and overall climate proofing of the dams. Estimating the value of such benefits is still a subject for future research.

Enhanced carbon sequestration also leads to avoided climate-related damage costs at the global level. When accounting for these, large-scale mosaic landscape restoration generates NPV to the 'global society' of US$12.1 billion for a 30-year time horizon, using a 6 percent discount rate (US$4.8 of benefits for every dollar invested).

Finally, it should be recalled that the mosaic landscape restoration scenario assumes that the land use area classified as grassland is still exclusively used for pastoral activities and

that orchards and woodlots are in proximity to irrigation infrastructure. This can be challenged, however, in that reforestation activities can also take place on pastureland. Thus, considering the importance of woodlots in reducing erosion processes, or orchards as a source of livelihood benefits, there is potential for even higher societal net benefits than those presented here if forest landscape restoration efforts were extended to degraded pastures.

Table 20: NPV and BCR of Large-Scale Restoration with the Vakhsh Catchment

NPVs		Whole Catchment - 30 Years			
		Mosaic	Rotational Grazing	Woodlots	Orchards
NPV (US$)	**Land user** - NTFPs, timber, fuel, and forage	7,810,426,455	38,668,550	5,860,390,636	1,980,893,399
BCR		3.5	2.1	3.3	4.2
NPV (US$)	**Tajikistan society** - land user benefits + water + carbon credits and avoided dredging costs	8,235,617,711	255,291,638	6,096,845,544	2,012,671,614
BCR		3.6	8.1	3.4	4.3
NPV (US$)	**Global society** - land user benefits + Tajikistan society + avoided damage cost of carbon	12,054,850,324	1,477,690,610	8,492,879,406	2,403,998,607
BCR		4.8	42.2	4.3	4.9
	Total area in ha	966,616	751,360	182,909	32,347

Source: Original elaboration for this publication.

Overall, most landscape restoration benefits are captured by individual land users. The good news is that there is a business case among land users—individual, family, or collective Dekhan farmers; state forest enterprises or PUUs; FUGs; and groups of farmers that form common interest groups—to invest in landscape restoration.

Nevertheless, the wider society also stands to benefit as shown above. Added benefits include a potential reduction of the impacts of climate change and natural hazards in the Vakhsh catchment and in particular droughts, floods, extreme temperatures, fires, and mass movements (landslides and mudflows), all of which could lead to losses of lives, livelihoods, and biodiversity, as well as damages to infrastructure (dams and roads).

Sensitivity of the CBA Results to Changes in the Discount Rate, Yields, and Cost Structures

The implication of potential variations in the cost of capital, ICs and MCs, and changes in yields on land users are discussed above and illustrated in Table 20. Rotational grazing and woodlot restoration interventions do not breakeven under the most pessimistic assumptions (20 percent discount rate and lower yields). However, from a **global perspective**, which incorporates the positive externalities from reduced erosion, water cycling, and enhanced carbon sequestration, all the landscape restoration interventions stay profitable **in the pessimistic scenario**, generating an NPV of US$1,730 per ha or US$58 per ha per year under mosaic restoration. **In the optimistic**

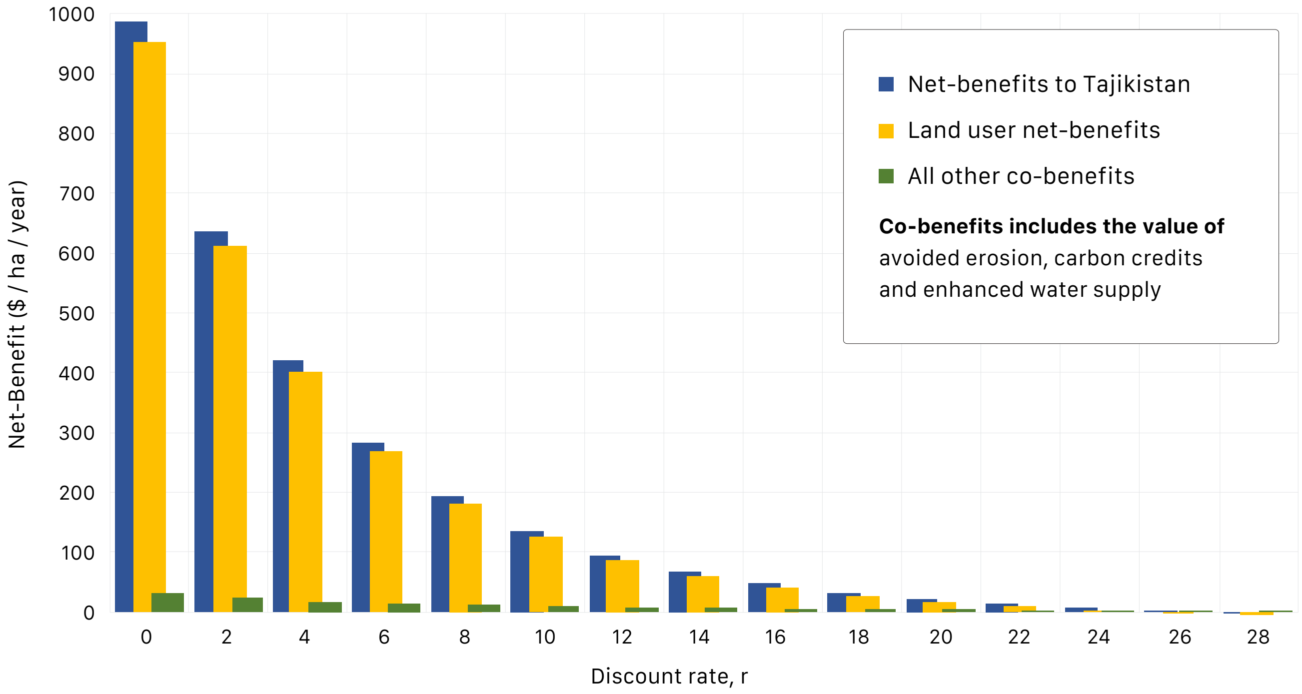
scenario, characterized by a low cost of capital (3 percent) and economies of scale, the mosaic restoration intervention generates an impressive NPV benefit of US$22,375 per ha restored over a 30-year time horizon (or US$746 per ha per year).

Sensitivity of Results to Changes in the Discount Rate

Considering exclusively the sensitivity of results to changes in interest rates, Table 21 and Table 22 show the full set of results under a 6 percent and 20 percent discount rate. The results prove that even under a high lending rate of 20 percent, which is closer to the lending rates faced by the private sector, the NPV to land users for woodlots and orchards stays positive (generating net incomes of US$30–350 per year), underscoring the business case for investing in forest landscape restoration. Considering however that land users bear all the risks, spontaneous adoption of rotational grazing and mosaic landscape restoration approaches cannot be expected. The results underscore the importance of ensuring that land users have access to long-term capital credit at lower-than-market interest rates, to encourage investments in landscape restoration.

For the Tajik society, landscape restoration provides US$1.5 (under r = 20 percent) to US$3.6 (under r = 6 percent) of benefits for every dollar invested. Figure 17 shows the annual net benefits per hectare per year for the Tajik society, under mosaic landscape restoration, for different interest rates. The figure highlights that net benefits are overly sensitive to the discount rate and thus the time value of money, since it takes a few years for ecosystem service benefits to kick in. For example, at a 2 percent discount rate, mosaic landscape restoration generates net benefits of more than US$600 per ha per year.

Figure 17: Net benefits (in US$/ha/year) from Mosaic Landscape Restoration to the Tajikistan Economy for Different Discount Rates



Source: Original elaboration for this publication.

Table 21: Full CBA Result Display at 6% Interest Rate

	Discount Rate @6%			Total per ha - 30 years		
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$/ha	US$11,361	US$86	US$45,508	US$80,182
	Costs	US$/ha	-US$3,281	-US$41	-US$13,820	-US$18,943
Reservoir and hydropower	**Reduced Erosion**	**m^3/ha**	**US$132**	**US$88**	**US$289**	**US$100**
	Enhanced storage for irrigation	US$/ha	US$5	US$4	US$15	US$7
	Reservoir restoration cost	US$/ha	US$27	US$21	US$75	US$34
	Avoided reservoir dredging cost	US$/ha	US$162	US$127	US$449	US$202
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	**m^3/ha**	**853**	**599**	**1540**	**1598**
	Benefit of enhanced water supply	US$/ha	US$43	US$39	US$58.6	US$60.8
	Enhanced carbon sequestration	**tCO_2-eq/ ha**	**97**	**35**	**317**	**296**
	Voluntary Carbon Market	US$/ha	US$235.2	US$83.8	US$771.1	US$720.1
	Avoided Social Cost of Carbon	US$/ha	US$3,951	US$1,408	US$12,956	US$12,098
NPV	**Landuser - NTFPs, timber and forage biomass**	US$/ha	US$8,080	US$45	US$31,688	US$61,239
BCR			3.5	2.1	3.3	4.2
NPV	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$/ha	US$8,520	US$294	US$32,967	US$62,221
BCR			3.6	8.1	3.4	4.3
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$/ha	US$12,471	US$1,702	US$45,923	US$74,319
BCR			4.8	42.2	4.3	4.9

	Discount Rate @6%			Per Year per ha		
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$/ha	US$379	US$3	US$1,517	US$2,673
	Costs	US$/ha	-US$109	-US$1	-US$461	-US$631
Reservoir and hydropower	**Reduced Erosion**	**m^3/ha**	**US$4.4**	**US$2.9**	**US$9.6**	**US$3.3**
	Enhanced storage for irrigation	US$/ha	US$0.2	US$0.1	US$0.5	US$0.2
	Reservoir restoration cost	US$/ha	US$0.9	US$0.7	US$2.5	US$1.1
	Avoided reservoir dredging cost	US$/ha	US$5.4	US$4.2	US$15.0	US$6.7
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	**m^3/ha**	**28**	**20**	**51**	**53**
	Benefit of enhanced water supply	US$/ha	US$1.4	US$1.3	US$2.0	US$2.0

	Discount Rate @6%		Per Year per ha			
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Carbon and hydrological ESS benefits	**Enhanced carbon sequestration**	**tCO_2-eq/ha**	**3.2**	**1.1**	**10.6**	**9.9**
	Voluntary Carbon Market	US$/ha	US$8	US$2.8	US$25.7	US$24.0
	Avoided Social Cost of Carbon	US$/ha	US$132	US$46.9	US$431.9	US$403.3
NPV	**Landuser - NTFPs, timber and forage biomass**	US$/ha	US$269	US$1.5	US$1,056	US$2,041
BCR			3.5	2.1	3.3	4.2
NPV	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$/ha	US$284	US$10	US$1,099	US$2,074
BCR			3.6	8.1	3.4	4.3
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$/ha	US$416	US$57	US$1,531	US$2,477
BCR			4.8	42.2	4.3	4.9

	Discount Rate @6%		Whole Watershed - 30 years			
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$	-10,981,999,795	US$74,538,108	US$8,416,227,605	US$2,593,635,302
	Costs	US$	-US$3,171,573,340	-US$35,869,558	-US$2,555,836,969	-US$612,741,902
Reservoir and hydropower	**Reduced Erosion**	**m^3**	**127,984 830**	**76,026,188**	**53,405,914**	**3,236,722.1**
	Enhanced storage for irrigation	US$	US$5,215,914	US$3,671,903	US$2,767,189	US$217,383
	Reservoir restoration cost	US$	US$26,079,572	US$18,359,515	US$13,835,943	US$1,086,917
	Avoided reservoir dredging cost	US$	US$156,477,430	US$110,157,093	US$83,015,658	US$6,521,504
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	**m^3**	**824868285**	**519790591**	**284872352**	**51697539**
	Benefit of enhanced water supply	US$	US$41,395,688	US$33,709,637	US$10,828,937	US$1,965,194
	Enhanced carbon sequestration	**tCO_2-eq**	**93,477,822**	**30,378,912**	**58,644,249**	**9,577,944**
	Voluntary Carbon Market	US$	US$227,318,138	US$72,756,359	US$142,610,312	US$23,291,518
	Avoided Social Cost of Carbon	US$	US$3,819,232,613	US$1,222,398,972	US$2,396,033,862	US$391,326,992
NPV	**Landuser - NTFPs, timber and forage biomass**	US$	US$7,810,426,455	US$38,668,550	US$5,860,390,636	US$1,980,893,399
BCR			3.5	2.1	3.3	4.2
NPV	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$	US$8,235,617,711	US$255,291,638	US$6,096,845,544	US$2,012,671,614
BCR			3.6	8.1	3.4	4.3
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$	US$12,054,850,324	US$1,477,690,610	US$8,492,879,406	US$2,403,998,607
BCR			4.8	42.2	4.3	4.9

Source: Original elaboration for this publication.

Table 22: Full CBA Result Display at 20% Interest Rate

	Discount Rate @20%		Total per ha - 30 years			
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$/ha	US$1,895	US$26	US$6,726	US$17,993
	Costs	US$/ha	-US$1,371	-US$28	-US$5,811	-US$7,458
Reservoir and hydropower	**Reduced Erosion**	**m³/ha**	**US$132**	**US$88**	**US$289**	**US$100**
	Enhanced storage for irrigation	US$/ha	US$1	US$1	US$4	US$2
	Reservoir restoration cost	US$/ha	US$7	US$6	US$19	US$9
	Avoided reservoir dredging cost	US$/ha	US$42	US$37	US$117	US$52
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	**m³/ha**	**853**	**599**	**1540**	**1598**
	Benefit of enhanced water supply	US$/ha	US$12	US$12	US$12.9	US$13.4
	Enhanced carbon sequestration	**tCO_2-eq/ ha**	**97**	**35**	**317**	**296**
	Voluntary Carbon Market	US$/ha	US$96.3	US$34.3	US$315.8	US$294.9
	Avoided Social Cost of Carbon	US$/ha	US$1,419	US$506	US$4,652	US$4,344
NPV BCR	**Landuser - NTFPs, timber and forage biomass**	US$/ha	US$524	-US$2	US$915	US$10,535
			1.4	0.9	1.2	2.4
NPV BCR	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$/ha	US$675	US$81	US$1,361	US$10,896
			1.5	3.9	1.2	2.5
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$/ha	US$2,094	US$587	US$6,013	US$15,240
BCR			2.5	21.7	2.0	3.0

	Discount Rate @20%		Per Year per ha			
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$/ha	US$1,895	US$26	US$6,726	US$17,993
	Costs	US$/ha	-US$1,371	-US$28	-US$5,811	-US$7,458
Reservoir and hydropower	**Reduced Erosion**	**m³/ha**	**US$132**	**US$88**	**US$289**	**US$100**
	Enhanced storage for irrigation	US$/ha	US$1	US$1	US$4	US$2
	Reservoir restoration cost	US$/ha	US$7	US$6	US$19	US$9
	Avoided reservoir dredging cost	US$/ha	US$42	US$37	US$117	US$52
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	**m³/ha**	**853**	**599**	**1540**	**1598**
	Benefit of enhanced water supply	US$/ha	US$12	US$12	US$12.9	US$13.4

	Discount Rate @20%			Per Year per ha		
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Carbon and hydrological ESS benefits	**Enhanced carbon sequestration**	tCO_2-eq/ha	97	35	317	296
	Voluntary Carbon Market	US$/ha	US$96.3	US$34.3	US$315.8	US$294.9
	Avoided Social Cost of Carbon	US$/ha	US$1,419	US$506	US$4,652	US$4,344
NPV	**Landuser - NTFPs, timber and forage biomass**	US$/ha	US$524	-US$2	US$915	US$10,535
BCR			1.4	0.9	1.2	2.4
NPV	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$/ha	US$675	US$81	US$1,361	US$10,896
BCR			1.5	3.9	1.2	2.5
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$/ha	US$2,094	US$587	US$6,013	US$15,240
BCR			2.5	21.7	2.0	3.0

	Discount Rate @20%			Whole Watershed - 30 years		
		Unit	Mosaic	Rotational Grazing	Woodlot Reforestation	Orchard Establishment
Local communities	**Landuser benefits**	US$	US$1,832,096,373	US$22,910,809	US$1,243,903,445	US$582,014,785
	Costs	US$	-US$1,325,307,411	-US$24,568,104	-US$1,074,598,608	-US$241,237,511
Reservoir and hydropower	**Reduced Erosion**	m^3	**127,984,830**	**76,026,188**	**53,405,914**	**3,236,722.1**
	Enhanced storage for irrigation	US$	US$1,357,733	US$1,062,730	US$720,316	US$56,586
	Reservoir restoration cost	US$	US$6,788,667	US$5,313,648	US$3,601,578	US$282,931
	Avoided reservoir dredging cost	US$	US$40,732,002	US$31,881,889	US$21,609,468	US$1,697,586
Carbon and hydrological ESS benefits	**Water supply (groundwater, soil water, river**	m^3	**824868285**	**519790591**	**284872352**	**51697539**
	Benefit of enhanced water supply	US$	US$11,925,926	US$10,173,233	US$2,388,930	US$433,534
	Enhanced carbon sequestration	tCO_2-eq	**93,477,822**	**30,378,912**	**58,644,249**	**9,577,944**
	Voluntary Carbon Market	US$	US$93,084,026	US$29,792,848	US$58,397,197	US$9,537,595
	Avoided Social Cost of Carbon	US$	US$1,371,342,883	US$438,917,526	US$860,325,703	US$140,510,815
NPV	**Landuser - NTFPs, timber and forage biomass**	US$	US$506,788,961	-US$1,657,295	US$169,304,837	US$340,777,274
BCR			1.4	0.9	1.2	2.4
NPV	**Tajik society - landuser benefits + water + carbon credits & avoided dredging costs**	US$	US$652,530,916	US$70,190,674	US$251,700,432	US$352,445,988
BCR			1.5	3.9	1.2	2.5
NPV	**Global society - Landuser benefits + tajik society + avoided damage cost of carbon**	US$	US$2,023,873,799	US$509,108,201	US$1,112,026,135	US$492,956,803
BCR			2.5	21.7	2.0	3.0

Source: Original elaboration for this publication.

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

Catchments are recognized as a critical form of green infrastructure that supplies a flow of economic benefits (World Bank 2019). Meanwhile, sedimentation is steadily depleting reservoir storage capacity worldwide, threatening the reliability of water supplies, flood control, hydropower energy, and structural integrity of dams. In some cases, reservoirs filled with sediment have not only impaired functions or made useless the dam infrastructure but also posed safety hazards (California State Coastal Conservancy 2007; Kondolf et al. 2014; US Bureau of Reclamation 2006; Wang and Kondolf 2014). Annandale (2013) estimated that global net reservoir storage has been declining from its peak of 4,200 km^3 in 1995 because rates of sedimentation exceed rates of new storage construction. With increasing demands for water storage, loss of capacity in reservoirs threatens the sustainability of water supply (Annandale 2013). Thus, one can think of the sediments accumulating in reservoirs as 'resources out of place', because these same sediments can be used productively on crops and rangelands and are also needed by the downstream river system to keep its morphology and ecology.

Reducing sediment yield from the catchment is one of several strategies available—along with routing sediment-laden flows; removing deposited sediment following deposition and adapting capacity loss—to combat reservoir sedimentation. Successful management will typically combine multiple strategies (Morris 2020). Catchment restoration also comes with significant co-benefits to land users and wider society, which have been analyzed as part of this assessment.

It was found that mosaic landscape restoration within the Vakhsh River Basin, combining orchards, woodlot rehabilitation, and rotational grazing, reduces erosion by an average of 4.4 m^3 per ha per year. The total sediment reduction, for the whole of the Vakhsh catchment, is in the order of 6.7 percent per year for the mosaic landscape restoration scenario (an average reduction of 92.4–86.2 million tons of sediment per year). This is a reasonable result as it must be kept in mind that the landscape restoration interventions are only carried out in the more downstream portions of the Vakhsh catchment. Most of the sediments are generated in the high elevation and steep slope areas where mostly bare soil is present. In addition, the hydrology of the Vakhsh is primarily influenced by snow and glacier melt, and the major sediment generation must be attributed to these melting processes. This occurs in locations and during a time when vegetation cover and grazing is not taking place.[55] Moreover, where degraded pastures are subject to reforestation efforts, sediment reduction benefits would be higher than those estimated here, due to the impact of reforestation on root cohesion and soil stabilization.

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[55] Field observations related to sediment sources in the Vakhsh River Basin (by UCA, Annex 1) also confirmed that the dominant sources of sediment to tributaries and the main stem of the Vakhsh River are derived from mass wasting, including shallow and deep landslide, debris flows that directly enter channels, and gully erosion (sometimes more than 100 m deep). Gully erosion is deep implying that mass wasting along the flanks contributes with far more sediment than surface erosion processes.

In monetary terms, reduced erosion from the mosaic landscape restoration scenario translates into a present value benefit of US$5.4 per year per ha restored, using a conservative avoided dredging cost of US$3 per m^3, for a 30-year time horizon, a 6 percent discount rate, and assuming it takes up to 15 years for the full restoration benefits to kick in. The present value benefit is in the order of US$0.9 per ha land restored land per year, in terms of the avoided reservoir restoration cost. Arguably, this latter estimate, however, does not capture the benefits in terms of reduced mechanical wear and tear of turbines, improved flood control, and other benefits, which result from removing sediments from a reservoir with sedimentation issues (as in the case of Nurek). If landscape restoration is scaled to its maximum potential, within the Vakhsh River Basin, total present value benefits amount to US$26 million in avoided reservoir restoration cost, or US$156 million, in terms of avoided dredging costs over a 30-year period.

Despite the construction of Rogun upstream of Nurek, there will continue to be sediment inflow to Nurek, resulting in an added 50 million m^3 of sediment by 2050 under BAU practices. Large-scale landscape restoration can reduce sediment inflow to Nurek by 11 million m^3. Second, landscape restoration also allows for enhancing the overall availability of water through enhanced plant evaporation, lateral return flow, groundwater, and soil moisture, by 26 m^3 (rotational gazing) to 66 m^3 (woodlot establishment) per year per ha restored. The present value benefit is about US$1.3 per year per ha restored under the mosaic landscape restoration scenario. Third, the implementation of sustainable and rotational grazing schemes, setting up orchard and woodlots in the mosaic landscape restoration scenario, allows for increased carbon sequestration in the order of 3.2 tCO$_2$-eq per year per ha. The present value benefits in terms of potential sale of carbon credit are US$8 per ha per year, or US$104 per ha per year in avoided climatic damage costs. The latter stands for benefits that are beneficial globally. Fourth, land users and rural communities stand to benefit significantly. The average annual net income increase, in present value terms, is in the order of US$2,041 per ha for orchards and US$1,068 per ha for woodlot establishment, supplying respectively US$4.2 and US$3.3 of benefits for every dollar invested.

Enhanced biomass productivity from rotational grazing provides between US$2 and US$8.5 of benefits for every US$1 invested, pending on the associated rotational grazing management and investment cost. The per hectare net benefits are significantly lower though (US$1.5–3) than those of orchards, but pastures typically stretch over much larger areas than woodlots and orchards and need not be found close to settlements. Grazing and forest landscape restoration interventions can therefore not be directly compared. Combining all the marketable benefits of landscape management, value of reservoir capacity from water storage, enhanced water yield, pasture biomass, timber and NTFP, and sale of carbon credits, land users may enjoy an average of US$270 per ha per year under mosaic landscape restoration and the wider society may enjoy US$285 per ha per year. Scaling up these interventions to the maximum potential surface area of 966,616 ha (30 percent of the Vakhsh catchment), the mosaic landscape restoration scenario provides US$8.3 billion in benefits in present value terms over a 30-year time horizon. The BCR to the Tajikistan society, including land users, is in the order of 3.6. These are arguably very conservative estimates of the true benefits, as they do not account for some added benefits (such as enhanced drought and flood resilience and reduced landslide risk).

The results presented here echo those found in the Kali Gandaki catchment in Nepal (World Bank 2019). At the US$500,000 budget level, each US$1 invested yields US$4.38 in benefits. The benefits there are driven largely by local benefits and the value of avoided lives lost in landslides, with the next highest beneficiary being downstream hydropower. Together, the studies add important contributions to the existing evidence base and mounting recognition that catchments are a critical form of green infrastructure that supplies a flow of economic benefits (Annandale et al. 2016). There are still arguments, however, that the benefits of reducing sediment inflow to reservoirs are not clearly shown. Kondolf et al. (2014), for example, point to the San Francisco-based Pacific Gas & Electric Company, which invested in catchment restoration and erosion control projects in the catchment above their dams, until concluding that, "other benefits aside, they could not justify the cost in terms of reduced maintenance or greater generation at their facilities" (Kondolf and Matthews 1993). This conclusion highlights an important aspect around resource mobilization for landscape restoration. Notably, if landscape restoration is to be used as a strategy for reducing sedimentation of reservoirs, it is crucial that investment costs are shared among key beneficiaries—including land users themselves, but also water user unions, energy utilities, hydropower providers, and the international community that stand to benefit from climate change mitigation and greater water food and energy security in Central Asia. Such cost-sharing arrangements could help capital-constrained risk-averse farmers overcome the long pay-off periods (in the order of 6–8 years) for the interventions considered here and make the landscape restoration investment competitive, as a sediment management strategy for hydropower providers.

Various instruments can be used to mobilize finance for restoration interventions. Currently, for example, irrigation water is underpriced. In Tojikobod, farmers pay a flat fee of US$17 per ha irrigated orchard. As an orchard requires approximately 8,000 m^3 per ha of irrigation water, the implicit cost of water is US$0.002 per m3 against an estimated true economic cost of US$0.1 per m^3. Volumetric pricing, closer to the full cost of water, would encourage water conservation, reduced losses, and problems of salinization. This would likely reduce water consumption, making water available to a wider range of consumers and reducing waterlogging problems. Water use conservation efforts would greatly reduce costs for the individual farmer and the public treasury, heavily subsidizing electricity for pump stations.

The freed-up financial resources could then, for example, be used to help farmers invest in land regeneration efforts, for example, by subsidizing key inputs (such as tree seedlings, drip irrigation schemes, or mobile fencing options). Tax credits, or exceptions for land taxes, conditional on investments into sustainable land management, may also be considered along with blended finance options that can help make low interest credit available to farmers.

From an economic perspective, the logic also works the other way around: further degradation of the landscape, through deforestation or overgrazing, imposes losses and costs on society. A first approximation of the costs of land degradation can be inferred from the (forgone) benefits estimated here. For example, for every hectare of rangeland that becomes moderately degraded, the present value social damage costs from reduced carbon sequestration are US$1,408 over 30 years. Or for every hectare of woodlot that is deforested, there is an increased present value cost of erosion of US$450 for a 30-year period (or US$15 per year) approximated by dredging costs. The cost estimates should be taken as a lower bound. While soil restoration takes time, losses in ecosystem services can be more abrupt. The results can nevertheless be used as an entry point to internalize environmental external costs, through taxation, fees, and fines.

Data were found to be consistent with there being no single dominant spatial source of sediment, and therefore, landscape remediation efforts can be directed to specific sites or indeed to all sites without risk of missing somewhere else in the catchment where anthropogenic inputs are overwhelming background 'natural' inputs. Research by Griffith University and results from the Integrated Model show there is no single dominant spatial source of sediment, and therefore, landscape remediation efforts can be implemented with consideration to other success factors, for example, where there is access to rural credit, enabling land tenure regimes, and social acceptance and willingness among communities to invest. Respective policies and legislation as well as tools could be implemented that supply access to affordable credits and/or grants for investments that consider catchment rehabilitation actions.

A catchment-wide landscape restoration approach, such as regeneration by simply removing grazing pressure, for example, can thus be implemented with the certainty that it will most definitely have a positive/beneficial effect. The assessment provided is not a strict guide to favor specific landscape restoration interventions over others, but rather, the proposed forest landscape restoration and sustainable grazing measures should be seen as complementary and to be implemented over time, with the aim to address large areas of underused landscapes and abandoned unproductive land. An exception to this catchment-wide landscape management approach would be toward the management of active gullies and landslides for which landscape restoration measures should include a mix of nature-based solutions and the use of a control system.

The proposed landscape restoration interventions are also beneficial for Nurek and Baipaza Dam, even after the completion of the Rogun Reservoir. The results show that the catchment rehabilitation measures downstream of Rogun reduce sediment input to the two downstream reservoirs. In this regard, the Rogun–Nurek section can supply a test ground for assessing the contribution of landscape restoration to reduced sedimentation (post 2024 when sediment transfer from Rogun is predicted to be reduced to 30–40 percent).

The potential increase in high-flow events as a consequence of climate change is significant, considering that discharge that transports the most bedload and sediment is linked to bank-full and higher discharges (Emmet and Wolman 2001). While assessing climate change impacts has not been part of the study, increased reservoir sedimentation under climate change scenarios is likely and will reduce the economic lifetime of Nurek and Rogun, predicted to be over 100 years for Rogun (TEAS 2014). Due to the high uncertainties and nonlinear relationship between climate, erosion, and sediment transport processes, only a qualitative estimate can be provided. However, from the results obtained, it can be inferred that the proposed landscape restoration interventions supply a means for climate change adaptation and mitigation.

The proposed restoration measures support soil and water conservation, and reduce flood peaks, by reducing runoff and increasing return flow to rivers. In this light, efforts to attenuate siltation and fluctuations in overall water availability through landscape restoration and climate-resilient farming are well invested. The Vakhsh catchment and its hydropower facilities will benefit from these, particularly under future climate change impacts. Beyond the benefits described, the planned interventions can therefore also be seen as an effective measure to support climate proofing of the agriculture, forestry, hydropower, and water sectors in the Vakhsh catchment.

The study has shown that large-scale mosaic landscape restoration in the Vakhsh catchment can supply NPV benefit to the Tajikistan society in the order of US$8.3 billion. There are multiple other benefits, however, that could not be considered within the scope of this study and may be the subject of future work.

In terms of limitations to valuing the full suite of hydrological benefits, it is shown that runoff is decreased, which means that inflow is reduced and irrigation systems downstream of the dams have less water available, under the assumption that dams do not spill. Whether the dams spill can be challenged[56] (AIIB 2017), especially in the case of Nurek. Enhanced streamflow also implies that water can be released more timelier for irrigation. In that case, there would be negligible impact on water availability along the river downstream of the dams—annual reservoir operation through more lateral return flow. River flow into the reservoirs is therefore likely more balanced, which has benefits for flood retention and hydropower and overall resilience to climate change impacts. While there is evidence of spills from major reservoirs in Tajikistan (AIIB 2017), there was not enough information to estimate the share of runoff that is spilled, at Nurek, or the expected or reduced spills when Rogun will be completed. As a result, the economic loss in useable inflow may be overestimated (Chapter 3). Additionally, the benefits from reducing flood peaks and ensuring more balanced reservoir retention (due to reduced runoff) have not been valued as part of this assignment. They are still, however, a useful subject for future research. Overall, the hydrological benefits estimated in this assessment are conservative estimates of the true economic benefits from landscape restoration.

Added impacts of natural disasters were beyond the scope of this study to quantify, including the potential impacts of climate change and an increase in natural hazards (droughts, floods, extreme temperatures, and fires) which could lead to losses of lives, livelihoods, and biodiversity, as well as damages to infrastructure (dams and roads). Natural disaster risks in Tajikistan are generally so severe that property, infrastructure, and assets cannot be repaired and replaced. World Bank (2020a) estimates the average total cost of replacing buildings and other infrastructure damaged by snow avalanches, mud flows, rock falls, and heavy floods to be in the order of US$25 million per year, equivalent to 0.4 percent of Tajikistan's GDP.

4.2 POLICY AND TECHNICAL RECOMMENDATIONS

The sections below present the list of recommendations from this study, divided as follows: (a) policy recommendations for decision makers, (b) technical recommendations for technicians and sector specialists, and (c) future research needs that the report has identified.

4.2.1 Policy Recommendations

- **Develop a strategy to address landscape restoration along the Vakhsh River Basin.** Developing a strategy will aid with land management in the Vakhsh River Basin while also serving as a basis for future strategies for other projects. Such a strategy should include a wider developmental vision for the areas

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[56] According to AIIB (2017), HPP power generation is very dependent on water flows in Tajikistan's major rivers, which decline sharply in cold winter months when water flow is low. On the other hand, the Tajikistan power system generates excess power in summer because of high water flows, and while some power is exported to Afghanistan and the Kyrgyz Republic, water is frequently spilled from reservoirs. https://www.aiib.org/en/projects/approved/2017/_download/tajikistan/document/document_nurek-hydropower-rehabilitation-project.pdf.

surrounding the Vakhsh River Basin while also addressing policies, economic measures, data, and technical capabilities needed for landscape restoration to succeed.

- **Mainstream and implement sustainable grazing and landscape restoration measures into respective policies and legislation, at the local and national levels.** Examples at the national level are design manuals for non-rotational grazing; requirements for compensation measures; requirements for consideration of erosion prevention measures; and broader aspects such as no-grazing buffering zones along riverbanks, active natural hazard zones, and roads.
- **Establish closer coordination and planning with local authorities and farmers to identify what landscape restoration intervention will work best for their communities.** Through discussions with local stakeholders, this report has identified several landscape restoration interventions and has highlighted their economic benefits. The choice of landscape restoration is dependent on the local context, and more cooperation between central and local governments is therefore key. Examples of such coordination mechanisms could include councils, commissions, and inter-local administration cooperatives for coordinating landscape restoration activities across communities.
- **Landscape restoration and sustainable sediment monitoring and management approach should be integrated into the design, implementation, and operation phases of the Tajikistan hydropower sector.** Using this report and the Vakhsh River Basin as a best practice, these aspects should be integrated and implemented into the growing and crucial hydropower sector in Tajikistan to sustainably manage water resources.
- **Identify the fiscal policies and green finance needed to implement the proposed restoration interventions and to scale up restoration finance for future projects.** Considering the significant pay-off period, especially for farmers, co-financing arrangements such as public-private partnerships (PPPs) may be necessary to scale up restoration efforts and attract public and private capital into restoration.
- **PES schemes should be designed and implemented to protect and restore the upper part of the Vakhsh River Basin,** to control the stock and flow of the sediment more effectively and ultimately regulate the quantity of eroded sediment reaching the stream network and the catchment’s water quality and quantity.
- **Repurpose existing inefficient policies and subsidies within agriculture and irrigation toward incentives for landscape restoration, green infrastructure, and nature-based solutions.** Reshaping inefficient subsidies in water irrigation and agriculture can open opportunities for investments in landscape restoration to increase resilience of infrastructure, people, and ecosystems in the Vakhsh River Basin.

The agriculture, forestry, energy, and water sectors within the Vakhsh catchment can use this valuation method to make a case for why landscape restoration and watershed management programs are good investments for the development of the Vakhsh River Basin, as well as for the rest of the country. Understanding and quantifying the benefits for different sectors enables the design of more efficient and robust PES schemes, financing arrangements, and payment structures and can use investment from multiple stakeholders.

The developed tools also have relevance for ESF, by supplying a data-driven and systematic way to incorporate impacts on ecosystem services and livelihoods into the project's environmental and social management plans and to show opportunities to avoid, reduce, and mitigate these impacts. This would enable decision makers to develop priorities based on the cost and benefits of investments and the impact of the environmental externalities on these investments and move toward green infrastructure.

4.2.2 Technical Recommendations

- **It is recommended to set up a bathymetric survey program for the reservoirs in the Vakhsh River Basin, to regularly measure sediment build-up and monitor trends against first predictions.** The rate of sedimentation is critical information for the entire life cycle of hydropower and water storage reservoirs, from design to decommissioning. While sediment models can be useful for undertaking projections and simulation scenarios, real data are essential for planning any type of interventions.
- **A climate change impact assessment for the Vakhsh River Basin and hydropower cascade is recommended in the future.** The assessment, which can further underpin the values of green infrastructure for increasing climate resilience and sectoral adaptation, should include an assessment of the impacts of climate change on soil erosion and reservoir sedimentation rates. As climate change affects the hydrological and ecological system in a complex spatio-temporal cause-effect chain, particularly in snow and glacier-dominated regions, quantitative causes of the changes cannot be drawn without a detailed climate change impact assessment.
- **It is recommended to prepare catchment-scale strategic environmental and social assessment of the Vakhsh River Basin.** The results of this study supply useful information for the environmental and social assessment processes for Rogun Dam construction as part of the implementation of the World Bank's ESF.
- **It is recommended to include in future work the assessment of the potential adverse impacts of soil erosion and sedimentation on water quality for the Vakhsh River Basin,** using a combination of global studies and tools (that is, WaterWorld tool[57]) and field measures to estimate upstream–downstream links and surface water and groundwater quality impacts. This work would allow for including additional benefits of landscape restoration into the CBA results and inform the environmental and social assessment of the Vakhsh River Basin and Rogun.
- **It is recommended that any efforts to regenerate landscapes are accompanied with capacity building in climate change adaptation strategies among water user associations, PUUs, and FUGs** to emphasize the importance of landscape restoration as an adaptive measure and prepare the communities for the expected future conditions.

The hydropower sector can benefit from the valuation and prioritization methodologies developed for this study to design interventions and PES schemes that more effectively control sediment from watersheds. Application of the sediment modeling and prioritization tools can inform the design of watershed management programs to reduce sediment and improve soil and water quality/quantity, by targeting interventions to the best places to achieve outcomes and balancing trade-offs, thereby making such programs more cost-effective and transparent. Where policy mechanisms exist that require revenue sharing from HPPs, the sediment budget and prioritization tools

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[57] https://www.policysupport.org/waterworld.

can be used to find priority areas for investment that promotes rural development (satisfying the motivation for why such policies often exist) while simultaneously reducing sediment-induced impacts on O&M of hydropower facilities within the Vakhsh catchment.

Landscape restoration along with other regenerative farming practices, however, offers a strategy for the Tajikistan farming sector to reduce its dependency on irrigated croplands as a source of income, with further positive knock-on effects in terms of more drought-resilient farming systems and the savings that are generated from running the irrigation and drainage network. These added benefits have not been estimated as part of this assessment and could be considered in future work.

4.2.3 Future Research Needs

The erosion and hydrology simulations are subject to significant uncertainties, given the data availability and lack of information on sediment sources and budgets. Therefore, while qualitatively the results are robust, **field validation of the estimated sediment budgets** (for example, through sediment fingerprinting) **and expected impacts of the interventions is needed.** For instance, most of the overall sediment reduction is considered to occur due to the impacts of the interventions on gully erosion. It would therefore be beneficial to check the feasibility and realistic implementation of the measures in the locations where gully erosion is the most severe.

During the undertaking of the geochemical tracing in the Vakhsh River Basin, elemental concentration ratios were often found to be near unity across tributary junctions, reducing the discriminatory power of the geochemical 'fingerprints.' Future studies may need to be restricted to more localized studies near distinct geological boundaries, with samples collected closer to tributary junctions to reduce the influence of catchment contributions sourced from the region between the upstream samples and the downstream sample.

The ideal way to thus approach the assessment of ongoing erosion and/or the impact of remediation is by direct monitoring at a smaller scale. For example, any landscape restoration works should be accompanied by paired catchment type studies (for example, similar catchments with a control and different treatments) that employ a 'multiple lines of evidence' approach to the assessment of the changes brought about by landscape restoration efforts. This might be based on repeat terrestrial or airborne Lidar combined with water quality (that is, sediment concentration) monitoring, erosion plots and erosion pins, and so on. It was found that sources appear evenly distributed in the landscape and it should therefore not be difficult to find paired sub-catchments.

The use of higher-resolution mapping and monitoring of active gullies would allow to check the feasibility of the measures in the locations where gully erosion is the most severe. The erosion and hydrology simulations undertaken in this study are subject to significant uncertainties, given the data availability and lack of precise information on sediment sources and budgets. Therefore, while qualitatively the results are robust, field validation of the estimated sediment budgets and expected impacts of the interventions is recommended. For instance, most of the overall sediment reduction is considered to occur due to the impacts of the interventions on gully erosion. **Further assessments are also advisable to compare the study results** with the indicators of suitability for restoration, benefit indicators such as the potential to generate jobs, and other key metrics provided by open-source tools such as se.plan.[58]

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[58] https://docs.sepal.io/en/latest/modules/dwn/seplan.html.

As climate change affects the hydrological and ecological system in a complex spatio-temporal cause-effect chain, particularly in snow and glacier-dominated regions, quantitative causes of the described changes cannot be drawn without a detailed climate change impact assessment. A climate change impact assessment is therefore suggested to be conducted in the future, which can further underpin the values of green infrastructure for increasing climate resilience.

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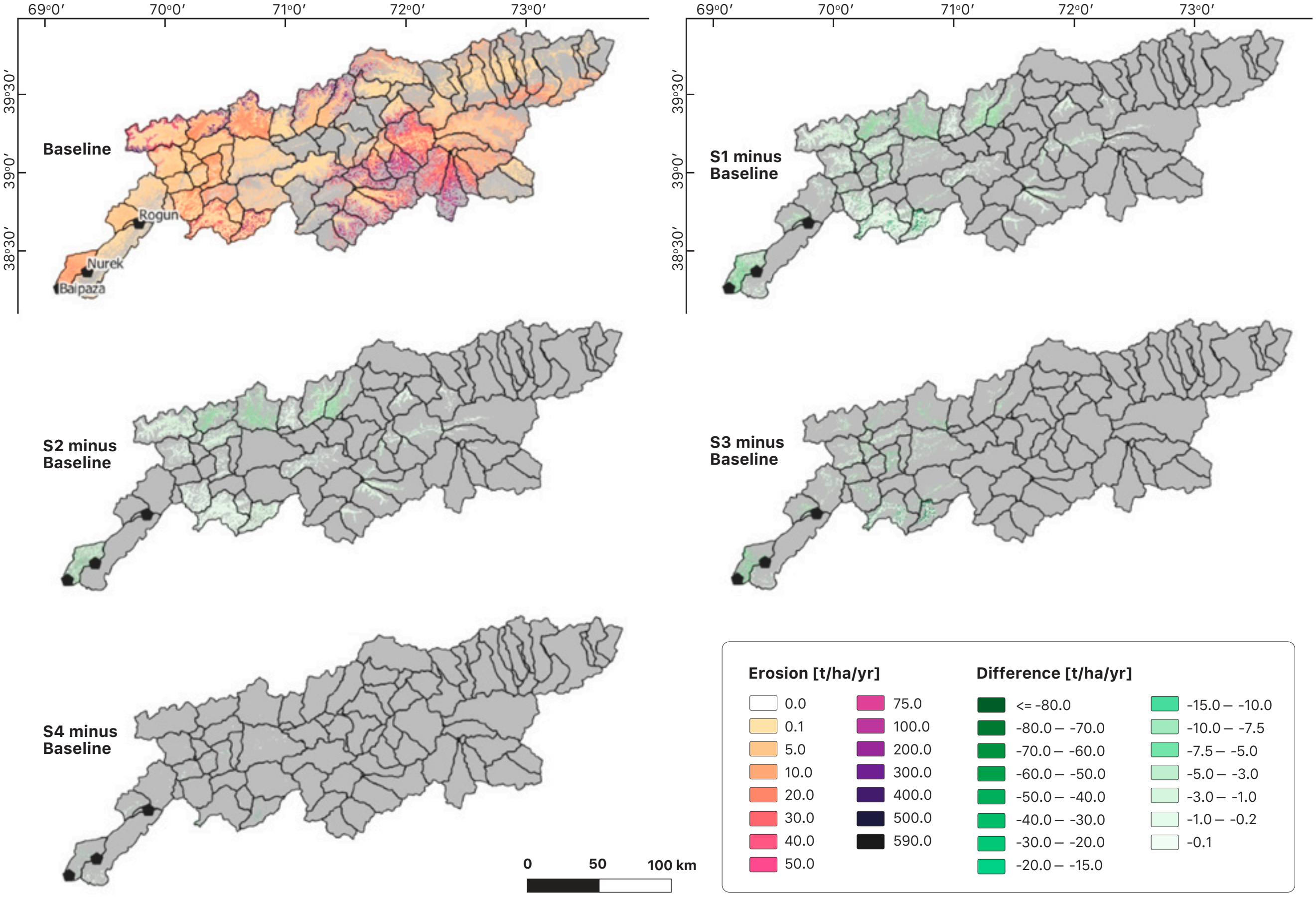
ANNEX 1. ADDITIONAL INFORMATION ON SEDIMENT SOURCING AND EROSION ANALYSIS

A1.1 INTERVENTION IMPACTS ON SHEET AND RILL EROSION

Figure A1.1 shows the spatial distribution of sheet and rill erosion for the baseline and the four scenario interventions. The mosaic scenario leads to the highest reductions. Downstream sub-catchments are subject to the most significant changes. The rotational grazing scenario (S2) affects larger areas than woodlots (S3) whose effects are more localized. Limited effect can be seen for the S4 scenario.

Figure A1.1: Sheet and Rill Erosion for the Baseline and Interventions

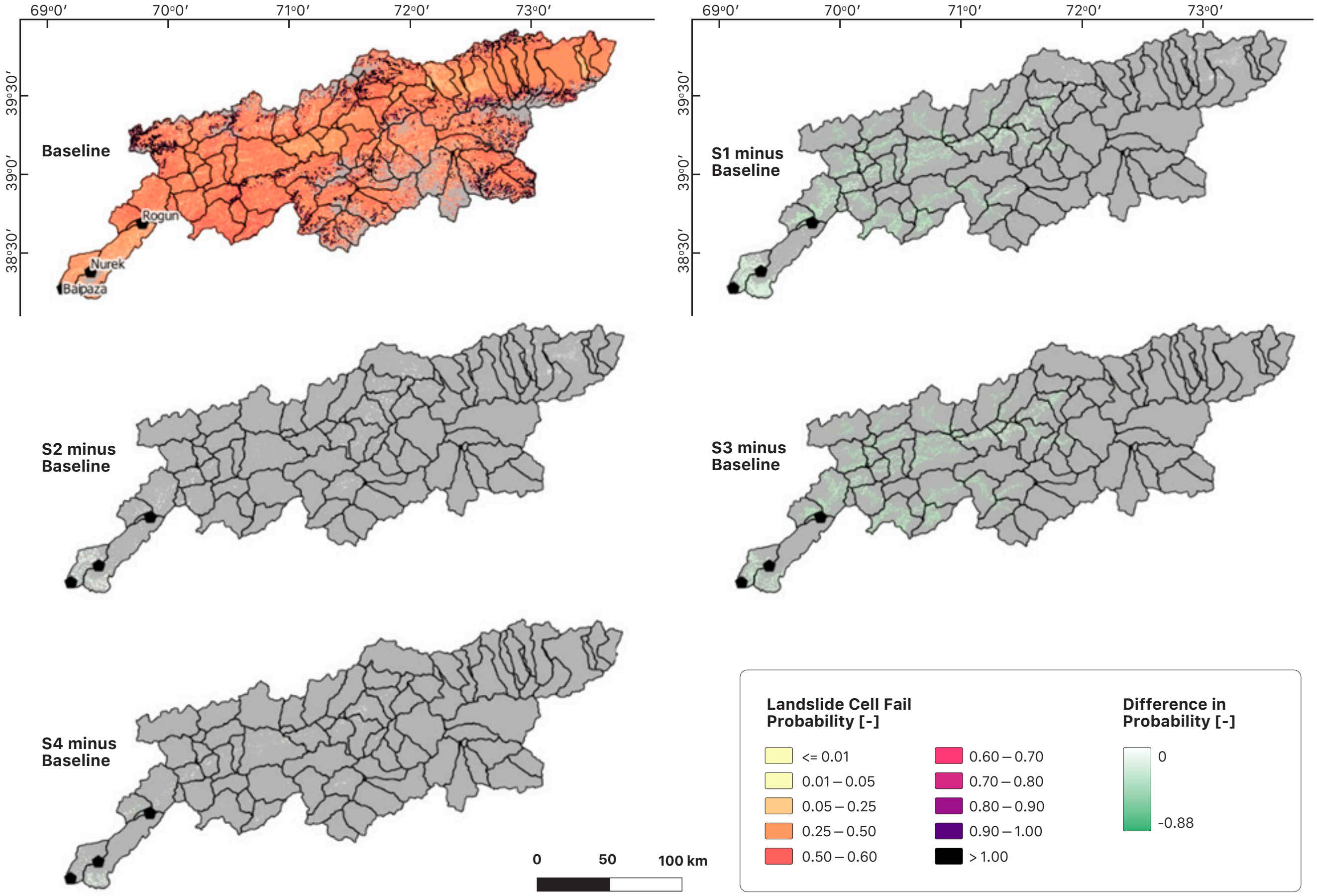


Source: Original elaboration for this publication.

A1.2 INTERVENTION IMPACTS ON LANDSLIDE RISK

Figure A1.2 shows the spatial distribution of landslide risk for the baseline and the four scenario interventions. The black areas are locations where the simulation shows that individual slope cells fail within a 10-year period (areas > 1, which is equal to 100 percent risk). Those are rarely found near settlements, where the risk within the 10-year period is mostly considered lower than 1. The interventions did not reduce the sediment input from landslides but reduced landslide risk, also near settlements. Again, the mosaic scenario (S1) shows the highest risk reduction, which can be attributed to the implementation of the woodlots (S3). The increase in root cohesion due to the trees has a significant impact on landslide risk. As the woodlots have tighter tree spacing than orchards (S4), they have a greater impact on soil cohesion. Moreover, the criteria for suitable sites for woodlots was areas with lower soil stability, which also leads to the more pronounced benefits relevant to orchards which favored lower slope angles between 0 and 30 percent. Overall, the rotational grazing (S2) and orchards scenarios have limited effectivity due to the minimal impact on root cohesion and very localized implementation of the orchards, respectively.

Figure A1.2: Landslide Risk for the Baseline and Interventions

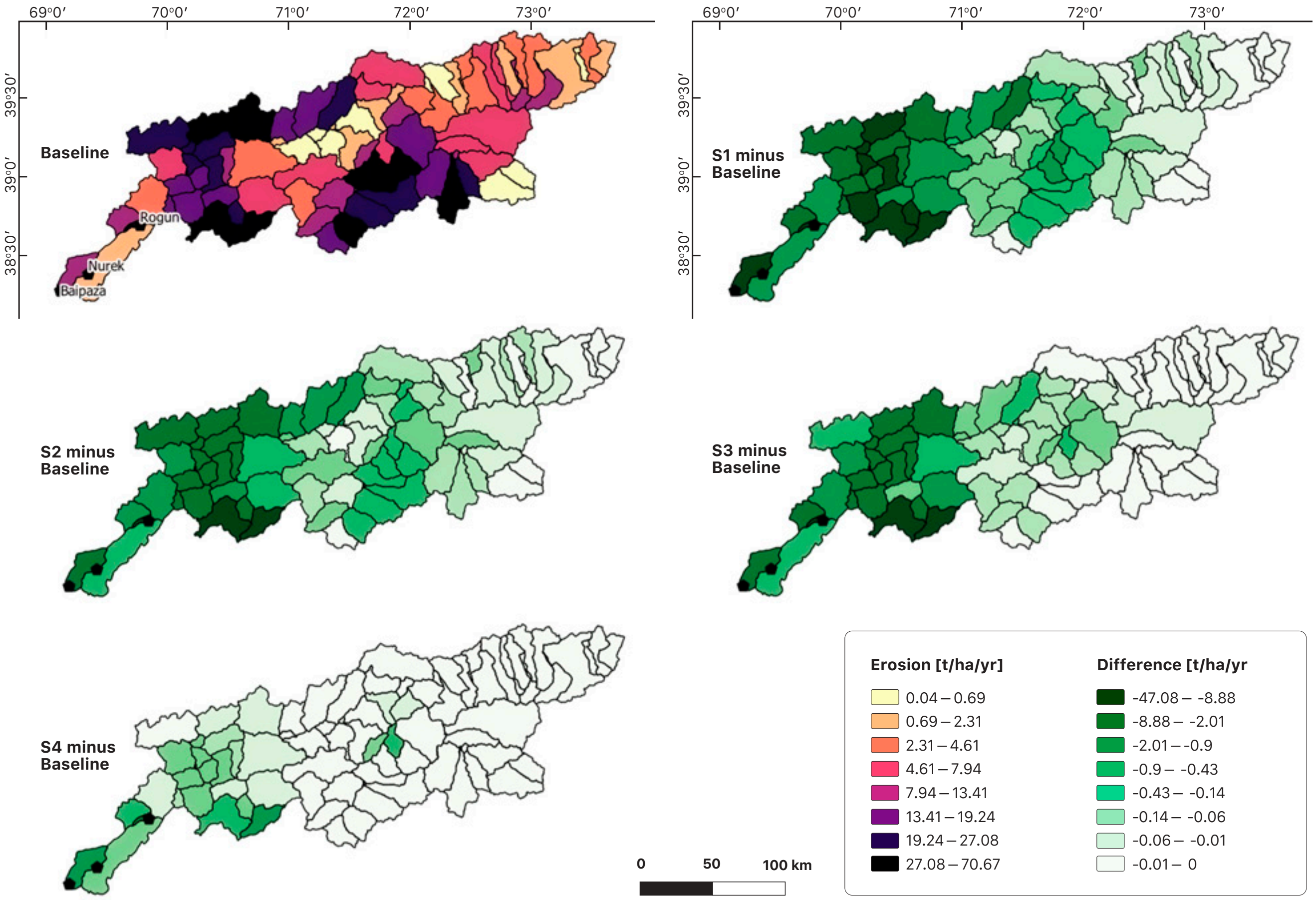


Source: Original elaboration for this publication.

A1.3 INTERVENTION IMPACTS ON GULLY EROSION

Figure A1.3 shows the spatial distribution of gully erosion for the baseline and the four scenario interventions. The mosaic scenario leads to the highest reductions. Downstream sub-catchments are subject to the most significant changes. The rotational grazing scenario (S2) and woodlots (S3) are the most effective in rehabilitating the gullies and reducing the headcut advancement of the gullies. In some catchments, reductions of up to 50 percent are possible. If orchards were placed in gullies, the trees could stabilize and reduce headcut advancement; however, the feasibility and access to these areas would have to be assessed case by case.

Figure A1.3: Gully Erosion for the Baseline and Interventions



Source: Original elaboration for this publication.

Table A1.1: Erosion Sources and Sediment Reduction Potential between Rogun and Nurek

Erosion Sources between (m^3/year)						Sediment Reduction Potential for Proposed Measures		
All sources	Channel	Gully	Landslide	Screes	Sheet and Rill	All Sources (m^3/year)	All Sources (m^3/ha/year)	Proposed Measure
442,309	204,168	155,481	9,938	51,100	28,879	—	—	Baseline
360,650	203,838	79,339	9,854	51,100	23,621	82,228	1.51	Combined (mosaic)
384,760	204,023	98,728	9,880	51,100	28,180	57,550	1.23	Rotational grazing
405,625	204,050	122,649	9,899	51,100	25,162	36,684	3.48	Woodlot reforestation
429,118	204,041	143,496	9,935	51,100	27,802	13,192	1.94	Orchards establishment

Source: Original elaboration for this publication.

ANNEX 2. ADDITIONAL INFORMATION ON METHODOLOGY FOR ECONOMIC ANALYSIS

A2.1 PARAMETERIZATION OF SCENARIO INTERVENTIONS

Table A2.1 shows a summary of the parameterization for the different models and the respective intervention compared to the baseline.

Table A2.1: Parameterization of Scenario Interventions in the Models

Scenario Intervention	SWAT				Gully Model		Landslide Model	
	CN2 Hydrol. Soil Group C [-]		USLE-P [-]		Root Cover Factor (RCF) [-]		Root Cohesion [kPa]	
	BL	Int	BL	Int	BL	Int	BL	Int
Grazing winter	79	74	1	0.8	0	0.5	0	1
Grazing summer	83	77	1	0.8	0	0.5	0	1
Grazing autumn	81	76	1	0.8	0	0.5	0	1
Grazing all year	86	79	1	0.8	0	0.5	0	1
Woodlots	a	70	a	0	a	1.4	a	14
Orchards	a	72	a	0	a	1.2	a	11

Source: Original elaboration for this publication.
Note: BL = Baseline; Int = Intervention; a. Varies by initial land use.

A2.2 ASSUMPTIONS USED TO MODEL EROSION TYPES IN THE INTEGRATED EROSION AND SEDIMENT TRANSPORT MODEL

Sheet and Rill Erosion

SWAT uses the MUSLE (Williams 1995) to simulate sheet and rill erosion on agricultural fields, degraded pasture, and bare areas and on gentle slopes. The MUSLE considers surface runoff as the erosive force instead of rainfall as the original USLE/RUSLE approach. This has two advantages: it implicitly considers the delivery ratio of the eroded sediment to the streams since sediment delivery occurs only if surface runoff reaches the streams and surface runoff originating from snowmelt and glacier melt has an erosive force which makes it possible to consider this process in SWAT. The MUSLE needs land use, soil, and topographic input data and catchment management information and is dynamically linked to SWAT's hydrological algorithms that calculate surface runoff. Sheet and rill erosion is calculated for each computational unit in SWAT, a unique combination of soil, slope, and land use within each of the 83 hydrological sub-catchments in the Vakhsh River.

Gully Erosion

Gullies are considered a significant sediment source in the Vakhsh River (Sidle et al. 2019). Numerous approaches exist to model gully occurrence, advancement, and the resulting sediment input to streams (Vanmaercke et al. 2021). To calculate sediment input into the streams from gullies, the locations of gullies are estimated according to a simple relationship developed by Meliho, Khattabi, and Mhammdi (2018) who found that barren and sparse vegetation with slope gradients above 50 percent were very susceptible to gully erosion. The SWAT computational units that match these conditions are selected as prone to gully erosion. Further, for each of these pre-selected units, gully erosion is simulated according to the model described in Allen et al. (2017). They developed an empirical relationship of the daily gully headcut advancement and the associated generated sediment which can be linked to SWAT. The model requires information on soil properties, vegetation characteristics, gully geometry, and surface runoff, which is again calculated from SWAT. The model then calculates a time series of daily sediment loss in case overland flow was generated on that day from each computational unit prone to gully erosion.

Landslides

The landslide model approach used for the application in the Vakhsh River Basin is based on World Bank (2019) and Wu and Sidle (1995), which describe a model of connected hillslope stability in detail. The models use typical equations that are often used to assess hillslope stability and are considered well suited to depict landslide processes in the Vakhsh catchment. The model calculates the landslide processes on a 30 m by 30 m grid. First, a spatially varying factor of safety based on soil properties and slope is used to find cells that can potentially reach failure and therefore can trigger a landslide. These cells are further processed by grouping those to landslide objects according to their spatial connection. All cells within the connected landslide are then evaluated if they fail under certain soil moisture conditions—the 'threshold moisture' which is obtained from the SWAT model. The amount of sediment mobilized in a landslide will not fully reach the streams. Larger landslides will have longer runout lengths than smaller landslides. Therefore, for each landslide object, the runout length is calculated and the part of sediment reaching the streams (the delivery ratio) is calculated.

Screes

Screes can contribute significant amounts of sediment when found sufficiently close to streams. They occur on slopes that exceed the internal friction angle of non-cohesive soils, which is in the range of 38–42°. From these slopes, sediments roll down and can enter the stream channels. Imaizumi et al. (2015) have estimated that slopes susceptible to screes contribute sediments between 20 and 25 t per ha per year. These dependencies are used to model scree input on a 30 m by 30 m grid where all cells that exceed a slope of 38° and are within a downslope vicinity of 1,500 m to streams contribute 22.5 t per ha per year of delivered sediment to the streams.

Sediment Transport in River and Fluvial Erosion

The previously described sediments from the four erosion processes are entering the stream network at various locations within the Vakhsh catchment. Depending on the amount of sediment and its spatio-temporal distribution, sediment transport, deposition, or added fluvial erosion occurs within the stream network. If the sediment in the water column is lower than the transport capacity and erodible sediment is present in the stream, channel erosion occurs. If the sediment exceeds the transport capacity, sediment is deposited. This complex process is simulated by SWAT's in-stream sediment transport algorithms on the sub-basin scale. Sediment that leaves one stream section is entering the next downstream section until the sediments are routed through the entire network. Results of the in-stream sediment transport are therefore available for each stream section within the 83 hydrological sub-catchments. At the Rogun Dam's location, the Vakhsh River drains into the dam, thus there is an accumulation of all upstream erosion and sediment transport processes.

A2.3 CRITERIA FOR MAPPING LANDSCAPE RESTORATION LOCATION

Table A2.2: Main Variables Used to Parameterize the Landscape and SWAT Modeling and Define the Location of the Landscape Restoration Interventions

	Orchards	Woodlots	Grazing
Land uses that are assumed feasible for each landscape restoration option	• **Cropland** • **Mosaic cropland** (>50%)/ natural vegetation (tree, shrub, and herbaceous cover) (<50%) • **Mosaic natural vegetation** (tree, shrub, and herbaceous cover) (>50%)/ cropland (<50%) • **Herbaceous cover.**	• **Cropland** • **Mosaic cropland** (>50%)/natural vegetation (tree, shrub, and herbaceous cover) (<50%) • **Mosaic natural vegetation** (tree, shrub, and herbaceous cover) (>50%)/cropland (<50%) • **Herbaceous cover.**	• **Grassland** • **Mosaic cropland** (>50%)/ natural vegetation (tree, shrub, and herbaceous cover) (<50%) • **Mosaic natural vegetation** (tree, shrub, and herbaceous cover) (>50%)/cropland (<50%) • **Herbaceous cover** • **Urban areas (used for village pastures).**
Distance from village/ roads	Village < 1.5 km	Roads < 1.5 km	All year: Village < 0.8 km Winter: 0.8–1.8 km Spring/fall: 1.8–30 km Summer: 0–600 km
Altitude	Altitude < 2,800 m	Altitude < 2,800 m	All year: Village < 2000 m Winter: < 2,000 m Spring/fall: < 2,000 m Summer: 2,000–3,400 m
Soil moisture		Soil moisture threshold 0–2.5 from SWAT Sidle, based on Sidle (1988)	
Slope	Slopes 0–30%	No slope criteria	No slope criteria

Source: Original elaboration for this publication.

Table A2.3: Hectares for Each Landscape Restoration Scenario

Scenario		Whole Catchment (ha)
Mosaic scenario	Total mosaic	966,616
	Mosaic - rotational grazing	751,360
	Mosaic - woodlots	182,909
	Mosaic - orchards	32,347
Individual scenarios	Rotational grazing	867,969
	Woodlots	184,939
	Orchards	32,347

Source: Original elaboration for this publication.
Note: Total catchment area is 3,125,291 ha.

A2.4 RANGELAND BIOMASS PRODUCTIVITY FOR DIFFERENT DEGRADATION LEVELS

Table A2.4: Biomass Productivity in BAU and Rotational Grazing Scenarios, Assumed Grazing Period, and Regeneration Time

	Degradation Status, Baseline	Baseline - Biomass (t DM/ha)[59]	Sustainable Pasture Management - Biomass (t DM/ha)	Grazing Period (Days)	Biomass Regeneration Time (Years)
Winter (20% increase)	Moderately degraded	0.6	0.72	150	5
Spring/fall (20% increase)	Moderately degraded	0.6	0.72	120	5
Summer (20% increase)	Low degradation	0.7	0.84	90	5
All year (50% increase)	Severely degraded	0.3	0.45	360	5
Average across all pastures		0.5	0.68		5

Source: Original elaboration for this publication.

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[59] Pasture experts in World Bank (2020a) estimated that the total amount of hay that can be harvested from undegraded pastureland is about 1.1 ton/ha.

A2.5 DATA INPUTS FOR THE CASH FLOW ANALYSIS OF THE RESTORATION INTERVENTIONS

Table A2.5: Rotational Grazing ICs, from Literature and Field Visits in Tojikobod

	US$/ha	Comment	Source
Rotational grazing - international (low)	8.1	New fencing	Wang et al. 2018
Rotational grazing - international (high)	112.3	New fencing, water systems, first year	Undersander et al. 2002
Rotational grazing - Tajikistan (mixed experiences)	10–120	Traditional fencing with mesh wire (low cost), traditional fencing (higher cost)	Davlatov 2022b
Rotational grazing and village pastures (reasonable average)	30.0[a]	Fences replaced every 5 to 6 years	Davlatov 2022b
Rotational grazing, use of herding, and pasture management plans	20.0[a]	In the first year	Davlatov 2022b

Source: Original elaboration for this publication.

Note: a. Assumptions that have been used in the CBA.

Table A2.6: Assumptions on Yields, Prices, and Tree Densities for Orchards Used in the CBA Analysis

Typical Situation in a Pure Orchard	Years to Harvest	Yield (Nuts, Fruits in kg/Tree and or Dry Wood kg/ha) (kg/Tree)	In Year	Trees per ha
Walnuts	5	40 kg per tree	10	100
Apples	4	100 kg per tree	10	400
Mixed orchard (50/50)	**Years to Harvest**	**Yield (Nuts, Fruits in kg/Tree and or Dry Wood kg/ha) (kg/Tree)**	**In Year**	**Trees per ha**
Walnuts	5	40 kg per tree	10	200
Apples	4	100 kg per tree	10	50
Fuelwood		60 m^3 per ha	20	
Price			**TJS/kg**	**US$/kg**
Walnut price			16.5	1.5
Apple price			4.5	0.4
Apricots/all fruits in Tajikistan (average)			10.0	0.9
			TJS/m^3	**US$/m^3**
Fuelwood			104	9.3
Timber			3,800	338.2

Source: Original elaboration for this publication.

Table A2.7: Investment and Management Costs of Orchards

Investment Costs	Number	TJS	US$	Source
Apple and walnut seedling cost		10	0.9	Kassam 2022
Wire with poles (per m)		30	2.7	Kassam 2022
Meters of wire for a 2 ha orchard	600			Kassam 2022
Meters of wire per ha	300			Derived
Scrub cost (per scrub) (1 scrub per m)		15	1.34	Kassam 2022
Total shrubs per 1 ha orchard	300			Derived
Total wire and shrub costs		13,500	1,201.5	Derived
Total seedling cost per ha		2,500	222.5	Derived
Drip irrigation system per ha			200	USAID 2020
Total IC per ha			**1,624**	Derived
Annual maintenance cost		**TJS**	**US$**	**Source**
Thinning, pruning, and fruit and nut harvesting cost per ha		8,000	712	Davlatov 2022a
Annual orchard irrigation cost per ha[60]		190	17	Davlatov 2022b
Harvesting cost at peak harvest per day		130	11.6	Davlatov 2022b
Yearly harvesting cost (55 days)		7,150	636.35	Derived
Transportation cost (per 2,000 kg)		100	9	Davlatov 2022b
Transportation cost per kg		0.05	0.00445	Derived
Transportation cost per ha per year at peak harvest[a]		1,123	100	Derived

Source: Original elaboration for this publication.
Note: a. 2,000 kg of walnuts and 20,000 kg of apples.

Table A2.8: Timber and NTFP Yields from Woodlots

Typical Woodlot (400 Trees per ha)	Years to Harvest	Nuts-Fruits (kg/Tree)	Years after Planting	Trees per ha
Apricots	4	70	10	100
Walnuts	5	20	10	100
Dog rose and other trees used for timber				200
Yield	**m^3/ha**	**As of Year**	**How Often**	
Sustainable fuelwood harvest (m^3)	30	5	Annually	
Timber harvest - short rotation[a]	100	14	One-off, at the end of the rotation	
Timber harvest - long rotation	150	30	One-off, at the end of the rotation	

Source: Original elaboration for this publication.
Note: a. From the Tojikobod field visit (Davlatov 2022a).

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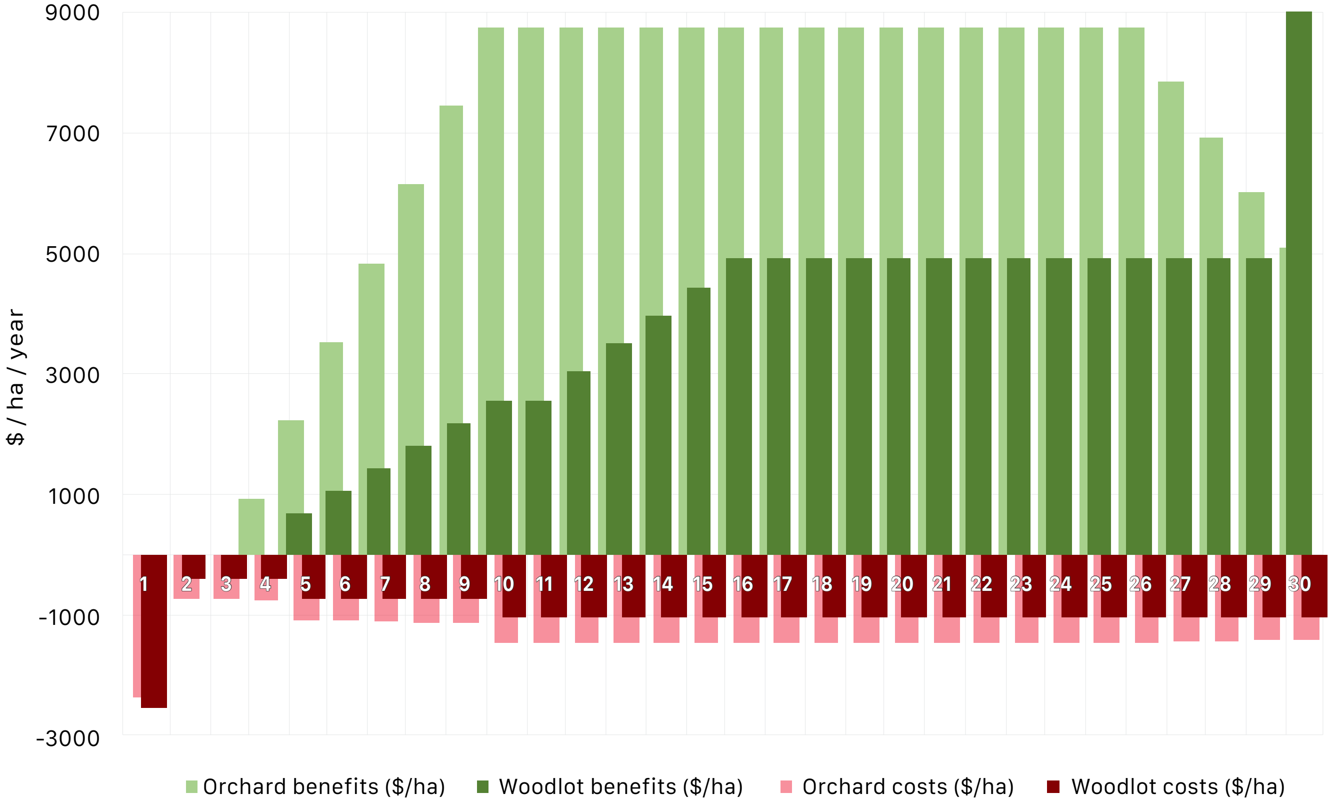
[60] Irrigation costs vary according to the crop under consideration. For example, in Tojikobod, farmers pay TJS 200 per year for cotton, TJS 130 per year for potato, and TJS 190 per year for orchards. They purchase water from the water user association and the water department and pay a flat fee. There is thus no direct link between what the farmer pays and how much he/she uses.

Table A2.9: Implementation, Management, Harvesting, and Opportunity Cost of Woodlot Establishment

Costs	Comment	Value per ha (US$/ha)
Opportunity cost (degraded pasture)	Average biomass productivity of 0.55 ton/ha selling at US$52.3/ton	28.8
Total first year IC (drip irrigation, small excavator, wire, shrub, and seedling cost)		2,491.5
Annual maintenance and NTFP harvesting costs (NTFP harvesting costs, thinning, pruning, and pesticides)	Half that of orchards (Davlatov 2022b), see Table A2.6	363
Woodlot establishment costs, irrigation costs, fencing establishment	Like those of orchards (Kassam, 2022)	See Table A2.6

Source: Original elaboration for this publication.

Figure A2.1: Flow of per Hectare (Non-Discounted) Revenue Streams from Timber, Fuelwood, Fruits, and Nuts Harvests from Woodlots and Orchards



Source: Original elaboration for this publication.
Note: Woodlots are cut for timber at the end of the 30-year rotations, leading to a peak in revenue of US$50,000 in future value terms (beyond what is illustrated on the graph).

Table A2.10: Questions on Woodlots, Asked during Field Visits to Tojikobod in February 2022 to the Head of the Agricultural Department and the Head of the Forest Department

Guiding Question	Response	Source
General impression regarding changes in land productivity over the last 10 years	There is a total of 35,791 ha of pastureland in Tojikobod, but productivity is declining every year.	Head of Agriculture Department
	There is a total of 3,186 ha of crop lands, but productivity is decreasing.	Head of Agriculture Department
What activities are currently undertaken to address land degradation?	Planting of esparset, pasture rotations, and establishment of woodlots and orchards	Head of Agriculture Department and from a farmer
Have there been any initiatives, among private, public authorities within the last 5 years to plant woodlots and orchards?	Yes, the area dedicated to woodlots increases by 2–3 ha per year.	Head of Forest Department
	Yes, the area dedicated to orchards increases by 2–5 ha per year.	Head of Forest Department
If yes, on what kind of land are these found (Private Dekhan farms, public land, and so on)?	Woodlots are typically found on public land. Orchards are found on Dehkan farms.	Head of Forest Department
What is the average size of a typical woodlot?	2–3 ha	Head of Forest Department
What is the average size of a typical orchard?	2–5 ha	Head of Forest Department
Total area dedicated to woodlots in Tojikobod	1,446 ha	Head of Forest Department
Total area dedicated to orchards in Tojikobod	510 ha	Head of Agriculture Department
What are farmers' primary motivations for planting woodlots and orchards, in order of importance?	First, to increase their incomes and livelihoods from marketable produce Second, disaster risk reduction and reduction of landslides, mudflows, and flooding Third, to regenerate soil productivity, (using fertilizer, crop rotations, and so on)	Head of Forest Department and Head of Agriculture Department
What are the preferred species for woodlots?	Total 1,446 ha of woodlots in Tojikobod district	Head of Forest Department
	Starting from 2007, they have woodlots with mixed species including walnut, almond, apricot, acacia, cherry, pistachio, dog rose, and juniper	Head of Forest Department
What is the market value of a timber tree (in TSL/tree and/or TSL/m^3 of timber) 20–30 years after it has been planted?	Every year planted more trees and cost of one tree seedling is TJS 20–30.	Head of Forest Department
What is the average market value of fuelwood?	1 m^3 is TJS 104 and bushes TJS 52 per kg	Head of Forest Department

Table A2.10

Guiding Question	Response	Source
How much fuelwood can be harvested (sustainably) per year from a hectare of woodlot?	30 m^3 x 104 c = TJS 3,120	Head of Forest Department
How much timber (m^3/ha) can sustainably be harvested per year from a hectare of woodlot?	100 m^3 (after 14 years approximately, this is what we have observed in Tojikobod between 2007 to 2022)	Head of Forest Department
What is the average market value of a m^3 of timber?	TJS 3,800 (~US$350)	Head of Forest Department
What is the spacing density of trees within woodlots?	400 trees/ha	Head of Forest Department
What is the average annual maintenance cost for a woodlot?	Half that of orchards, TJS 4,000/ha (for thinning, pruning, pesticides, and harvesting)	Head of Forest Department

Source: Original elaboration for this publication.

A2.6 FULL ECONOMIC COST OF WATER

Since markets for water either typically do not exist or are highly imperfect, it is not simple to find what this value is for different users of water. A broad range of methods have therefore been used to estimate the value of water. To value the benefits of supplying irrigation water, the World Commission on Dams (Aylward et al. 2001) recommends estimating the net value of the resulting increase in crop production by measuring gross benefits in terms of the physical outputs that the project is estimated to produce at the projected price for those products. When combined with cost data on purchased inputs (variable and fixed), the financial net benefits are obtained. Accounting further for the policy distortions to inputs and output prices, the net value increase is obtained. Insufficient data on input costs precluded this approach in this assignment. Moreover, highly subsidized infrastructure and electricity costs needed to supply irrigation water (World Bank 2017b) leads to inefficient use of water and therefore potentially negative net benefits, were these to be accounted for.

In this assessment, the value of water is therefore assessed with respect to its full economic cost. Historically, water has been undervalued in Tajikistan. Undervaluation leads to misuse and misallocation of water. All too often, it is used for purposes that do not maximize well-being and is regulated in ways that do not recognize scarcity or promote conservation.[61] Efficient use of water requires consideration of the full economic cost, which requires an assessment of the use cost of water and the opportunity cost of the resource (Briscoe 1996). The use cost corresponds to the marginal financial cost of supplying the water to the user (that is, costs incurred in financing and running the abstraction, transmission, treatment, and distribution systems), and the opportunity cost reflects the value of water in its best alternative use, in farming, typically the gross benefits forgone by not irrigating a neighboring field. These elements are analyzed below to attach a value to the enhanced water availability (groundwater, soil moisture, and irrigation capabilities) regenerated from the hydrological cycle and improved reservoir storage capacity.

Use Cost of Water

Irrigation water supply and condition of pump stations, irrigation distribution, drainage, and

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[61] https://blogs.worldbank.org/water/standing-value-water.

canal systems are deteriorating in Tajikistan due to environmental factors and insufficient maintenance. High seepage water losses throughout systems due to insufficient structures and inefficient drainage systems are causing land salinization. The replacement and maintenance of deteriorating irrigation and drainage infrastructure is therefore of paramount importance to ensure sustained agricultural production.[62] Moreover, in many cases, the river water level is at a lower elevation as compared to the agricultural land, which makes it necessary for water to be lifted by large pumping stations into main canals. There are also many instances where boreholes are drilled from aquifers deeper than 150 m depth. About 44 percent of irrigated agriculture in Tajikistan is dependent on pump stations to supply agricultural land.[63] In DRS, 15,085 ha rely on pump irrigation (World Bank 2017a). Pump irrigation and the associated electricity use usually absorb an exceptionally large part of the annual O&M budget, for example, 70 percent in Uzbekistan (ADB 2021a). Given this, and the absence of estimates of the financial resources that would be needed to effectively upgrade, run, and keep irrigation infrastructure within the Vakhsh River Basin, we use electricity costs for pumping as a proxy for the use cost of water in irrigation.[64]

Water abstraction costs were around US$0.014 per m^3 (OSCE 2018). However, due to heavy subsidization of water supply services during the Soviet era heritage, electricity tariffs, especially in agriculture, have been kept artificially low[65] (SIWI 2016). According to the World Bank (2017b), subsidies were estimated to cover up to 70 percent of the energy costs in 2015. The economic cost of water abstraction from pump stations for irrigated agriculture is therefore significantly higher than what farmers pay. This has been incorporated in the estimates of the use costs in Table A2.11, yielding an economic use cost of irrigation of US$0.05 per m^3.

It should also be mentioned that Tajikistan has enacted, recently, a new tariff policy to ensure better services of the water supply systems. According to Asia Plus (2022), the new water tariff for urban water supply and sewage (which covers user costs) is around US$0.45/m^3. It is included for comparison, in Table A2.11, as another proxy-indicator for the use cost of freshwater resources in urban settings.

Table A2.11: Economic Cost of Water in Tajikistan

Use Cost of Irrigation Water	Unit	Value
Use cost of urban freshwater supply (for reference)	US$/m^3	0.45
Water abstraction use cost - subsidized (covering 70% of the true electricity cost)	US$/m^3	0.014
Water abstraction use cost - unsubsidized	**US$/m^3**	**0.048**

Source: Original elaboration for this publication.

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[62] https://alri.tj/storage/aUWGqCvpM4o6af6uSo2b.pdf.

[63] In areas of eastern Tajikistan, for instance, pumps supply 21 percent of the land, while northern areas rely up to 85 percent on pumped irrigation (Xenarios, Laldjebaev, and Shenhavet 2021).

[64] While this may be an overestimate of the use cost for irrigation systems that rely on gravitation, overall, this is counteracted as we have not been able to incorporate replacement, repair, and damage costs of infrastructure in the use cost.

[65] As a result, water conservation and willingness to pay full-cost recovery tariffs have not institutionalized.

Opportunity Cost of Water Used for Irrigation

While financial sustainability of irrigation systems is important for O&M reasons, from the point of view of managing water as an economic resource, the key challenge is to ensure that users consider the opportunity costs of water. Opportunity costs vary considerably depending on 'alternative uses' that come into play. In irrigation systems, a typical situation is one in which users are charged a small, subsidized amount for the 'use cost' (as in Tajikistan), and the opportunity cost is essentially that of the opportunities which the farmer forgoes on another (unirrigated) field.

To approximate the value of the forgone output on 'another' field, we estimate the average value of water as an input into agricultural production, by considering average irrigation volumes per hectare, water productivity for wheat in the Vakhsh River Basin, water efficiency, and the market price for wheat. According to World Bank (2017a), the average annual abstraction for irrigation in Tajikistan is over 15,000 m^3 per ha. But water appropriation to croplands is seriously affected by irrigation water losses. Only an estimated 30–35 percent of the water that is initially lifted is delivered to croplands in Tajikistan, due to decaying irrigation infrastructures (Xenarios, Laldjebaev, and Shenhavet 2021). In the Vakhsh catchment, water productivity of wheat is 0.35 kg wheat/m^3 of water, calculated from water consumption at the farm level and average crop yields per region (ADB 2013). For fully irrigated wheat (unconstrained by water) and with sufficient other inputs, water productivity should be in the order of 0.8–1.0 kg/m^3 based on potential yield of 4 t/ha and annual water demand of 4,000 m^3/ha. The reasons for the low level of water are multiple, including limited access to farm inputs and degraded soils (ADB 2013; World Bank 2020a).

Consequently, we estimate the value of water as an agricultural input, according to Equations 4, 5, and 6 and assume that this is the benefit that farmers forgo by irrigating one field over another.

$$\text{Added wheat yield} = V\ (15{,}000\ m^3/ha) \times E\ (35\%) \times WP\ (0.35\ kg/ha) = 1{,}838\ kg/ha \quad \text{(eq 4)}$$

$$\text{Revenue} = P \times \text{added yield}\ (1{,}838\ kg/ha) = US\$739.06/ha \quad \text{(eq 5)}$$

$$\text{Gross benefit from 1 } m^3 \text{ of water} = \text{Revenue}/V = US\$0.05/m^3 \quad \text{(eq 6)}$$

Table A2.12: Assessment of the Value of Water - Assumptions and Results

	Parameter	Unit	Value
A	Yield of wheat (for a typical irrigation volume V)	kg/ha	1837.5
V	Irrigation volume per hectare	m^3/ha	15,000
P	Average price of wheat grain in Tajikistan[a]	US$/kg	0.402
WP	Water productivity in Vakhsh, for wheat	kg/m^3	0.35
E	Water efficiency	%	35
Revenue	Revenue per ha of additional wheat	US$/ha	739.1
OC	Gross benefit/opportunity cost of irrigation	US$/$m^3$	0.05
	Full economic cost of water (use cost + opportunity cost)	**US$/$m^3$**	**0.1**

Source: Original elaboration for this publication.
Note: a. From World Bank (2020a).

According to these estimates, by irrigating one field over another, the farmer forgoes US$0.05 worth of output for every 1 m^3 of irrigation water used. If it would be possible to transfer the water among a wider universe of potential users of that water (which will usually include other farmers, and may include neighboring towns and industries), then the 'opportunity cost' would be greater still, since it is the value placed by the highest alternative use that defines the opportunity cost.

Combining the use value and the opportunity cost of irrigation water yields an economic cost of US$0.1/$m^3$ of irrigation water, a price which would ensure that users consider the full economic cost of water when using it.[66] This value is used in the study to assess the value of enhanced groundwater and soil moisture, lateral return flow, and runoff, contributing to reservoir replenishment.

The case for full-cost pricing in Tajikistan

While Tajikistan is rich in water resources, only 51.4 percent of the country's population have access to clean water. This is attributable to poor infrastructure (Circle of Blue 2020). It should also be noted that preservation of ecosystems in the basin depends on improving the efficiency of water use in irrigation systems. That can only come about with adequate pricing. At present, substantial amounts of water are lost in depressions at the ends of irrigated areas; such water could possibly be transferred for recharge of previously vibrant environmental assets and ecosystems, particularly the Aral Sea. Wastage and excessive irrigation also lead to soil salination. If full-cost pricing for irrigation water was implemented, this would be prevented. An orchard farmer in Tojikobod pays a flat fee for irrigation of US$17 per ha owned. Using an average 8,000 m^3 of water on an orchard (Davlatov 2022b), the implicit volumetric price is US$0.002 per m^3, significantly lower than the full economic cost of water.

A2.7 ADDITIONAL DETAILS ON COST COMPONENTS OF DREDGING

The costs of dredging equipment and associated labor include mobilizing and demobilizing the equipment to the site and running and keeping it for the work. Pipelines and booster pumps would go with hydraulic dredging work, one or more support scows would go with in-water mechanical dredging, and several types of earthmoving equipment would be needed for any work done over exposed land area.

The costs associated with site usage include achieving access for the dredging equipment. In confined or high-relief settings (such as reservoirs in narrow canyons), equipment access may require the construction of new infrastructure to ease the work. If reservoir sediments are not delivered to the downstream river channel, costs are associated with managing, stockpiling, transporting, disposing, and/or reusing the dredged material. This may include the application of dewatering or screening methods to make the dredged material better suited to its final placement or use. In some cases, a significant amount of land space may be needed for the management or placement of the dredged material, which could involve negotiated land leases or purchase costs.

The costs associated with implementing needed and proper protocols for safety and environmental protection include any permit requirements. The costs associated with quality control and assurance include owner oversight and surveys (Western Dredging Association 2021, 42).

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[66] Interestingly, the same estimate was quoted by a sediment management specialist, Dr. Detering (with 27 years of experience). When attempting to infer a value of reservoir storage, he said: "US$0.10/$m^3$ is my best guess on typical water value for irrigation in these climate conditions." (D-Sediment 2022).

A2.8 ADDITIONAL DETAILS OF SEDIMENT REDUCTION VALUATION

Water Storage Infrastructure Is Critical for Development

Large dams and reservoirs supply hydroelectricity and contribute to flood control, irrigation, and drinking water and often perform multiple functions simultaneously (Perera, Williams, and Smakhtin 2023). Reservoir sedimentation is a significant contributor to the decline in performance of reservoirs (Annandale, Morris, and Karki 2016), affecting the safety of dams and reducing energy production, storage, discharge capacity for irrigation, and flood attenuation capabilities (Shellenberg et al., 2017). Moreover, abrasive sediments can damage turbines and other dam components and mechanisms, decreasing their efficiency and increasing maintenance costs (Sangal, Singhal, and Saini 2018). Reservoirs therefore can be seen as assets that supply a variety of market and nonmarket benefits, for multiple years. Sediment that settles in a reservoir this year will reduce benefits in later years. As a result, the benefit from reduced erosion can be assessed in terms of the benefits of the increase in the quality and availability of reservoirs services (Hansen and Hellerstein 2007).

As with any economic valuation assessment, the services that are valued should be a function of what matters in the local and national context, as well as resources and data that are available. As noted by the World Commission on Dams (Aylward et al. 2001) in their review on best practice and the performance of benefit valuation of large dams, "flood control, navigation, fisheries and recreation benefits are rarely valued in dam appraisals, where these uses are secondary benefits." Aylward et al. (2001) also note that "formal appraisals prepared by multilateral agencies rarely use a systematic approach to the valuation of environmental and social impacts of large dam projects. Oftentimes the limiting factor is information on how ecosystem function changes when a dam is built," or as sedimentation progresses.

That said, when extensive data for modeling reservoir benefits is lacking, the replacement cost approach can be used as an indirect method of benefit estimation. The replacement cost theory is built on the assumption that the willingness to pay for an improvement in environmental quality is greater than, or equal to, 'replacement costs' made to offset environmental damages (Lew et al. 2011) Because dredging recovers losses in reservoir services, dredging expenditures can be viewed as replacement costs—this approach, with a different extension, has been used in Lee and Guntermann (1976) and later by Clark, Haverkamp, and Chapman (1986) and Hansen and Hellerstein (2007).

The avoided dredging cost approach is also used in this study—in addition to more conservative approaches—to appreciate the cost of sedimentation from different societal angles, and since Tajikistan is unlikely to dredge Nurek or Rogun (Kochnakyan 2022). The valuation approaches that are used in this study therefore include:

(a) Enhanced reservoir storage for irrigation,

(b) Avoided reservoir rehabilitation costs, and

(c) Avoided dredging costs, that is, using the replacement cost method, assuming sediment is dredged in the same year as it was deposited, to reflect the immediate benefits of reduced sedimentation.[67]

The justification and limitations of each of these approaches are supplied below.

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[67] Moreover, it is not known if and when dredging would be undertaken by dam operators in Tajikistan.

The Value of Enhanced Reservoir Storage for Irrigation

The benefits of supplying water for irrigation can be estimated in terms of the net value of the resulting increase in crop production, or with reference to the full economic cost of providing that water for irrigation as done and argued for in the preceding section. As highlighted by the WCD (2000) however, the valuation of irrigation benefits remains a difficult endeavor due to the complexity of correctly estimating the respective contribution of irrigation water to augmenting productivity, due to the difficulties of accurately projecting hectares that will be brought under irrigation, crop choice and crop yield. Most agencies, therefore, do not prescribe specific methods for irrigation benefit valuation but rather supply guides and handbooks to supplement agricultural economic texts that describe available methods (Young 1996).

The Value of Avoided Reservoir Restoration Costs

The value of reservoir storage, which is used for productive services such as irrigation or hydropower production, may be considered as an incomplete assessment of the true benefits of reduced erosion. As highlighted above, reduced erosion improves dam safety, flood protection, and multiple other services. According to Dr. Detering (D-Sediment 2022), it is therefore common within the sediment management industry to use reservoir restoration cost—the cost of replacing the storage that has been lost by the construction of new infrastructure—as a proxy for the benefit of reducing sedimentation. This is done by estimating the original reservoir construction cost and inflating it into present value terms (D-Sediment 2022). Alternatively, one may use the new-build estimates of costs for storage capacity. For a nominal active capacity of 10 km^3, recent estimates suggest that the construction cost of Rogun powerplant is in the order of US$5 billion (Asia Plus 2022). This leads to a specific storage cost of only US$0.5 per m^3, which has been used as a proxy for the avoided reservoir restoration cost in this study.[68] The same approach was also adopted in Jordan, to assess the benefits of reduced erosion from sustainable pasture management (Myint and Westerberg 2015).

The avoided reservoir rehabilitation costs approach however has its limitation in that, in most cases, 'other effects' and the true costs of sedimentation are not accounted for in the construction design and associated financial feasibility assessment (Randle and Boyd 2018). Sedimentation, for example, affects the safety and flood attenuation capabilities. As sedimentation progresses, the reservoir becomes a delta-filled valley that takes a meandering course such that a flood wave does not spread out to allow flood routing.[69] Sediments will often block low-level outlets designed to allow for reservoir drawdown. As sedimentation continues, clogging of spillway tunnels or other conduits reduces spillway capacity, as seen in Nurek (AIIB 2017). The two outer dam gates of Nurek were already inoperable, in 2014, due to sedimentation (D-Sediment 2014).

Sediment has other environmental impacts, such as CH_4 emissions from anoxic sediments, upstream aggradation, and downstream degradation. Moreover, turbine equipment is damaged through erosion of the oxide coating on the blades, leading to surface irregularities and more serious material damage. Sustained erosion can lead to extended shutdown time for maintenance or replacement. Recent studies have highlighted the synergic

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[68] In comparison with Europe and West Asia, reservoir construction estimates are seen in the range between EUR 2 and 6 per m^3 (Westerberg and Myint 2015; D-Sediment 2022).

[69] https://www.hydroreview.com/world-regions/dealing-with-sediment-effects-on-dams-and-hydropower-generation/#gref

effect of cavitation erosion and sediment erosion, showing that the combined effect of cavitation and sand erosion is stronger than the individual effects (Thapa, Dahlhaug, and Thapa 2015). There is thus a significant range of present and future costs and risks associated with unabated sediment accumulation, whether for Nurek or Rogun under construction.

For this reason, it may be equally justified to consider the benefit of reduced sedimentation with respect to the avoided dredging (or sediment transfer) costs, which embeds a wider range of benefits from reducing sedimentation, as argued below.

Avoided Dredging Costs

The direct and indirect benefits (more balanced reservoir operation, reduced flood risk, reduced damage to equipment, and minimized environmental harm) of reduced sedimentation, justify expenditures on dredging and active sediment management of reservoirs (Hansen and Hellerstein 2007). Consequently, the benefit of reduced erosion on hydropower dams in the Vakhsh catchment is also estimated in terms of averted dredging costs.[70]

Estimates of Continuous Sediment Transfer and Dredging Costs

Unfortunately, active sediment and reservoir management is part of standard practice worldwide,[71] at least not until a reservoir fills with sediment and becomes a liability to owners or downstream residents. Evidence suggests that, in most cases, sedimentation consequences beyond the 50 to 100 years 'design life' of the reservoir has been ignored in best practice engineering (Morris 2020; Perera et al., 2023), and this appears to be case for Nurek as well.

Dredging refers to the excavation of material from beneath the water. There are broadly two types of dredging: mechanical-lift dredging removes sediment by buckets such as a backhoe, clamshell, dragline, or bucket ladder, placing the excavated material into a barge or truck for transport and hydraulic dredging mixes sediment with water for transport in a slurry pipeline, reintroducing the sediment back to the river below the dam, or discharging to a containment area for dewatering. A critical limitation to dredging is its high cost. This cost is reduced by discharging to the river below the dam instead of upland disposal sites, for example, using continuous sediment transfer (Detering 2014, 2018). This allows for restoring sediment transport along the fluvial system, through the reintroduction of sediment into the river below the dam. This strategy implies essentially continuous sediment transfer as opposed to large dredging campaigns at intervals of decades (Morris 2020).

Key cost drivers of dredging are shown above. To obtain a range of estimates for potential dredging costs for Nurek and Rogun, we have drawn on personal interviews and (scant) literature. Dredging costs from East Asia are in the order of US\$4.67 per m^3 based on seven inland river dredging projects each removing over 1 million m^3 of sediment in India (Indian Infrastructure 2019) and US\$3.46 per m^3 in Bangladesh (Dhaka Tribune 2020). In the United States, the most typical dredging price over the last decade has been in the range of US\$3.5–5.8 per m^3 for hydraulic

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[70] Flushing is not an option for Nurek, nor for Rogun (TEAS 2014). In the case of Nurek, the effect is limited to a tiny section of the reservoir directly in front of the dam (D-Sediment 2014). Other sediments will remain in place, and flushing will come with a loss of valuable water. Dredging and sediment reuse or continuous sediment transfer could therefore offer promising options for managing sediment, in combination with the reduction of sediment from catchment—as a source of green infrastructure—the first best option for sediment management (Randle and Boyd 2018).

[71] As noted in Morris (2020) sediment inflows worldwide have been designed on the basis of the "life of reservoir" paradigm, whereby sediment inflows have been calculated using a 50 to 100-year planning horizon and the corresponding sediment storage volume allocated in the storage pool. No consideration was given to sedimentation consequences beyond this planning horizon. Reservoir design and operation without a long-term sediment management strategy management strategy is not a sustainable approach, and no longer represents an engineering best-practice.

dredging into a nearby confined placement site. Higher-priced exceptions apply to projects where access was particularly difficult or the containment area required a significantly higher amount of preparation (Western Dredging Association 2021, 44). Discussion with Royal IHC IDH suggests dredging costs to be in the order of US$1–4 per m^3, with the most important parameters affecting being the type of material, dredging depth, and pumping distance (World Bank communications, 2022). Moreover, as mentioned above, costs are expected to be lower if reservoir sediments are delivered to the downstream channel and more natural sediment transport conditions are restored to the environment (Western Dredging Association 2021).

A continuous sediment transfer could potentially come with a lower cost and higher environmental compliance than conventional dredging, due to significantly smaller dimensions and a 24/7 operation. In the case of Nurek, very roughly, D-Sediment estimates the implementation of a continuous sediment transfer possibility for Nurek to be in the order of approximately US$2 per m^3 transferred (D-Sediment 2022). Water as well as power needs for continuous sediment transfer would be compensated by keeping reservoir storage capacity and therefore avoided power losses and water losses. In the light of this data, a conservative sediment removal cost of US$3 per m^3 is used to infer the value of reducing erosion through landscape restoration.

ANNEX 3. STAKEHOLDER CONSULTATIONS

The following list of stakeholders helped with data acquisition and made this study possible.

- First Deputy Prime Minister, Government of the Republic of Tajikistan
- Deputy Prime Minister, Government of the Republic of Tajikistan
- Assistant to the President on Economic Issues, Executive Office of the President of the Republic of Tajikistan
- Head of International Relations Department, Executive Office of the President of the Republic of Tajikistan
- Minister, Ministry of Foreign Affairs of the Republic of Tajikistan
- Minister, Ministry of Finance of the Republic of Tajikistan
- Ministry of Transport of the Republic of Tajikistan
- Minister, Ministry of Energy and Water Resources of the Republic of Tajikistan
- Minister, Ministry of Economic Development and Trade of the Republic of Tajikistan
- Minister, Ministry of Agriculture of the Republic of Tajikistan
- Deputy Minister, Ministry of Energy and Water Resources of the Republic of Tajikistan
- Chairman, Committee for Environmental Protection under the Government of the Republic of Tajikistan
- Director, Agency for Statistics under the President of the Republic of Tajikistan
- Director, Agency of Land Reclamation and Irrigation under the Government of the Republic of Tajikistan
- Chairman, Committee of Emergency Situations and Civil Defense of the Republic of Tajikistan
- Chairman, Committee for Land Management and Geodesy of the Republic of Tajikistan
- Agency of Forestry under the Government of the Republic of Tajikistan
- Agency for Hydrometeorology under the Committee for Environmental Protection under the Government of the Republic of Tajikistan
- Director, Agency for Hydrometeorology under the Committee for Environmental Protection under the Government of the Republic of Tajikistan
- Chairman, Committee for Tourism Development under the Government of the Republic of Tajikistan
- Head of the Main Department of Geology under the Government of Republic of Tajikistan
- President, Academy of Sciences under the Government of the Republic of Tajikistan
- Director, Institute of Geology, Earthquake Engineering and Seismology under the Academy of Sciences of the Republic of Tajikistan
- Chairman, OSHC ‘Barki Tojik’
- Deputy Chairman, OSHC ‘Barki Tojik’.

The following stakeholders were directly consulted to support the provision of data for the CBA. The detailed report for the Tojikobod field visit is provided in a separate document.

Table A3.1: List of Stakeholders Consulted During Field Visit

Function	Interviewed When
Head of Committee, Emergency Situation and Civil Protection	During field visit to Tojikobod in February 2022 and later follow-up calls
Head of Forest Department	
Head of Water Department	
Head of Agriculture Department	
Head of local market, Tojikobod	
Farmer	
Consultant for IFAD Livestock and Pasture Development Projects I and II,	Phone calls and email, March 2022
Caritas Switzerland Country Director for Tajikistan	Phone calls and email exchanges
Natural Resource Management Specialist. Consultant for the project	Throughout the study process in 2022

Source: Original elaboration for this publication.

Valuing Green Infrastructure: A Case Study of the Vakhsh River Basin, Tajikistan

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