Climate Adaptation in Uzbekistan: Landscape Restoration Opportunities

April 2024

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MINISTRY OF ECOLOGY, ENVIRONMENTAL PROTECTION AND CLIMATE CHANGE OF THE REPUBLIC OF UZBEKISTAN

MINISTRY OF ECONOMY AND FINANCE OF THE REPUBLIC OF UZBEKISTAN

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Acknowledgments

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[1] ICARDA = International Center for Agricultural Research in the Dry Areas.

[2] FAO = Food and Agriculture Organization of the United Nations.

Acronyms

BAU	Business-as-Usual
BCR	Benefit-Cost Ratio
CA	Conservation Agriculture
CCDR	Country Climate and Development Report
CMIP	Coupled Model Inter-comparison Projects
CN	Curve Number
DRIHVW	Director Research Institute of Horticulture, Viniculture and Wine-marking
DRM	Disaster Risk Management
DSIVCMP	Director Scientific Research Institute of Vegetables Crops, Melons and Potatoes
EGED	Effective Governance for Economic Development
ESA	European Space Agency
FAO	Food and Agriculture Organization (of the United Nations)
FOLU	Forestry and Other Land Use
FRA	Forest Resources Assessment
FS	Factor of Safety
GCM	General Circulation Model
GDP	Gross Domestic Product
GEF	Global Environment Facility
GPP	Gross Primary Productivity
GPR	Gaussian Process Regression
GSL	Growing Season Length
ICARDA	International Center for Agricultural Research in the Dry Areas
LDN	Land Degradation Neutrality
LLL	Laser Land Leveling
LULC	Land Use Land Cover
MODIS	Moderate Resolution Imaging Spectroradiometer
MoEF	Ministry of Economy and Finance of the Republic of Uzbekistan
MR	Maintenance Respiration
MRB	Mechanized Raised Bed
NASA	National Aeronautics and Space Administration
NBS	Nature-Based Solutions
NDC	Nationally Determined Contribution
ND-GAIN	Notre Dame Global Adaptation Initiative
NGO	Non-Governmental Organization
NPP	Net Primary Productivity
NTFP	Non-Timber Forest Product
PA	Protected Area
PES	Payments for Ecosystems Services
PM	Particulate Matter
PPP	Public-Private Partnership
PSN	Net Photosynthesis
R&D	Research and Development
RESILAND	Resilient Landscape Restoration Project
RIOS	Resource Investment Optimization System
RUSLE1	Revised Universal Soil Loss Equation
SD	Standard Deviation
SDR	Sediment Delivery Ratio
SPEI	Standardized Precipitation Evapotranspiration
SSP	Shared Socioeconomic Pathways
SWY	Seasonal Water Yield
TNC	The Nature Conservancy
UN	United Nations
UNEP	United Nations Environment Programme
USDA	United States Department of Agriculture
WBCCKP	World Bank Climate Change Knowledge Portal
WBIC	Weather-Based Irrigation
WUA	Water User Associations
WWF	World Wildlife Fund

Units

ha	Hectare
$ktCO_2e$	Thousand Tons of Carbon Dioxide Equivalent
MtC	Metric Ton of Carbon
US$	United States Dollar

Abstract

This report highlights the challenges affecting Uzbekistan's landscapes due to climate change, population growth, and increasing land use pressures and suggests efficient ways to restore landscapes. Using multifaceted models for ecosystem services under the changing climate, the study identifies future land degradation hotspots and opportunities for adaptation and landscape restoration in Uzbekistan. Investment in an integrated technological suite in these future hotspots is financially viable, proven by cost-benefit analysis at the province level for national and province-level optimized portfolios. The analysis shows that Uzbekistan is facing challenges to its natural capital use in agriculture, water, and forestry. By addressing these issues and optimizing the hotspots with the highest ecosystem restoration potential, Uzbekistan can gain substantial economic benefits for its development goals. The report concludes by identifying existing gaps and relevant policy recommendations. It represents a key step in addressing adaptation issues in land use sectors and serves to aid policy makers in addressing resilient landscape restoration.

Executive Summary

Land use plays a pivotal role in Uzbekistan's development, and embracing sustainable agriculture offers a promising pathway to achieving middle-income status. Agriculture accounts for 27 percent of total employment and 18 percent of gross domestic product (GDP) in Uzbekistan. Sustainable land use is, therefore, crucial, as land degradation harms crop yields and reduces the value added of the agriculture sector. With land restoration as an enabler, Uzbekistan can pursue opportunities in sustainable agriculture as a pathway for achieving middle-income status.

This report aims to identify hotspots of land degradation and declining productivity along with areas of adaptation opportunity where landscape restoration can offset these trends under changing climate conditions. It also analyzes the costs of land degradation (cost of inaction) compared to investing in adaptation technologies (cost of action). The report recommends technological, institutional, and policy options to reduce natural capital degradation in the agriculture, forest, and water sectors.

The analytical work focused on filling knowledge gaps on Uzbekistan's current and projected climate outlook, differentiated vulnerabilities, and interactions between climate-induced environmental hazards. It shed light on the exposure of critical infrastructure and key productive assets to climate change impacts, as well as on the combined effects of climate change, land degradation, and natural resource depletion, and the potential role of climate change as a risk multiplier. The analysis also examined how climate change poses threats to key sectors in Uzbekistan, including agriculture, livestock, fisheries, environment, ecosystems, health, forestry, energy, infrastructure, human settlements, and water resource management. By building this evidence base, the study aims to facilitate consensus building with national and international stakeholders and make the case for scaled-up investment in adaptation and landscape restoration efforts.

This report utilizes the Land Degradation Neutrality (LDN) of the United Nations (UN) to study land degradation as a cascade of processes, including drivers, degradation processes, and ecosystem services. It considers climate change effects, remote sensing data, ecosystem services modeling, and population growth projections. An adaptation scenario reveals potential positive impacts of landscape restoration technologies, identifying areas where these technologies can most effectively combat degradation trends.

Land Degradation Risk Hotspots in Uzbekistan

Hotspots of land degradation are areas where degradation of natural capital, especially water, agriculture, and forests, is exacerbated by chronic impacts of climate change and natural hazards, as well as growing population pressures in Uzbekistan. Degradation hotspots stem from climate change, natural hazards, and rising population pressure, which are worsening water, agriculture, and forest capital depletion in Uzbekistan.

The study's analysis reveals a constant decline in vegetation productivity in at least one-third of agricultural landscapes in Uzbekistan over the last 20 years. Out of the total land area of 44.9 million ha in Uzbekistan, around 13.7 million hectares (ha) (30 percent) is severely degraded. Out of the 13.7 million ha of severely degraded land, about 7.1 million ha (52 percent) is in the natural pasturelands, while around 5.6 million ha (41 percent) is in lands that are not used for agriculture, pastures, or forest. Five areas show a significant reduction in vegetation productivity: Ferghana Valley, Gulistan-Jizzakh corridor, north of Nukus, north Namangan, and around Tashkent. The causes of these hotspots vary, with intensive cropland hotspots attributed to water stress and soil degradation, while western areas may be affected by water access limitations, desertification, and dust storms.

Sectoral Climate and Land Degradation Impact

Climate change has significant adverse effects on ecosystem services, livelihoods, and biodiversity. It intensifies soil, water, biodiversity, and carbon emissions risks, affecting local economies, agriculture, biodiversity, and livelihoods. Soil erosion damages infrastructure, especially in rural areas dependent on agriculture. Uzbekistan's forest coverage is low, accounting for 8.6 percent of the country's land area. Degradation over the past 30 years is attributed to uncontrolled animal husbandry, increased wood demand, irrigated agriculture, and changing climate conditions and wildfires.

Climate change is expected to increase infrastructure damage in Uzbekistan by the middle of the century, particularly with recurring 20–25-year floods (damage increasing between 50 and 150 percent). In the interim (2031–2050), infrastructure damage is expected to rise due to floods and temperature risks. Labor supply will be adversely affected by increasing extreme heat and cold; this is even more serious for the agriculture sector, which requires outdoor labor.

The Cost of Inaction on Land Degradation

Loss of ecosystem services due to inaction on land degradation adversely affects Uzbekistan's GDP. The study results show that the total value of ecosystem services lost in Uzbekistan's priority hot spot of degradation areas due to inaction on land degradation is estimated to be at least US$2.8 billion per year, which is equivalent to 4.6 percent of GDP or about US$15 billion for a 10-year period. The losses are concentrated in losses of crops and water.

The loss in crop production on existing and abandoned agricultural lands is associated with an estimated monetary loss of US$1.1 billion, equivalent to 1.8 percent of GDP. Annually, consumptive, non-consumptive, indirect, and nonuse values constitute 1.62 percent, 0.03 percent, 0.03 percent, and 0.12 percent, respectively. In relative terms, the top three provinces suffering the highest crop loss per unit crop area are Khorezm, Karakalpakstan, and Jizzakh.

For pasturelands, this loss level has a total value of US$93 million (0.15 percent of GDP). The largest loss occurs in Navoiy, Karakalpakstan, and Samarkand, where the first two are among the provinces with the largest pasturelands. In relative terms, however, Samarkand, Tashkent, and Syrdarya are, in descending order, experiencing the highest yield losses per unit area.

Inaction or inadequate action in forests has led to a loss of US$2.2 million (0.016 percent of GDP). Total forest/shrub biomass has suffered 63,868 tons of loss annually, which is associated with a total value of US$2.2 million (0.016 percent of GDP). In relative terms, however, the most loss per unit area occurred in Khorezm, Bukhara, and Karakalpakstan.

A conservative estimate of 1.79 percent of GDP is lost due to expenditure on irrigated water loss. The amount of water lost (that is, the annual amount of water that will not be available for immediate use from surface water and groundwater sources) due to inaction in priority intervention areas is estimated to be 3.56 billion m3, which is 39 percent of the total supply in said areas.

This report suggests how to prioritize sustainable landscape interventions and focus on the hotspots of adaptation opportunity with the highest return in terms of ecosystem services produced under the changing climate and with the highest population growth trend. Even though the cost of inaction is high, reversing the degradation trend and achieving resilient landscape restoration in all areas with severe land degradation (13 million ha) it is not economically feasible or technically possible. However, over the next 10 years, it is possible to prioritize and focus landscape restoration interventions in the country's adaptation opportunity hotspots of degraded lands (1.6 million ha).

Future Hotspots of Adaptation Opportunity

Hotspots of adaptation opportunity are identified in the areas where implementing integrated adaptive and climate-smart technologies can show the greatest improvement in ecosystem services and agriculture productivity combined. Hotspots are identified in the areas with the greatest potential to offset ongoing trends in land degradation, as it is critical to prioritize using limited resources. The report identifies several farm-level technologies for the management of crop production, pastures, forestlands, water, and landslides/floods. These technologies should be used in an integrated way to maximize benefits while accounting for local conditions.

While investing in adaptation and integrated landscape restoration benefits the entire country, the highest opportunity areas are in the east. These are predominantly located in Tashkent, Surkhandarya, Kashkadarya, Samarkand, Jizzakh, and Syrdarya. In Uzbekistan's southwest, more minor but significant potential is identified in highly degraded Khorezm, Karakalpakstan, and Bukhara.

Technologies to reverse land degradation and increase the resilience of landscapes. To reverse degradation, several integrated land and water-saving technologies could be applied. The report recommends an integrated suite of technological, institutional, and policy interventions to reduce land degradation and enhance ecosystem services in croplands, grazing lands, and forestlands. These technologies should be implemented at the farm level to protect against floods and landslides, help achieve food security and cost recovery, and avoid irreversible land conditions.

Benefits of Action: An Analysis of Two Portfolios

To identify land restoration opportunities, this study's analysis focuses on two distinct portfolios for investments: the nationally optimized portfolio and the province-optimized portfolio. Opportunity scores are assigned to districts to estimate benefits based on improvements from baseline conditions. These scores are based on biophysical models that evaluate ecosystem services within productive landscapes, such as erosion control and agricultural productivity. Two investment portfolios are developed, each covering 1.6 million ha and maintaining consistent biome/technological distribution. The nationally optimized portfolio selects investments for maximum ecosystem benefits without considering regional equity of benefits while the province-optimized portfolio accounts for equity of benefits by allocating a minimum of investments per province before further prioritization.

The criterion considered by the optimization tool during the portfolio formulation process is the potential return in ecosystem services that each land parcel of agricultural landscapes in Uzbekistan could offer. The potential return is calculated as the difference between the offer of ecosystem services in the Business-as-Usual (BAU) - Inaction scenario and the offer if the technology packages of sustainable production are implemented (Sustainable - Counterfactual scenario of adaptation). Both scenarios consider changing climate. Areas where these differences are larger reflect a greater potential benefit and are selected by the algorithm until their total area reaches 1.6 million ha, representing about 20 percent of the severely degraded productive lands. The ecosystem services that are evaluated in every area or pixel within the productive landscapes correspond to (a) erosion control, (b) sediment retention by vegetation, (c) runoff reduction, (d) baseflow enhancement, and (e) landslide risk mitigation. Agricultural productivity and rural population density are also included to reflect future potential for agriculture and emerging socioeconomic opportunities.

In 2030, the expected carbon stock (the sum of all above- and below-ground carbon in each province) for the BAU - Inaction scenario is estimated at 92.8 million MtC. An improvement in carbon sequestration in the hot spot of opportunities (1.6 million ha) from the BAU to the integrated landscape restoration scenario shows the carbon stock increase from 40 percent to 100 percent by 2030 (up to 4.7–6.7 million MtC for each portfolio).

The total value of all the benefits of action to control land degradation in the hot spot areas is estimated at US$8.86 billion (for the province-optimized portfolio) and US$10.66 billion (for the nationally optimized portfolio) over 10 years. This is US$1.5–1.8 billion annually or 2.42–2.91 percent of GDP. Sustainable land management and adaptation technologies can significantly reduce and potentially reverse land degradation, reducing the loss of ecosystem services and generating additional ecosystem services. The province-optimized scenario has the greatest benefits from croplands and water, with Karakalpakstan, Khorezm, and Kashkadarya being the top three provinces. The nationally optimized portfolio focuses on more productive croplands in the east of Uzbekistan, with the greatest benefits from croplands and water.

Cost of action. Investment needs for the adaptation opportunity hotspots (1.6 million ha) are estimated at US$489–560 million. Those investment needs are US$560 million (US$340 per ha) for the province-optimized portfolio to implement the recommended technological, institutional, and policy changes, which is 0.8 percent of GDP in 2021. For the national optimized portfolio, the investment needs for the adaptation opportunity hotspots are estimated at about US$489 million (US$304 per ha), which is 0.7 percent of GDP in 2021. Technologies in cropland and water sectors account for a large share of this investment requirement, averaging 48 percent and 45 percent, respectively, while forests and natural pastures follow with 3 percent and 4 percent, respectively. The benefits of the investment are higher in croplands and water sectors, followed by forests and pasturelands. These effects highlight the developmental potential that land restoration can have for Uzbekistan, indicating a pathway for meeting the country's development goals in achieving middle-income status.

The returns of the adaptation investments identified in this report are high, at a benefit-cost ratio (BCR) of between 19 (nationally optimized portfolio) and 15.8 (province-optimized portfolio). Although the economic analysis justifies investments in the first portfolio, the political economy of Uzbekistan and addressing the equitable distribution of adaptation benefits between different provinces make the province-optimized portfolio relevant for the government. This second portfolio also justifies the government's objective to improve the resilience of the most vulnerable bottom 40 percent of the population residing outside of the more developed eastern part of Uzbekistan.

Alternatively, the nationally optimized portfolio allows for achieving 30 percent more carbon stock than the province-optimized one. Weighing different objectives—building on synergies—and the feasibility of each policy decision will guide the selection of priority resilient landscape restoration investments in Uzbekistan. The interventions and policy recommendations indicated in this report are attractive for financing, even in terms of loans, and could make private investments in resilient landscape restoration more attractive if the enabling environment is in place. Concerted efforts will be required to maximize returns on investments. Consequently, the Government of Uzbekistan, its national and international development partners, civil society, and citizens should join forces to raise awareness about the benefits of resilient landscape restoration to prevent further degradation where restoration benefits are the highest, and take mitigative measures to improve socioeconomic outcomes and meet Uzbekistan's development goals.

Policy Recommendations

To capitalize on these benefits, Uzbekistan will have to address different barriers: (a) institutional and policy barriers, (b) financial barriers and a lack of prioritization for investments, and (c) technological barriers. The identified barriers and corresponding policy recommendations are summarized in Table 1.

Table 1. Barriers to adoption of landscape restoration technologies and policy recommendations.

Overcoming institutional and policy barriers	Options for overcoming institutional and policy barriers
Uzbekistan faces challenges in landscape restoration due to institutional and policy issues, including limited data, fragmented sectorial approach, outdated land use planning, inconsistent regulations, and harmful subsidies.	• Develop a landscape restoration approach as an element of a broader framework for the national adaptation plan so that initiatives are anchored to this broad goal. • Develop an integrated rural land use plan by district and introduce rotational grazing or, if required, a grazing ban in the most degraded areas. • Strengthen economic incentives for investments in climate-smart agriculture and forest landscape restoration by repurposing harmful agricultural subsidies into incentives for landscape restoration initiatives and by introducing payments for ecosystem services. • Promote a land tenure reform and liberalize land use policies. • Establish a legal framework for public-private partnerships (PPPs) for research and development (R&D) in climate adaptation. • Pilot innovative landscape restoration models, for example through the implementation of the Uzbekistan Resilient Landscapes Restoration Project.
Enhancing the adoption of technologies	**Options for enhancing the adoption of technologies**
Technological adoption for landscape restoration in Uzbekistan is hindered by the lack of capacities to uptake technologies, the lack of knowledge exchange platforms, and weak extension services	• Create knowledge exchange and networking platforms on successes in applying technologies in different contexts, with options for scaling up in similar contexts. • Develop a government program to help farmers improve their use of technology as a tool for increasing the efficiency of agriculture, water use, and forestry and DRM in an integrated manner • Increase extension services capacity in integrated landscape restoration and develop a support mechanism for initial upfront investment costs. Work with communities to increase their buy-in for landscape restoration activities.

Lack of prioritization of investments for landscape restoration	Options for prioritizing investments for landscape restoration
Priority areas for landscape restoration, costs of action, and benefits of action identified in this report could inform national landscape restoration initiatives.	• Large-scale landscape restoration projects such as the Uzbekistan Resilience Landscape Restoration project (RESILAND), the “Yashil Makon” (Green Nation) and national agricultural programs could start prioritizing the adaptation opportunity hotspots. • Develop landscape restoration portfolios to prioritize spending where the highest socio-economic benefits are achievable.
Mobilizing finance for landscape restoration	**Options for mobilizing finance for landscape restoration**
The lack of financing for landscape restoration for both private and public sectors .	• Include **forestry and landscape restoration as an activity for green taxonomy.** • Develop a **carbon credit framework** for forestry and other land use (FOLU) projects and establish a robust system for monitoring and evaluating the success of restoration efforts • Use **Public Expenditure Review** as an instrument to optimize public spending, ensuring that investments in landscape restoration contribute effectively to building resilient and sustainable landscapes. • **Mainstream impact investing for landscape restoration** by creating an implementation framework. • **Issue restoration bonds** quantifying the expected environmental and social benefits, ensuring bond issuance viability, and enhancing creditworthiness through international organizations or foundations. • **Reduce private sector risk** by offering guarantees for landscape restoration projects. • **Convene multi-donor platforms for large-scale resource mobilization** for landscape restoration and integrate donor-financed projects in the agricultural sector’s financial planning and implementation.

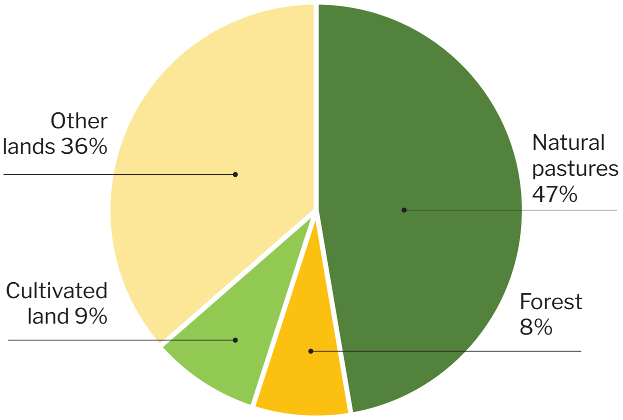
1. Introduction

1.1. Context and Background

Ecosystems play a critical role in supporting Uzbekistan's prosperity, stability, and sustainable development. Climate change, coupled with changes in rainfall patterns, increasing frequency and severity of droughts, high population growth rates, and the resulting land use pressures, is driving ongoing degradation of the country's natural resource base.[3] Widespread and inefficient use of irrigation and the heavy application of agrochemicals pose risks to water quality and drive increasing soil salinity (Khamidov et al. 2022). Land degradation and fragmentation threaten the flow of ecosystem services which support economic and social prosperity, including soil retention, water flow regulation, food production, wild pollination, biodiversity, and carbon sequestration, to name a few (Quillérou et al. 2016).

Natural pastures dominate land use structure in Uzbekistan. The country has a total land area of 44.9 million ha, out of which 47.32 percent is natural pastures, 7.65 percent is forest, 8.6 percent is cultivated land, and the remaining 36.43 percent is other lands, mainly deserts. Out of the total cultivated area, the top three crops in terms of area are cereals, cotton, and fruits, which account for about 41 percent, 28 percent, and 12 percent, respectively. These figures are illustrated in Figure 1.

Figure 1. Total land area of Uzbekistan per share of land type



Source: Original elaboration for this publication.

Farming in Uzbekistan is highly dependent on irrigation, where 58 percent of its agricultural land is irrigation dependent and uses approximately 90 percent of the surface water for irrigation (World Bank 2022a). Lack of water resources and land degradation will continue to threaten this sector's productivity. A typical example of water scarcity and further depletion is noted in the Aral Sea, which is exacerbated by climate stressors such as increasing temperatures, more frequent and extreme droughts, and lower precipitation levels during the year (Narbayep and Pavlova 2022). The Aral Sea has already lost 57 percent, 80 percent, and 64 percent of its area, volume, and depth, respectively, over the past four decades.[4]

Land degradation is accelerating biodiversity loss and agricultural productivity, further increasing the agricultural sector's vulnerability. Land degradation is driving biodiversity loss in Uzbekistan by putting pressure on natural ecosystems and increasingly challenging the Uzbek economy's foundations. Degradation of land used for agriculture will likely affect the Uzbek agricultural sector, which accounts for 27 percent of total employment and 18 percent of gross domestic product (GDP).[5] The extent of the problem presents a challenge for the Uzbek government; investments at this scale in landscape restoration would be staggering. Therefore, it is important to identify hotspots where land degradation and climate risks overlap with areas of opportunity for climate adaptation. By taking this approach, Uzbekistan can begin to act in the areas that are most likely to show positive improvements to its economy and its people.

1.2. Report Objective

This study aims to identify hotspots of land degradation and declining productivity and hotspots of adaptation opportunity where the benefits of landscape restoration have the greatest potential to offset ongoing trends in land degradation under changing climate conditions. Further, the report includes an indicative benefit: cost analysis of landscape restoration in terms of the costs borne due

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[3] https://zoinet.org/wp-content/uploads/2018/01/UZB-climate-summary-en.pdf.

[4] https://iea.blob.core.windows.net/assets/0d00581c-dc3c-466f-b0c8-97d25112a6e0/Uzbekistan2022.pdf.

[5] https://projects.worldbank.org/en/projects-operations/project-detail/P174135.

to a lack of action to combat degradation, compared to the costs and benefits of investing in landscape restoration using a suite of adaptation technologies. Finally, a set of recommendations are proposed for technological, institutional, and policy options that Uzbekistan could implement to reduce the degradation of the natural capital in the agriculture, forest, and water sectors throughout the country.

1.3. Methodology

The methodology applied in this study included the following phases:

(a) Identify the historical baseline for land degradation trends (2000–2020) (Step 1 in Figure 2).

(b) Develop a map of future land degradation hotspots at a national scale that identifies districts that are most vulnerable to multiple risks from climate change, land degradation, population pressure, and an associated decline in ecosystem services, including disaster risk management (DRM), with a continuation of current degradation trends and climate futures up to the middle of the century (Business as Usual [BAU] scenario - Step 2 in Figure 2).

(c) Assess the costs of ongoing land degradation to Uzbekistan's economy (cost of inaction), evaluating physical losses from agriculture and ecosystem services.

(d) Propose adequate landscape restoration and climate-smart technologies at the district level for forest, agriculture, water, and DRM.

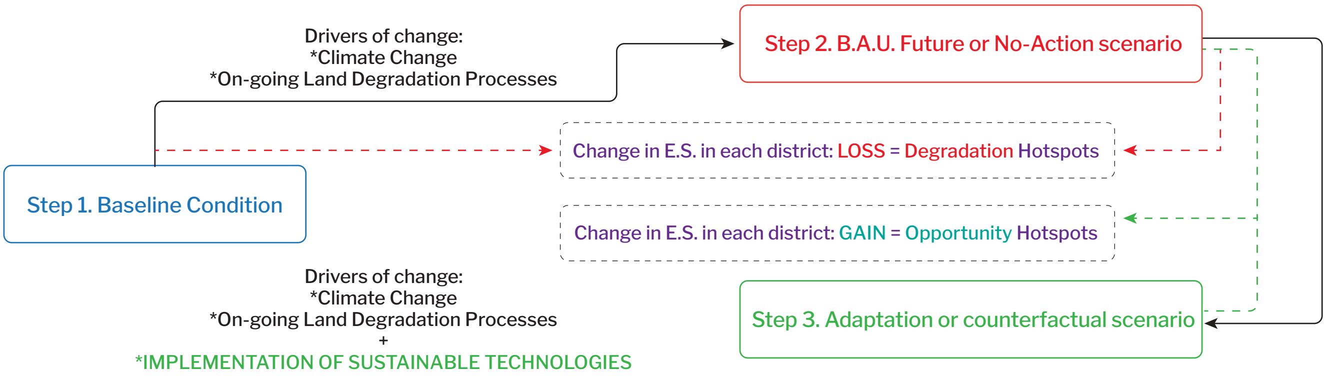
(e) Use spatial modeling of ecosystem services and identify the set of integrated landscape management interventions in the hotspots of adaptation opportunity with the highest potential for landscape restoration and adaptation actions to reduce land degradation, improve water regulation, and mitigate landslide and climate change risks while increasing production (Step 3 in Figure 2). These hotspots cover about 20 percent of severely degraded lands in forests, rangelands, and crops (1.6 million ha in adaptation opportunity hotspots from 8.3 million ha severely degraded lands in the same biomes). Two portfolios for the selection of the future adaptation hotspots are used: national-level optimization and province-level optimization. The first maximizes the production of ecosystem services at the national level, and the second maximizes these benefits at the provincial level, providing the second-best solution with a smaller production.

(f) Assess the costs and benefits of investing in an integrated suite of landscape restoration and climate-smart technologies (cost of action and benefits of actions) in the identified hot spot areas based on the two portfolios of investments.

(g) Propose policy recommendations informed by the results of the analysis to facilitate the adoption of resilient and climate-smart technologies in Uzbekistan.

Through these seven phases, figure 2 shows the schematic of modeling approach from evaluating drivers of change in the baseline condition, developing a BAU/No-Action scenario, developing an adaptation scenario, and using the results to identify hotspots of degradation risk and hotspots of adaptation opportunity. The report aims to provide policy makers with the necessary tools and information to address land degradation in Uzbekistan.

Figure 2. Schematic of the modeling approach



Source: Original elaboration for this publication.

The report is structured as follows: Section 2 summarizes the assessment results of risk drivers and identification of future degradation hotspots. **Section 3** contextualizes those results by discussing their impacts on key sectors in Uzbekistan. **Section 4** presents the costs of inaction on land degradation: estimated losses of ecosystem services and their values due to observed trends in the landscape. **Section 5** presents the potential for landscape restoration and climate-smart technologies to offset the observed trends in degradation. **Section 6** presents the map of future adaptation opportunity hotspots separately for each ecosystem service (4) and combined multi-criteria future adaptation opportunity hotspots. **Section 7** presents the costs of action and the benefits that arrive from these investments into landscape restoration and climate-smart technologies, estimating benefit-cost ratios (BCRs) for each portfolio of investments. Finally, **Section 8** provides overarching policy recommendations for addressing the (a) technical, (b) institutional, and (c) financial barriers. A detailed methodology is provided in Annex 1

Key terms and indicators used in the assessment of risk and opportunity hotspots

- **Climate risk** is an index of climate risk that aggregates changes in four indicators that directly affect the provision of ecosystem services from landscapes: drought, flood, water scarcity, and productivity.
- **Land degradation risk** is an aggregated indicator defined by the overlap of several risk factors that include climate risk, trends in land degradation indicators, natural hazards (landslide) risk, and population density change.
- **Baseline condition** is the state of land use, land cover, and vegetation condition in 2020.
- **Business-as-Usual** (BAU, or no-action) scenario assumes the continuation of current land use trends that result in land degradation.
- **The adaptation scenario** is a counterfactual scenario that reflects the potential positive impacts of landscape restoration with sustainable technologies to identify areas where these are most likely to be effective in confronting ongoing degradation trends.
- **Sustainable technology package** means a suite of conservation and resilience-building technologies that, if introduced in an integrated manner, can lead to substantial benefits in terms of ecosystem services that are translated into yield and income gains and reduction of negative effects of degradation in Uzbekistan's productive lands.
- **Future hotspots of land degradation** are defined at the district level by the overlap of risk factors that include climate risk, future trends in land degradation, natural hazards (landslide) risk, and population density change, and they reflect risks under the BAU scenario.
- **Future hotspots of adaptation opportunity** are defined at the district level by the optimization of the potential return in ecosystem services or the difference between the ecosystem's services in the BAU and the adaptation scenarios. The sustainable technology packages are implemented under the adaptation scenario.
- **Climate adaptation:** Adaptation refers to adjustments in ecological, social or economic systems in response to actual or expected climate change. It refers to changes in processes, practices, and structures to moderate potential damages or to benefit from opportunities associated with climate change.
- **Ecosystem services** are essential for life goods and services that natural systems produce. They can directly or indirectly benefit humans and improve their quality of life. Ecosystem services include provisioning, regulating and cultural services.
- **Consumptive use-values** of ecosystem services or provisioning services refer to the benefits derived from a direct use of natural ecosystems that involve harvesting or consuming the resources such as grain and straw on crop fields, wood and timber on forest lands, hay and leafy biomass from pastures, and so on.
- **Non-consumptive use-values** of ecosystem services or regulating and cultural services refer to the benefits derived from natural ecosystems that are associated with indirect use of an ecosystem while maintaining its health and sustainability. They are classified into the following four categories: (a) watershed, soil protection, and nutrient recycling; (b) gas (carbon dioxide and oxygen) exchange, carbon storage, and climate stabilization; (3) habitat and protection of biodiversity and species; and (4) aesthetic, cultural and spiritual values.

2. Uzbekistan's Land Use and Climate Risk Outlook up to the Mid-Century

2.1. Future Hotspots of Land Degradation and Climate Risks

In this study, hotspots of land degradation risk is a composite measure defined by the combination of four risk factors: (a) climate risk, (b) trends in land degradation indicators, (c) natural hazards (landslide) risk, and (d) population density change. Each of the four driving factors was analyzed separately, as described in the sections below, and a ranking score for each indicator was assigned by district. An equal-weighted combination of risk scores for each district was then used to produce an aggregated risk score (Section 2.2).

2.1.1. Climate Risk

Uzbekistan's climate is arid and continental. It is characterized by hot and dry summers, with an average monthly air temperature of 27.4°C in the hottest month (July). Winters are cold, with average monthly temperatures of −1°C to −3°C between December and February. The region also experiences large variations in temperature within days and between seasons.[6]

Drought occurrence in Uzbekistan has been increasing regularly, with one drought every five years on average during the 1980s and 1990s and four episodes between 2000 and 2012.[7] With climate change, Uzbekistan's summer months are expected to experience high temperatures, prolonged heat waves, and an expanded summer season. Heat waves and increased frequency of consecutive days above 39°C are expected to occur throughout the country. A continuous rise in temperature poses a severe problem for drinking water, where mountain glaciers—a vital drinking water source—melt faster than the global mean with an annual loss of 0.1–0.5 percent.[8] Droughts are predicted to become more frequent due to reduced river runoff, specifically from the Amu Darya and Syr Darya Rivers that feed the surrounding fertile valleys, including the Ferghana Valley (Hakimov et al. 2007). Those rivers also significantly contribute to water availability and storage in the Aral Sea. Furthermore, prolonged drought, in turn, is projected to worsen the potential for forest fires and shortened growing seasons.

Climate change in the central and southeast regions tends to lead to landslides and recurring floods, in contrast to the drought challenges noted in the northwest region. Data from the Centre of Hydrometeorological Service of the Republic of Uzbekistan (Uzhydromet) suggest that mudflows were responsible for over 38 deaths and damaged approximately 3,000 households and 5,000 ha of crops between 2005 and 2014 (Hakimov et al. 2007). Studies showed a total of 3,042 mudslides historically with high frequency in April, May, and June, mainly in Zerafshan, Ferghana Valley, Chirchik–Akhangaran, Surkhandarya, and Kashkadarya river basins in the south of Uzbekistan.[9] Precipitation and rapid snow melt are important mudflow triggers In Uzbekistan, the temperature-related variables exhibit greater differences between the optimistic (SSP1-1.9)[10] and pessimistic (SSP3-7.0) scenarios than precipitation-related variables, both in terms of percentile ranges (10th, 50th, and 90th) and time horizons (2030 and 2050) (Figure 3). Since the differences between climate change scenarios tend to be more pronounced toward the end of the century, the impacts of climate change on rainfall and temperature are most evident in the pessimistic scenario (SSP3-7.0) and for 2050.

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[6] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-09/15838-Uzbekistan%20Country%20Profile-WEB.pdf.

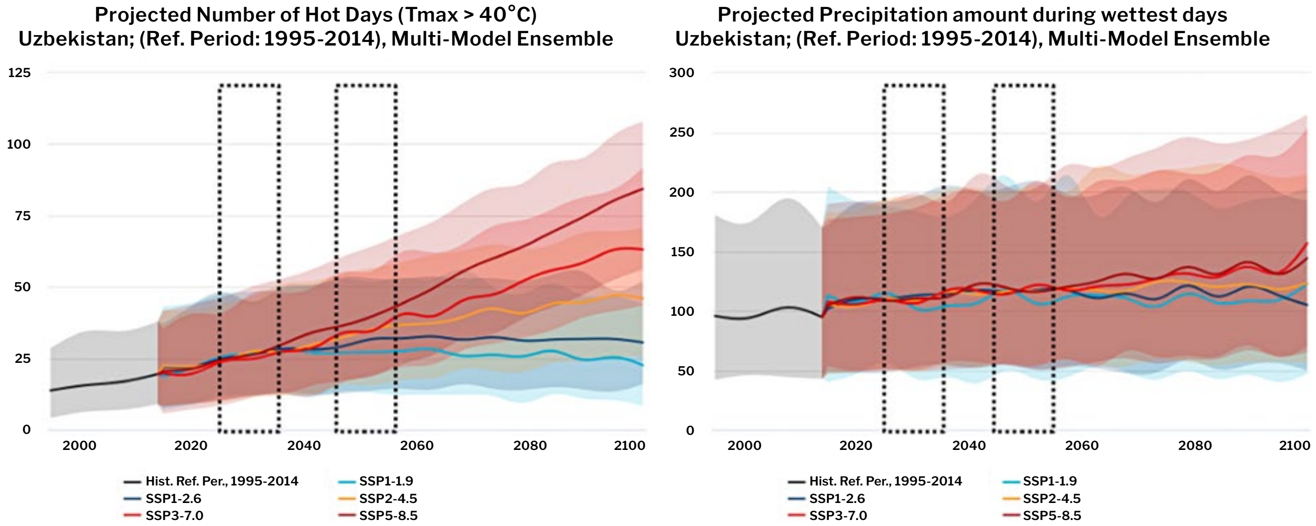
[7] WBG Climate Change Knowledge Portal (CCKP, 2021). Climate Data: Historical. https://climateknowledgeportal.worldbank.org/ country/uzbekistan/climate-data-historical.

[8] https://zoinet.org/wp-content/uploads/2018/01/UZB-climate-summary-en.pdf.

[9] https://www.sciencedirect.com/science/article/pii/S2212094721000906.

[10] SSP = Shared Socioeconomic Pathways.

Figure 3. Temperature and precipitation projected for Uzbekistan under a range of climate scenarios



Source: Original elaboration for this publication.

Note: The dashed boxes highlight the 2030 and 2050 time horizons featured in the Country Climate and Development Report (CCDR) analysis.

Because the 10th and 90th percentile values for rainfall and temperature cover a wide range in all of the SSP scenarios, there is very little variation between the optimistic, moderate, and pessimistic scenarios and between the two time periods (2030 and 2050) when these extreme values are considered. However, both moderate (SSP2-4.5) and pessimistic (SSP3-7.0) scenarios at their 50th percentile showed a clear difference from the optimistic scenario by 2050, with national average temperature rises of 1.21°C (optimistic), 1.78°C (moderate), and 1.94°C (pessimistic). In the pessimistic scenario, the extreme rise in temperature by mid-century is primarily experienced in the northwest, mainly in the Muynak district, where the Aral Sea is located. A similar extreme temperature rise is predicted for Andizhan, Namangan, and Tashkent provinces in the southeast (see Annex 1 for detailed climate projection maps). These high-temperature increases in the southeastern part of the country are concerning as they are likely to have a considerable impact on the melting of mountain glaciers, exacerbating drinking water scarcity and the occurrence of mudslides in the region.[11] This region also has the highest population density of Uzbekistan, with 400 people per km^2, and is the country's food basket, where crops will face the increased challenge of rising evapotranspiration, requiring high and timely water availability.[12]

While warming temperatures are predicted with greater certainty, rainfall patterns under future climate change are less consistent. The scenarios evaluated showed high intra-model (percentile-wise) uncertainties for precipitation with an enormous difference. The predicted rainfall for the 90th percentile was more than four times that predicted for the 10th percentile ensemble, regardless of SSPs undertaken (Figure 2, right). This presents a considerable policy concern for developing a strategy to address future rainfall and water availability challenges. While this variability reflects large uncertainties in the predictions, the median projected rainfall across all CMIP6[13] scenarios does not change significantly over the next few decades; however, the temperature will not cease to rise, potentially creating a more arid climate.[14]

To develop an integrated picture of climate risk hotspots in Uzbekistan, a climate change risk score was calculated for each district based on projected changes in four indicators that directly affect the provision of ecosystem services from landscapes (Figure 4). Figure 5 shows districts organized from low to high in five groups of equal number of districts per bin (quintiles), where the highest risk scores correspond with districts where climate ensemble predictions indicate a greater change from current climate in the future. These district-level climate change risk scores show that areas of greatest

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[11] https://www.sciencedirect.com/science/article/pii/S2212094721000906.

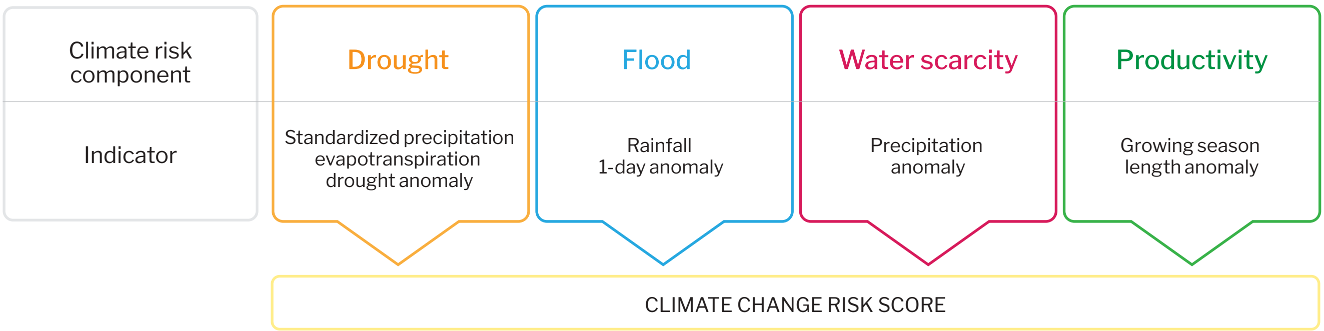
[12] https://www.undp.org/sites/g/files/zskgke326/files/migration/uz/uzb_un_eng_Investment_Guide_to_the_Ferghana_Valley.pdf.

[13] CMIP = Coupled Model Inter-comparison Projects.

[14] https://climateknowledgeportal.worldbank.org/sites/default/files/2021-09/15838-Uzbekistan%20Country%20Profile-WEB.pdf.

climate risk are heterogeneously distributed in the country, with three main climate risk hotspots in red and orange shades (80th percentile and above). Districts in green shades should not be interpreted as no climate change risk since all districts in the country will face climate-related risks. Lower scores simply mean that variation is expected to be lower in these regions compared to other parts of the country.

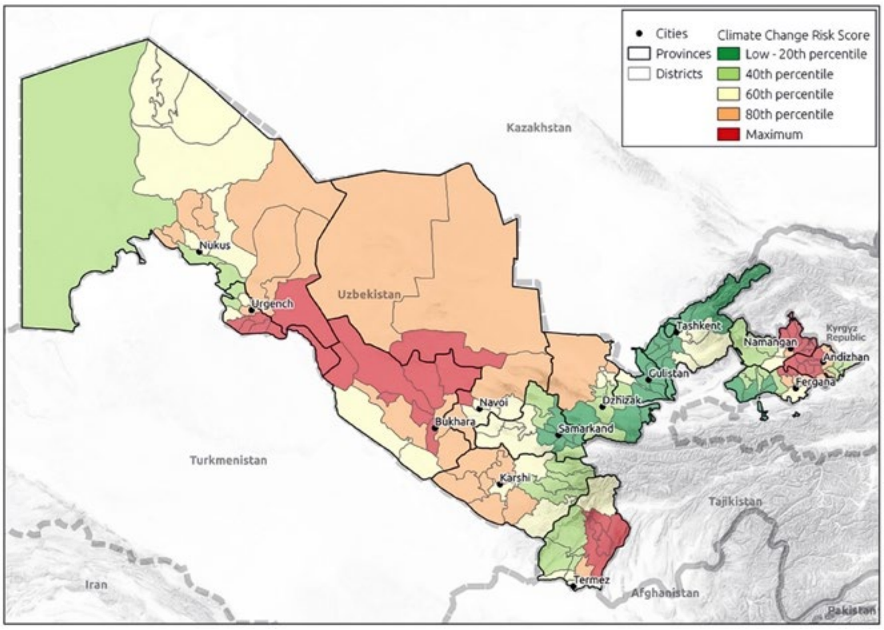
Figure 4. Components of the composite climate change risk score*



Source: Original elaboration for this publication.

Note: * Based on the average multi-scenario deviation of future climate variables from observed conditions, using CMIP6 data for three climate scenarios,

Figure 5. Distribution of district-level climate change risk scores until the middle of the century



Source: Original elaboration for this publication.

Note: Districts are colored by quintiles, so areas in green should not be interpreted as 'no risk'; rather, they are only low relative to other areas of Uzbekistan.

2.1.2. Future Land Degradation Risk

To identify areas of land degradation risk, a trend analysis was performed to map the agricultural landscapes that are under significant productivity reduction every year over the past two decades. Rather than looking at the absolute level of landscape productivity, trends are not affected by the naturally occurring variations in vegetation productivity between different ecosystems in different regions of the country; on the contrary, the trend analysis measures locally specific changes in productivity through time independent of the long-term average. Because of this, the trend can be more directly associated with ongoing land degradation processes in all ecosystems.

This analysis indicates that at least one-third of all agricultural landscapes in Uzbekistan have shown a constant decline in vegetation productivity in the last 20 years. The five areas where a significant diminution of vegetation productivity has occurred in the last 20 years are Ferghana Valley, Gulistan-Jizzakh corridor, north of Nukus, north Namangan, and around Tashkent (Figure 5). There may be different reasons for this since these five degradation hotspots are located in different and distant regions in the country, but in the intensive cropland hotspots (Ferghana Valley and Gulistan-Jizzakh corridor), causes could be a combination of water stress and soil degradation / salinity processes. In agricultural areas that surround densely inhabited areas (for example, around Tashkent, Namangan, and Ferghana), land use change due to urban sprawl might be the driving factor of decreases in vegetation productivity and even productive land replacement with other land uses, and in the western areas, a combination of water access limitations, desertification, and dust storms might be responsible for the decline in vegetation productivity of croplands and natural desert shrublands and riparian / flooded vegetation.

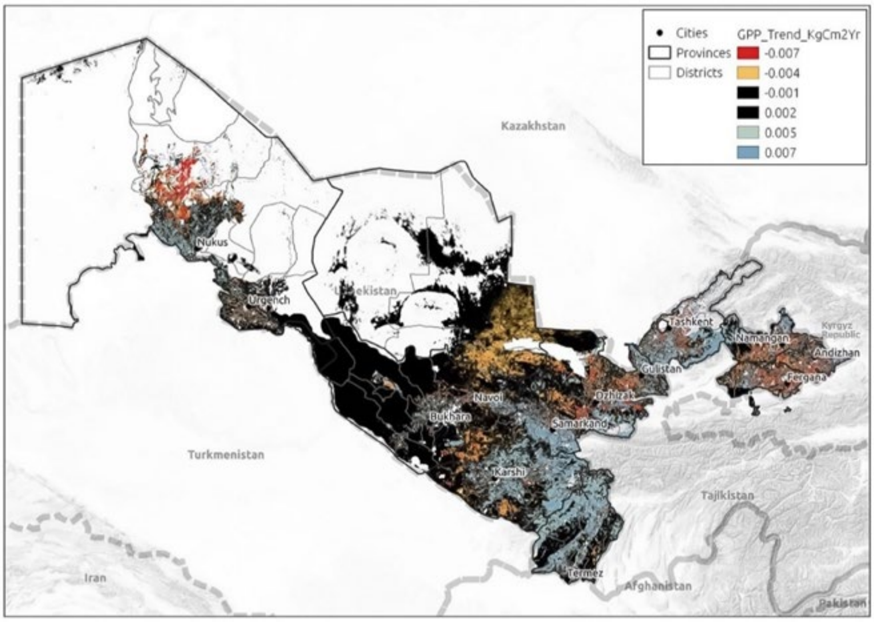
The most affected natural ecosystem in terms of the total area is the desert shrublands in the steppes north of Navoiy in Navoiy province, west of Aydar Lake in the center of the country. This arid ecosystem is losing an average of 17.5 kg of biomass per ha yearly (gross primary productivity [GPP] to biomass conversion rate factor for this biome in a province of 3.5×). This amounts to 350 kg of biomass per ha lost in the last 20 years of measurements. The natural ecosystem with the greatest net loss of biomass is the riparian woodlands north of Nukus, in the central Karakalpakstan province. This ecosystem has lost an average of 48 kg of biomass per ha yearly (GPP to biomass conversion rate factor for this biome in the province of 4.8×). This amounts to 960 kg of biomass per ha loss in the last two decades.

In the areas dedicated to cropland uses, the total balance considering all regions in the country is mixed, with some areas showing increasing trends and others the opposite. Rain-fed cropland areas show a stable trend, with few areas either in strong diminishing or increasing trends. Irrigated cropland areas, one of the most important sectors of agriculture in the country, show a different picture (Figure 6). There are entire regions with primary productivity losses as the predominant condition, being easily identifiable in the Ferghana Valley between the cities of Namangan, Andizhan, and Ferghana; the agricultural district north of Jizzakh; and the agricultural district surrounding Urgench. In these agricultural districts, the primary productivity has steadily decreased during the last 20 years, resulting in an average of 400 kg per ha of biomass loss. Some agricultural districts have shown no significant increasing or decreasing trend, such as those around the cities of Navoiy, Bukhara, and Karshi. Finally, agricultural districts showed a steadily increasing trend in biomass production during the study period, such as those north of Nukus, north of Termez, southeast of Samarkand, around the axis between Gulistan and Tashkent, and north of Namangan.

2.1.3. Natural Hazard Risks

Landslide hazards in Uzbekistan can have serious impacts not only on productive landscapes but also on human lives and infrastructure up to mid-century. Therefore, three indexes of landslide risk are defined that reflect the exposure of productive landscapes, road networks, and people to unstable slopes and potential landslide hazards up to mid-century; these three are then combined into an aggregated landslide risk score (Figure 7). Higher landslide risk scores are assigned to districts where the combined effects of vulnerable topography, climate change, and land degradation dynamics will increase the negative impacts of this natural hazard on productivity, infrastructure, and people. The resulting scores reflect that much of the infrastructure, productive land, and densely populated areas are concentrated in the southern and eastern portions of the country. However, as with climate risk, a low-risk score in the other areas does not indicate that there is no landslide risk, only that the risk is lower compared to other parts of the country.

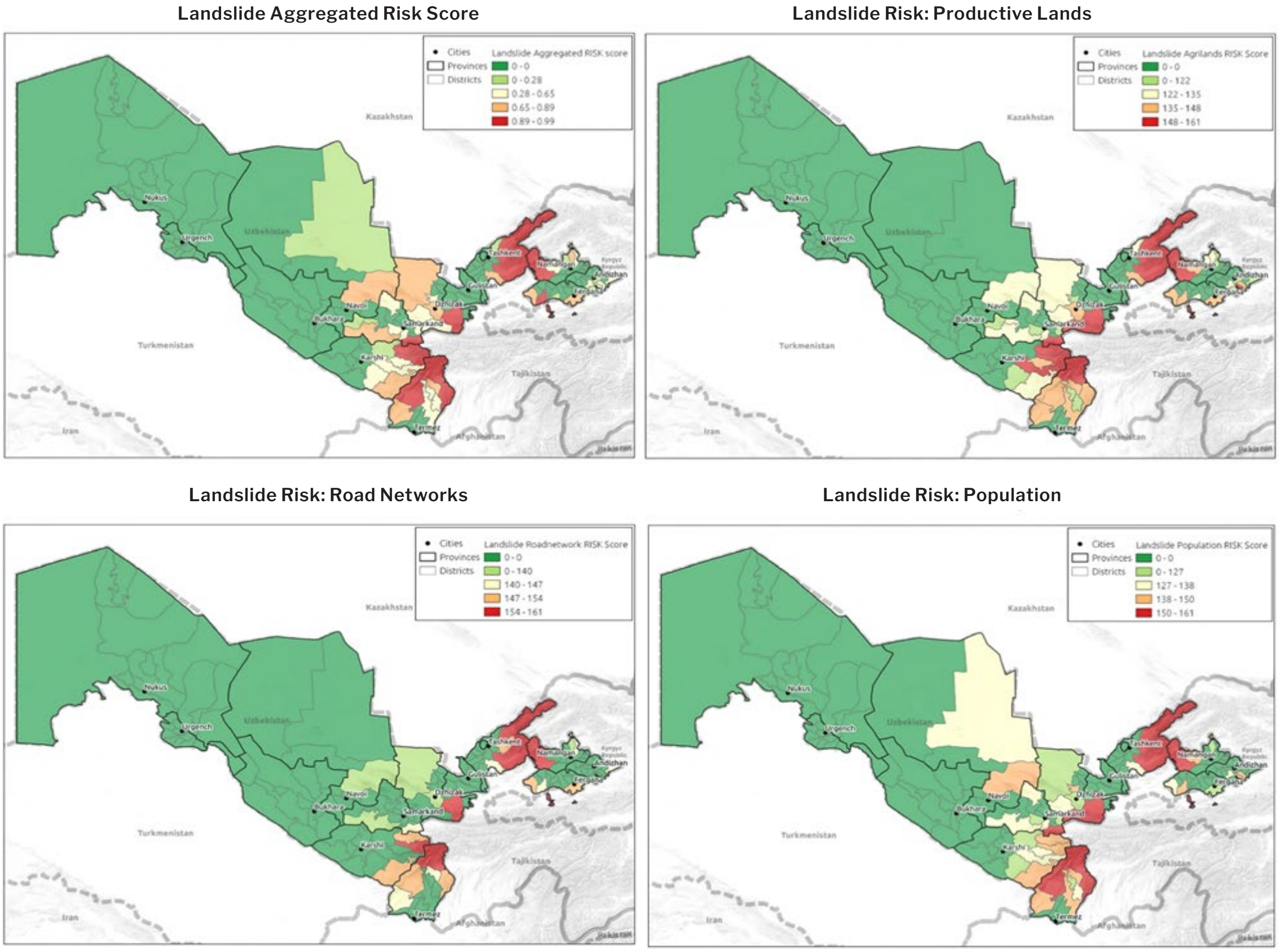
Figure 6. Trends in GPP nationwide, based on 2000–2020, projected to mid-century as gain/loss in kg of carbon per m^2 every year



Source: Original elaboration for this publication.

Note: Areas with declining productivity are assumed to be experiencing degradation, and yellow shades correspond to the areas where degradation is more acute.

Figure 7. Landslide risk scores by mid-century based on slope stability model



Landslide Aggregated Risk Score

Landslide Risk: Productive Lands

Landslide Risk: Road Networks

Landslide Risk: Population

Source: Original elaboration for this publication.

2.1.4. Population Pressure Risk

Uzbekistan's human population dynamics present a heterogeneous pattern. Although the country's total population change rate is on average positive, the spatial pattern reveals areas with significant population growth rates, both negative and positive.

Agricultural landscapes in the axis Nukus-Urgench in the west showed continuous population loss during the last 20 years. The same negative trend can be seen around Navoiy and north of Jizzakh. Interestingly, these areas also show a negative trend in vegetation productivity analysis. Climate out-migration hotspots are predicted to emerge in Uzbekistan by 2050 due to reduced water availability and crop productivity. This will exacerbate population declines in areas surrounding the Ferghana Valley and smaller irrigated croplands along the Amu Darya River. Uzbekistan already faces high internal migration, with 80,000 people migrating annually for employment or education (World Bank 2023).

The opposite trend, a sharp population increase, is found in agricultural landscapes of the Ferghana Valley, around Samarkand and Karshi. A population shift from agricultural areas toward urban and peri-urban areas can be seen in the Ferghana Valley. The same process is present in the axis between Tashkent and Gulistan, where negative population rates in the landscapes dominated by irrigated agriculture seem to boost higher growth rates in the urban Tashkent periphery.

Figure 8. Population density projected to 2035

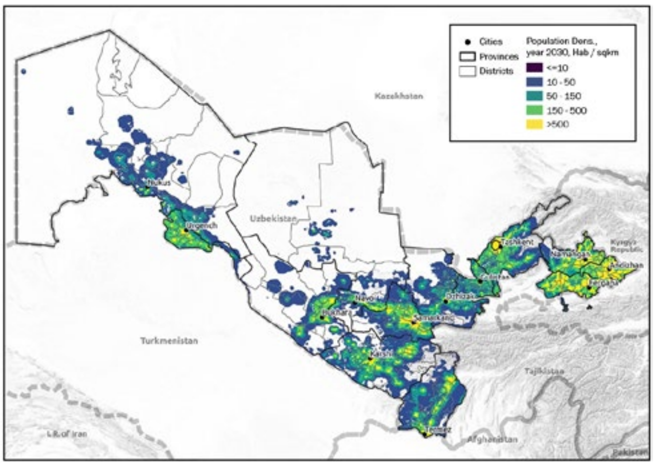
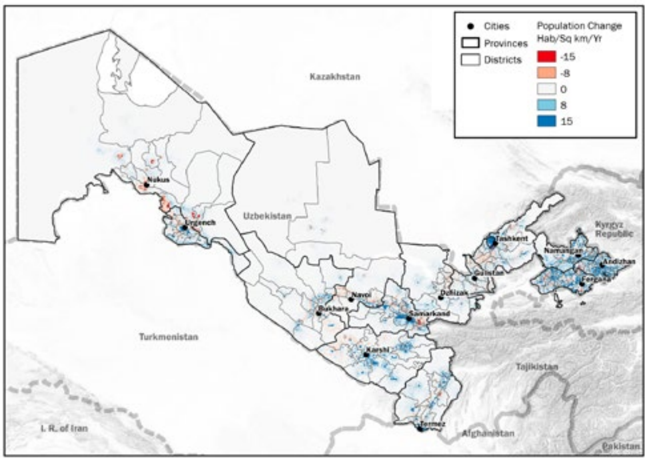


Figure 8a. Trend in Population Density by 2050, based on 2000–2020 trends



Source: Original elaboration for this publication.

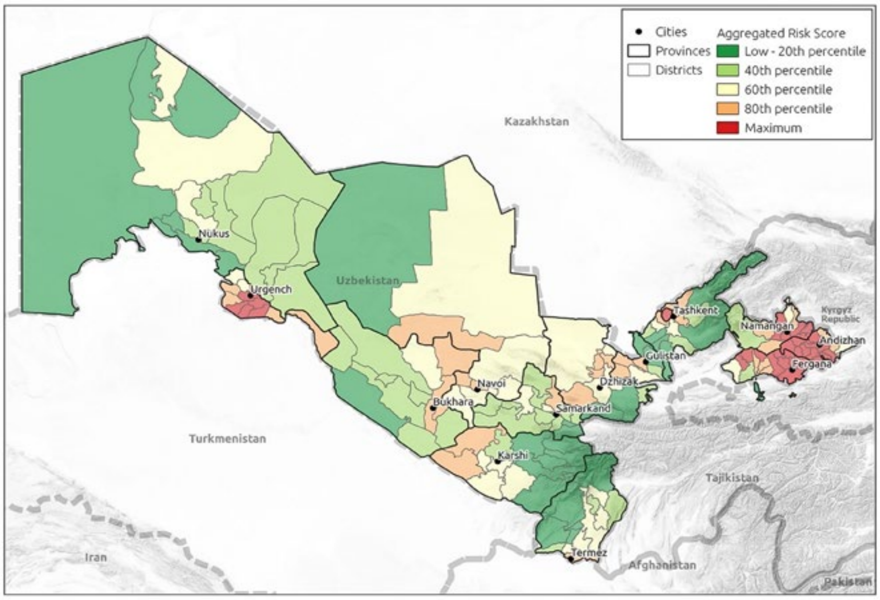
2.2. Multi-Criteria Future Hotspots of Land-Related Risks

The aggregated composite risk score (Figure 10) ranks each district in Uzbekistan based on its potential exposure to the combined effects of the risk factors described above, presenting BAU scenario by 2050. Districts with red and orange shades correspond to areas where the combined effects of ongoing vegetation productivity loss (GPP loss), considerable future climate anomalies from historical observed climate, landslide risks to people and infrastructure, and increased pressure on natural resources from higher population densities can produce further losses of ecosystem services due to the compounding effects of these drivers. This map forecasts future land degradation trends, combining climate change risks, continuing existing land degradation trends, and population change risks.

Although no districts are in no-risk condition in Uzbekistan, districts in green shades in Figure 10 correspond to places where only one risk driving factor is present, and yellow shades are where two factors are present. These are usually areas under climate change risk, whose impacts span over large areas affecting multiple districts. In contrast with climate change data, land degradation and population density data have much greater spatial detail. These two factors capture the country's in-district dynamics and even land parcel dynamics.

Out of three risk factors, land degradation trends can be both the most precise and discernible factor in assessing future risks for different areas of the country. Different from climate change

Figure 9. Composite map highlighting hotspots of risk from climate change, land degradation, natural hazards, and population pressures in Uzbekistan



Source: Original elaboration for this publication.

Note: Areas at high risk are likely to experience declining agricultural productivity, water availability issues, and heightened landslide risk that will affect more people.

data, for which all districts can be at different levels of risk depending on the future emission scenario selected, or population densities, which shows a very stable and predictable change, land degradation as measured is highly heterogeneous and sensitive to the other two factors. For example, the desert shrublands biome north of Navoiy that shows a continuous trend of slowly degrading vegetation productivity in the last 20 years matches the same area predicted to shift from a clod desert climate zone into a hot desert climate under a pessimistic climate scenario (Beck et al. 2018). In a similar way, the highly fragmented agricultural plots in the Ferghana Valley that exhibit the most acute degradation trends are spatially aligned with the areas where population density increases and urban sprawl has been mapped in recent years.

The combination of land degradation and loss of productivity in intensively managed croplands, the expansion of urban areas, and associated population pressures drive the aggregated risk score of districts at the national level. When one of these areas is also expected to have a significant shift in rainfall and temperature patterns in the future, the maximum risk score is reached. This is predicted to occur in three areas or risk hotspots: the Ferghana Valley ‘triangle’ between Namangan, Andizhan, and Ferghana cities; the agricultural district surrounding Tashkent; and the agricultural district south of Urgench. The regions in the next level of risk from the interactions of these factors, in which their slightly lower score is attributed to lower population growth pressure, are two agricultural belts in the center of the country. The first encompasses the areas between Navoiy, Bukhara, and Karshi; the second is along the line between Gulistan, Jizzakh, and Samarkand. It is important to note that this aggregated risk score reflects the expected worsening of conditions in the future, which is different from present-day conditions. This clarification is useful to understand the score assigned to Karakalpakstan districts, which are mostly in shades of green and yellow. It is known that both natural and agricultural landscapes in this province are under great environmental stress in the present day, and these lower risk scores for their districts might appear counterintuitive. However, these scores reflect changes in the future from current conditions, and in this province, no climate zone shift is expected (same climate zone in the future as in the present day), and population density is diminishing. Only GPP losses were mapped as significant risk factors, specifically north of Nukus in irrigated croplands and the remaining riparian woodlands/shrublands.

3. Sectoral Climate and Land Degradation Impact

Climate change and land degradation pose significant risks to Uzbekistan's economic and social structure, as the country's largely rural population relies heavily on agriculture for employment. Uzbekistan ranks 96 out of 181 countries in the 2019 Notre Dame Global Adaptation Initiative (ND-GAIN) Index[15] of climate vulnerability. Rising temperatures affect labor productivity and hydropower generation, while climate also affects slope stability and critical infrastructure. The country's reliance on irrigated agriculture and water supply also contributes to these risks. The period between 2001 and 2009 witnessed a loss of US$0.85 billion in ecosystem services (equivalent to 3 percent of GDP in 2009) due to changes in land use and land cover. Land degradation costs alone amounted to 4 percent of GDP in 2016 (Ministry of Economic Development and Poverty Reduction of the Republic of Uzbekistan, The World Bank, and the United Nations Development Programme 2022), and the cost of inaction was five times higher than the cost of action—highlighting that land degradation is being caused due to failure to protect land rather than by active land destruction.

Climate change is increasing risks of land degradation, affecting local economies, agriculture, biodiversity, carbon emissions, and livelihoods. It may lead to severe water shortages along the Amu Darya and Syr Darya by the 2040s and 2050s due to rising temperatures and more rapid glacier melt. Temperatures are projected to increase from 2.2°C to 3.1°C by the 2050s in the mountainous areas of Tajikistan, which could reduce glacial mass by 36–45 percent relative to today (Hagg et al. 2013). As glaciers recede, seasonal river flow patterns are expected to change, with peak flows shifting from the summer to the spring. A runoff reduction of 25 percent was projected during July and August for the main tributary of the Amu Darya, and there is some evidence that the same seasonal shift is affecting the Zarafshan river (Hagg et al. 2013). If this trend were to continue, it would put pressure on Uzbekistan's irrigated cotton and grain production. This increases water and nutrient availability in soil, affects biodiversity, and contributes to carbon emissions. Soil erosion damages infrastructure like roads and dams, leading to frequent floods, mudslides, and land collapses. The loss of arable land is particularly challenging for the rural poor, who rely heavily on agriculture, with around 80 percent of Uzbekistan's poor living in rural areas.[16]

Uzbekistan's Nationally Determined Contribution (NDC) acknowledges these challenges. It acknowledges that since the 1950s, the average growth rate of air temperature in Uzbekistan is 0.29°C per decade, which is twice the global average. This increasing air temperature increases the country's vulnerability to water shortages, increased desertification, droughts, land degradation, and unstable agricultural production. Irrigated agriculture is vulnerable to projected declines in water availability, a major threat to the livelihoods of a large population of agricultural laborers (Bekchanov and Lamers 2016). While Uzbekistan has significantly improved nutrition and food security in the past decade (Musaev, Yakhshilikov, and Yusupov 2010), the dependence on irrigated agriculture and projected climate changes could threaten food security (Zhao et al. 2019). Households spend a relatively high proportion of their income on food, 47.3 percent in 2016,[17] leaving poorer groups relatively exposed to rising food prices.

3.1. Impact on Agriculture and Forest

Climate change is expected to reduce crop yields and increase unmet water demand across all crops by mid-century. The global water demand for irrigation is expected to rise by 5 percent by 2030, 7–10 percent by 2050, and up to 25 percent by the 2040s due to the high emissions scenario (USAID 2018). Water shortages are expected to reach 7 km^3 a year by 2030 and 15 km^3 a year by 2050. Climate change

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[15] The ND-GAIN Index summarizes a country's vulnerability to climate change and other global challenges in combination with its readiness to improve resilience. It aims to help businesses and the public sector better prioritize investments for a more efficient response to the immediate global challenges ahead. University of Notre Dame (2019). Notre Dame Global Adaptation Initiative. https://gain.nd.edu/our-work/country-index/.

[16] https://www.undp.org/sites/g/files/zskgke326/files/2022-12/Final%20GGSF%20071222_FINAL_Clean.docx-2.pdf#:~:text=In%202019%2C%20about%2027%20percent%20of%20Uzbekistan's,poverty%20and%20inequality%2C%20including%20through%20job%20creation.

[17] The State Committee of the Republic of Uzbekistan on Statistics. https://www.stat.uz/en/.

is also predicted to shift peak flows from summer to spring. The pessimistic scenario sees a 3.9 percent increase in unmet water demand, while the warm/wet mean scenario sees a 0.2 percent increase. The Kashkadarya region, Zarafshan Valley, and Ferghana Valley will experience a 3.8 percent increase in unmet demand. The highest impacts will be seen in orchards, rice, and vineyard production, ranging from −6.7 to −22.5 percent, −8.1 to −20.3 percent, and −6.8 to −21.8 percent, respectively.[18] Other crops are expected to experience predominantly negative effects under climate change.

Meat production from cattle and sheep suffers significantly from climate change in Uzbekistan. Climate change impacts on livestock vary by animal and product and productivity shocks to meat (cattle, sheep, chicken, and swine), milk (cattle), and eggs in Uzbekistan. Overall, all products are negatively affected by climate change by mid-century, with the dry/hot mean scenario producing higher losses than the wet/warm mean scenario. This is primarily due to the high vulnerability of all products to increases in temperatures. Cattle, which is the main herd in the country in terms of revenues, may experience significant impacts in both meat and milk production, with meat dropping from about 180 to about 130 kg/head (−30 percent) and milk dropping from 2,575 to 2,515 kg per head (−2 percent) by the 2040s under a dry/hot mean scenario. Sheep meat is also heavily affected, in the same order of magnitude as cattle. Impacts on livestock, representing 39 percent of agricultural production, are unclear. Livestock productivity could be affected by heat stress and increased exposure to pests and diseases.

Land degradation and other anthropogenic factors significantly affect riparian tugai forests. Climate change is associated with increased wildfires[19] and pest and disease outbreaks. Researchers expect that future changes in temperature and precipitation will further negatively affect forest growth and survival.[20] Unfortunately, more than 90 percent of the riparian tugai forests have been lost due to various factors such as land clearance for agriculture, uncontrolled fuelwood removal and logging, and reduced river flows.[21] The loss of forest products, including fuelwood and non-timber forest products (NTFPs), will exacerbate land degradation, worsen rural livelihoods, and weaken vulnerable ecosystems' climate resilience. This degradation also affects forests' global public good roles, including biodiversity, climate regulation, and carbon mitigation. Uzbekistan's forests play a crucial role in sequestration. For example, between 2001 and 2020, forests in Uzbekistan emitted 14.0 ktCO$_2$e/year and removed 634 ktCO$_2$e/year. This represents a net carbon flux of −620 ktCO$_2$e/year.

3.2. Impact on Hydropower

Climate change can affect current and potential long-term water availability for hydroelectricity generation. It may affect hydropower generation directly through a reduction in river runoff and reservoir levels and indirectly through changes in the water demands for competing uses (for example, irrigation). It will generally have a negative impact on hydropower production in the country.[22] Looking at individual reservoirs, in the 2040s, the hydropower generation shock under the dry/hot mean scenario was the most significant for the Akhangaran reservoir (−19 percent), followed by the Tupalang reservoir (−16 percent). The Tupalang reservoir is the only reservoir that is expected to face a negative shock even under the warm/wet mean scenario, with all the other reservoirs experiencing a neutral or slightly positive shock (that is, a small generation gain). The exception to this trend is the Gissarak reservoir, which will have a +25 percent shock in the best case, with generation gains of +17 percent expected under the warm/wet mean scenario. Adequate adaptation and collaboration with upstream water countries such as Tajikistan on water management are therefore essential in meeting this objective.

Damages to infrastructure are projected to increase due to increased flood risk resulting from climate change. Climate change affects floods and has impacts on capital; from 2035 to 2064, capital shocks due to climate change are relatively similar throughout the country.[23] Impacts on capital relative to the baseline period are expected to be the highest on more frequent events such as the 20- and 25-year flooding, with shocks increasing between 50 and 150 percent. Increases in country-wide impacts

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[18] Industrial Economics Incorporated: Estimating the Economic Damages of Climate Change in Uzbekistan, forthcoming.

[19] According to Global Forest Watch, between September 2020 and September 2021, 1,089 fire alerts were reported in Uzbekistan's protected areas (PAs) alone—an unusually high number compared to previous years going back to 2012.

[20] https://documents1.worldbank.org/curated/en/099250007072236900/pdf/P1708700ef21870290b1a9019310003c250.pdf.

[21] https://unece.org/DAM/timber/publications/2020/Uzbekistan_DP85_1922478_E_WEB.pdf.

[22] Industrial Economics Incorporate: Estimating the Economic Damages of Climate Change in Uzbekistan, forthcoming.

[23] https://zoinet.org/wp-content/uploads/2018/01/UZB-climate-summary-en.pdf.

to capital are expected to decline when considering less frequent events (that is, 50- and 100-year events). From 2031 to 2050, impacts from climate change are expected to result in increased annual damages per km of infrastructure relative to the baseline period. Overall, damages are highest from wet/warm scenarios, with additional annual damages ranging from around US$12,000 to US$18,000 per km. Here, flooding-related impacts account for the largest share of damages, followed by temperature and precipitation-related damages. Among dry/hot GCMs, flooding and temperature-related risks are expected to contribute to most damages, while precipitation-related damages are negligible.

Relative to baseline conditions, annual road and bridge infrastructure damages are expected to increase, peaking before mid-century in 2040. Climate change may affect road and bridge infrastructure due to increased temperatures, precipitation, and flooding that cause the infrastructure to deteriorate faster, which influences infrastructure repair and maintenance costs and causes delays for passengers.[24] By the 2030s, additional damages are expected to range from about US$300 million to approximately US$2,100 million across GCMs. While the range of damages decreases through the next decade, the range of annual damages increases to approximately US$820 million to US$2,300 million. Damages under the wet/warm scenario are higher than under the hot/dry scenario, reaching US$1,840 million and US$1,275 million, respectively.[25]

3.3. Impact on Health

Climate change may affect human health through increased incidence of and deaths from vector-borne diseases such as heat-related diseases and waterborne infectious diseases that cause acute diarrhea, which all influence the total labor supply. Heat-related diseases are expected to increase the most, with over a twofold increase in death rates by 2050, compared to about a 25 percent increase for waterborne diseases under the worst-case scenario. Impacts are expected to grow as the mid-century approaches. Disease impacts relative to the baseline are greater under the dry/hot mean scenario. Air pollution is a growing environmental and health challenge. The annual costs of the damage to health from ambient $PM_{2.5}$[26] pollution, disproportionately borne by women, children, and vulnerable groups, have reached 6.5 percent of GDP (World Bank 2022b).

Climate change adversely affects labor supply, and the most vulnerable sectors, such as agriculture, suffer the most. Climate change affects the economy through six major channels: heat stress, human health, road damage, livestock losses, crop yield losses, and hydropower reductions, causing shocks to labor productivity, supply, and production.[27] Across macroeconomic sectors, agriculture is expected to experience the highest labor productivity shock by 2041–2050, followed by the industry and services sectors. During this period, shocks to the agricultural labor productivity from individual GCMs range from around −1.9 percent to −3.5 percent, with the wet/warm mean and dry/hot mean resulting in a shock of approximately −2.5 percent and −3 percent, respectively. Shocks to industry labor supply productivity range from around −1.3 percent to −2.5 percent across GCMs, with the wet/warm mean and dry/hot mean resulting in shocks of around −1.9 percent and −2.3 percent, respectively. Finally, the services sector is estimated to experience a similar range of labor supply productivity shocks, ranging from around −1.2 percent to −2.3 percent across GCMs, with the wet/warm mean and dry/hot mean resulting in a shock of around −1.7 percent and −2.1 percent, respectively.

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[24] Note the potential double counting of flooding impacts with the inland flooding impact channel.

[25] Industrial Economics Incorporate: Estimating the Economic Damages of Climate Change in Uzbekistan, forthcoming.

[26] Fine particulate matter of 1.5 microns or less in width that damages the respiratory system.

[27] World Bank analysis, CCDR background paper.

4. The Cost of Inaction on Land Degradation

The significant cost of inaction on land degradation in Uzbekistan justifies future actions to reduce these costs. The magnitudes of ecosystem services lost due to inaction and their monetary values in the land degradation hotspots were estimated for the most degraded lands. This analysis is primarily based on secondary data obtained from official sources, published and unpublished experimental and survey data.

Cost of inaction refers to the monetarization of negative consequences in terms of production losses and additional costs that can arise when the needed actions to manage and maintain a landscape are not taken. With the economic evaluation as a basis, the report analyzes a BAU/No-Action scenario, where it is assumed that no action is taken for landscape restoration. Consequently, ongoing land degradation processes are allowed to continue, leading to a cost of inaction in Uzbekistan.

For the cost of inaction, the objectives were to evaluate how land degradation associated with deforestation, unsustainable practices in agriculture, urbanization, and climate can affect agricultural and forest productivity, infrastructure, health, watershed hydrology, and water resource cycles, directly affecting water availability. A desk review estimates losses in ecosystem services per unit area of agricultural land (cropland and grassland) and forestland due to ongoing degradation. Methods applied for the valuation of ecosystem services losses are summarized in Table 2 and further described in Annex 3.

Table 2. Methods applied for ecosystem services losses from land degradation

Element	Cropland	Pastureland	Forest	Water	Infrastructure	Health
Provisioning service losses: loss of the use values	Yield gap in crop production and lost productivity of pasturelands and forestland due to land degradation			Water loss due to land degradation	The extent of roads, railways, runways, canals, buildings, and so on damaged due to land degradation	Cost of treating land-degradation-induced health problems
Loss of regulating services: loss of the indirect use values	Carbon emission due to soil erosion and diesel used for field and other farm operations (tons) under conventional tillage	Carbon emission due to soil erosion		Unwarranted pumping costs	Historical cost and degradation-induced natural disasters (emergencies)	
Cultural services loss: loss of the non-use values	Benefit-transfer					

Source: Original table for this publication.

Resulting losses of ecosystem services were estimated for each biome by province. A combination of market and nonmarket valuation methods were then used to monetize the losses to arrive at the cost of inaction, which included monetary values of provisioning services (crops, forage, timber, water, and resilient infrastructure), regulation (carbon loss), and cultural services provided by different biomes. Then, resulting losses for the cost of inaction were summarized by biome and province based on the percentage share of land falling under different levels of degradation and finally aggregated to a single national estimate using the percentage shares as weights.

Results show that the total value of ecosystem services lost in Uzbekistan's priority hot spot areas due to inaction on land degradation is estimated to be at least US$2.8 billion per year, which is equivalent to 4.61 percent of GDP (Table A4.16) or about US$15 billion over the 10-year period.[28] Over 96 percent of this loss is related to use value, with the remaining 4 percent being nonuse value. The top three biomes with the highest costs of inaction are croplands (39 percent), water (38 percent), and abandoned lands (12 percent).

4.1. Croplands

In croplands, the results indicate that Uzbekistan is annually losing a minimum of 1.28 million tons of potential production of different crops (cereals, legumes, cotton, vegetables, fruits, and others) and the associated crop residues which represent 3.4 percent of the current total national production—showing that land degradation has substantial food security implications in the country. In the top three crops/crop categories, namely vegetables, other crops, and cereals, 367,000, 282,000, and 210,000 tons of potential production is being lost annually due to land degradation in crop fields, with Samarkand, Khorezm, and Ferghana being the top three provinces where most of the crop loss (in absolute terms) is occurring. In relative terms, the top three provinces which are suffering the highest crop loss per unit crop area are Khorezm, Karakalpakstan, and Jizzakh (Table A4.1). This level of loss in crop production is associated with an estimated monetary loss of US$1.1 billion which is equivalent to 1.8 percent of GDP annually where consumptive, non-consumptive, indirect and nonuse values constitute 1.62 percent, 0.03 percent, 0.03 percent, and 0.12 percent, respectively (Table A4.2).

Currently, inaction in the agriculture sector in the prioritized intervention areas is causing the use of 119,400 tons of diesel for tillage and other agricultural activities every year. Using a standard energy-to-emission conversion factor (that is, 1 liter of diesel = 720 grams of carbon), tillage and other farm operations are annually generating a total emission of 86,000 tons of carbon with an estimated environmental cost of US$3.1 million (Table A4.3). Moreover, there are 402 greenhouses on 2,219 ha of land in these areas which are using at least 31 GW of electric power for heating every year, emitting 2,343 tons of carbon to the atmosphere costing Uzbekistan and the world US$85,929.

4.2. Pasturelands

Out of the total of 23.4 million ha of pastures in Uzbekistan, 34 percent are classified as severely degraded and hence are included as priority implementation areas. It is estimated that land degradation in pasturelands located in these hot spot areas is causing Uzbekistan to lose at least 338,000 tons of forage (hay). This level of loss has a total value of US$93 million (0.15 percent of GDP). The largest loss is happening in Navoiy, Karakalpakstan, and Samarkand, where the first two are among the provinces with the largest pasturelands. In relative terms, however, Samarkand, Tashkent, and Syrdarya are, in descending order, experiencing the highest yield losses per unit area (Table A4.4).

4.3. Forests

Uzbekistan has a rather low forest cover of about 3.2 million ha, representing only 7.2 percent of the total national area. The total growing stock is 26 million $m^{3,}$ including 7 million m^3 of coniferous and 19 million m^3 of deciduous (Prins and Zakhadullaev 2020). The low forest cover is partly due to the difficult climatic and physical conditions and partly due to the pressures on the forest. According to the Global Forest Resources Assessment (FRA) of the Food and Agriculture Organization (FAO), 0.8 million ha, 25 percent of Uzbekistan's forests in 2015, are considered 'planted forests', while just over 2 percent of forests are considered 'primary forests'. In recent years, degradation and anthropogenic impact on forests in Uzbekistan have intensified due to the expansion of agricultural land, increase in livestock numbers, uncontrolled harvesting of non-forest resources, increasing demand for industrial and fuel wood, large industrial development, water withdrawal for agricultural irrigation, and so on.

Forest/shrub biomass trends have been increasing in seven provinces, while six exhibit negative trends. Using data on forest degradation levels, average forest biomass per unit area, and long-term biomass accumulation rates obtained from Vogl and Leon (2022), this study includes conservative estimates of the costs of inaction (or inadequate

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[28] Total value of benefits estimated over a 10-year planning period using a discount rate of 12.7 percent, which is the 10-year average of the recent past discount rates published by the National Bank of Uzbekistan.

action) in the forest sector in Uzbekistan. The data show that while 7 out of the 13 provinces (Andijan, Ferghana, Jizzakh, Kashkadarya, Syrdarya, Surkhandarya, and Tashkent) have experienced, at varying levels, positive trends in their forest/shrub biomass between 2001 and 2020, the remaining 6 exhibited, also at varying levels, negative trends where the total volume of their forest/shrub biomass has decreased.

Inaction or inadequate action in these six provinces has led to a loss of 63,868 tons of total forest/shrub biomass annually, associated with a total value of US$2.2 million (0.16 percent of GDP). In terms of the absolute volume of biomass, Karakalpakstan, Navoiy, and Bukhara, in descending order, are the provinces that have suffered the most losses. In relative terms, however, the most loss per unit area happened in Khorezm, Bukhara, and Karakalpakstan (Table A4.7). Utilization of forest biomass for fuelwood has implications for carbon emissions. Assuming only 50 percent of the cleared forest is burned, an estimated 216,777 tons of carbon is emitted into the atmosphere, costing US$7.95 million.

In addition to all the losses described above, as shown in Table 4.8, inaction is causing Uzbekistan to lose at least 658,000 tons of topsoil annually in all biomes in the priority intervention areas, which has an estimated value of US$11.3 million. These soil losses also have implications for emissions through soil carbon loss. While the highest amount of soil is being eroded from pasturelands, the value is the highest in croplands because the opportunity cost is the highest in croplands. In absolute terms, in descending order, Tashkent, Kashkadarya, and Karakalpakstan are the top three provinces that are losing soil the most. Meanwhile, in relative terms, at 250, 218, and 127 tons/ha, respectively, the rates of soil loss are the highest in Karakalpakstan, Jizzakh, and Tashkent. Biome-wise, natural pastures, other lands, and cereal lands are the top areas that are experiencing high soil loss. Crop-wise, in descending order, lands planted for cereals, cotton, and other crops are losing the largest amounts of soil due to erosion. This level of soil erosion is associated with the release into the atmosphere of at least 1,922 tons of soil carbon per year (Table A4.9).

4.4. Water

Water demand in Uzbekistan is rising due to population and economic growth, while supply is decreasing due to climate change. The supply-demand gap for water is expected to grow even further in the future because of climate change, which is progressing in the region (Sutton et al., 2010). Agriculture in Uzbekistan highly depends on irrigation. Given that Uzbekistan is a predominantly arid country, making efficient use of this resource, which is getting scarcer, at least in per capita terms, should be given the utmost priority.

This level of irrigation water loss has an estimated value of US$1.1 billion per year (1.79 percent of GDP). Using the procedures explained in Annex 3, a conservative estimate was produced of the amount of water lost (that is, the annual amount of water that will not be available for immediate use from both surface water and groundwater sources) due to inaction in priority intervention areas of Uzbekistan to be 3.56 billion m^3, that is, 39 percent of total supply in these areas (Table A4.5).

Currently, inaction in the water sector causes 1,160 GW of electric power to pump water. Based on extrapolation of the amount of electric power used in Khorezm province (GEF and UNEP 2011), a total of 158 GW of electric power is being used annually for pumping irrigation water in the land degradation hotspots of Uzbekistan, which is generating a total carbon emission of 11,982 tons which costs the country and the world US$439,350 (Table A4.6).

5. The Potential of Climate-Smart Technologies for Adaptation through Resilient Landscape Restoration

To achieve the benefits of resilient landscape restoration, an integrated suite of technological, institutional, and policy interventions has been recommended to reduce land degradation and enhance ecosystem services in croplands, grazing lands, and pasturelands. All technologies are selected to be implementable at the farm level; agricultural and water use technologies are applied for croplands. All types of lands must be protected by the technologies that reduce floods and landslide risks. Selection of the integrated suite of technologies that present resilient landscape restoration allows us to move closer to food security, achieve reasonable cost recovery with expected returns, improve the adoption of new technologies/innovations, and avoid irreversible changes in land conditions given that a specific area in each biome is suitable/amenable for this technology. These technologies can be applied in landscape mosaics identified as adaptation opportunity hotspots for landscape restoration, and higher outcomes are expected when a combination of these technologies is used within same landscapes. A summary of these technologies is presented in the Annex 2. A short description is in Figure 10.

5.1. Crop Production Technologies

Conservation agriculture (CA), crop diversification, rotation, and agroforestry practices have been shown to reduce land degradation due to soil salinization. However, research on CA practices and their role in combating water and wind erosion has not yet been prioritized. The remaining soil coverage reduces wind and water erosion, improves soil quality, and increases organic matter. CA is not a uniformly applicable technology but a set of principles for local adaptation.[29] The definitions of these agricultural practices are summarized as follows:

- *Conservation agriculture practices.* A farming system that encourages the preservation of a permanent soil cover, minimizes soil disturbance, and encourages the diversification of plant species.[30]
- *Crop diversification* involves adding new crops or cropping systems to agricultural production, such as adding a new crop species, changing the current cropping system, adding more crops into an existing rotation, or incorporating seminatural habitats like hedgerows and flower strips.
- *Crop rotation* involves growing different types of crops in the same area over a sequence of growing seasons.[31]
- *Agroforestry* is a collective term for land use systems and technologies where woody perennials are used alongside agricultural crops and animals, involving ecological and economic interactions between the components.[32]

Landscape restoration in Uzbekistan requires crops that can withstand harsh environmental conditions like heat, drought, high salinity, and cold. Some high-yield, water-efficient, and tolerant crops are Atriplex, Tamarisk, Buffelgrass, Agave, Date Palm, Russian Olive, Jojoba, Quinoa, Alfalfa, and Buffalo Grass. Atriplex is a salt-tolerant plant that can grow in saline soils; Tamarisk is a hardy plant that can grow in saline and alkaline soils; Buffelgrass is drought tolerant; Agave is a succulent plant that can survive in arid environments with minimal water requirements;[33] Date Palms are drought-tolerant shrubs used for soil stabilization and windbreaks; Jojoba produces oil-rich seeds; Quinoa is a hardy grain crop suitable for crop diversification; Alfalfa is a perennial forage crop; and Buffalo Grass is a low-maintenance turfgrass.[34]

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[29] https://documents1.worldbank.org/curated/en/485571468318338846/pdf/Reducing-the-vulnerability-of-Uzbekistans-agricultural-systems-to-climate-change-impact-assessment-and-adaptation-options.pdf.

[30] https://www.fao.org/conservation-agriculture/overview/what-is-conservation agriculture/en/#:~:text=Conservation%20Agriculture%20(CA)%20is%20a,and%20diversification%20of%20plant%20species.

[31] https://www.fao.org/3/ca8987en/ca8987en.pdf.

[32] https://www.fao.org/forestry/agroforestry/80338/en/.

[33] https://www.biosaline.org/sites/default/files/publicationsfile/chapter_13_springer_published_1.pdf.

[34] https://link.springer.com/article/10.1007/s13593-015-0337-7.

Figure 10. Integrated technological suite for resilient landscape restoration

Crop production

1. Conservation practices
2. Crop diversification, rotation, agroforestry
3. High-yield, water efficient, heat / drought / salt / cold tolerant, disease resistant varieties
4. Planting wheat on standing cotton

Grazing lands

1. Rotational grazing and seasonal resting
2. Participatory: establish pastures on poor crop lands or alternate components of rotations for drought prone areas such as alfalfa and sainfoin

Forest lands

1. Reforestation using native tree/shrub species
2. Protection and management of vegetation
3. Agroforestry

Farm level water management

1. Irrigated farms: Mechanized Raised Beds; Drip Irrigation; Sprinkler irrigation; weather-based irrigation scheduling; laser-assisted land leveling; communal structures
2. Rainfed farms:-Water harvesting

Floods and landslides prevention

1. In the plains/steppe: Levee-setbacks, reconnecting floodplains/ floodway
2. In the hills: Reforestation, landscaping, terracing, bioengineering (headwater watershed management
3. Small river channels: Series of check dams, riverbank stabilization with gabions or anchored vegetation

Source: Original elaboration for this publication.

5.2. Grazing land technologies

Rotational grazing and resting are land management strategies in Uzbekistan that help prevent overgrazing, promote soil health, enhance forage quality, and support vegetation recovery. Rotational grazing involves moving animals between multiple pastures, allowing them to rest for a period.[35] Seasonal grazing is when animals are grazed in a particular area for only part of the year. This allows the land that is not being grazed to rest and allows for new forage to grow.[36] These strategies can help restore and sustainably manage grazing lands in Uzbekistan.

5.3. Forest landscape restoration technologies

Reforestation with native tree species can enhance local biodiversity and ecosystem resilience by promoting a high diversity of trees. The tree species are also valuable for community reforestation projects due to their non-timber benefits. Reforestation involves planting trees in depleted forests or woodlands, restoring ecosystem functions and biodiversity to degraded areas. Therefore, using native tree species in reforestation is beneficial.[37]

Protection and management of vegetation in forest landscapes is critical for preserving forest cover and accelerating growth. In Uzbekistan, forest restoration involves various strategies to protect and manage vegetation. These include protection and vegetation management practices such as fire management, livestock control, invasive species control, illegal logging prevention, reforestation and afforestation, soil preparation, protection measures, silvicultural practices, forest fire management, firebreaks, early warning systems, and community involvement.[38] Fire management involves creating firebreaks, educating the local community about fire prevention, controlling livestock grazing, identifying and controlling invasive species, enforcing strict regulations, promoting diverse planting, preparing soil for tree growth, using tree shelters or fencing, implementing thinning practices, and establishing fire monitoring systems.[39]

5.4. Farm-Level Water Management Technologies

Irrigation farms have proven efficient in providing water for crop growth; however, the following water-efficient and climate-resilient irrigation farm technologies are recommended for farm-level water management. Drip irrigation delivers water directly to plant roots, which is efficient for high-value crops. Sprinkler irrigation sprays water over crop areas, similar to natural rainfall. Raised-bed irrigation uses mechanized ploughs to create rows with furrows for water distribution.[40] Weather-based irrigation (WBIC) uses sensors and controllers to monitor weather and landscape conditions, calculate evapotranspiration, and adjust irrigation schedules to deliver water efficiently for homeowners and businesses. Laser land leveling (LLL) uses a laser-

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[35] https://www.fao.org/3/X5321E/x5321e09.htm.

[36] https://www.fao.org/3/X9137E/x9137e06.htm.

[37] https://www.sciencedirect.com/science/article/abs/pii/S0378112720315851.

[38] https://link.springer.com/article/10.1007/s11056-019-09713-0.

[39] https://onlinelibrary.wiley.com/doi/10.1111/gcb.15498.

[40] https://www.fao.org/3/i9220en/I9220EN.pdf.

equipped drag bucket to level land, reducing irrigation water use, energy, efficiency, and drainage. It can save rice and wheat irrigation time by 47–69 hours per ha and 10–12 hours per ha, respectively.[41] Rainwater harvesting is a traditional practice that collects, stores, and prevents rainwater runoff for irrigation in agricultural fields. It can increase water productivity, reduce water scarcity, boost crop production, save water bills, and improve small-scale farmers' livelihoods. Rainwater harvesting systems consist of collection, conveyance, and storage areas.[42]

5.5. Floods and Landslides Prevention Technologies

In the plains / steppe, levee setbacks and reconnecting floodplains and floodways are viable options for flood and landslide management. Levee setbacks are a proactive flood and landslide prevention strategy that create a buffer zone between a levee and adjacent land or water bodies. They reduce flooding risk, enhance ecological resilience, and improve public safety.[43] Reconnecting floodplains is a crucial natural flood management strategy that restores hydrological and ecological functions by allowing rivers and streams to spill over during flood events, reducing flooding risk, improving water quality, and supporting biodiversity.

Reforestation, landscape terracing, and bioengineering (headwater and watershed management) emerge as key technologies on hills. Terracing is a land management practice that creates level or gently sloping platforms on hilly terrain for agriculture, water management, erosion control, and landscape design.[44] Bioengineering is a nature-based approach to watershed management, particularly in headwater regions, focusing on sustainable and ecologically friendly techniques. Key techniques include live staking and fascines, coir logs and erosion control blankets, riparian buffer zones, wattle fencing and brush layers, vegetation restoration, terracing and check dams, in-stream structures, wetlands restoration, and habitat enhancement (Moreau et al. 2022). These techniques help control erosion, manage stormwater, and restore natural habitats while promoting sustainable and ecologically friendly practices. By incorporating bioengineering techniques, headwater watersheds can be better managed, reducing erosion and improving water quality.

Landscape restoration and adaptation of water, forest, and agricultural lands to climate and disaster risks require the implementation of a suite of conservation and resilience-building technologies. Introducing these technologies in an integrated manner can lead to substantial benefits in terms of ecosystem services that are translated into yield and income gains and reduction of negative effects of degradation in Uzbekistan's productive lands.

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[41] https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4126867#:~:text=The%20results%20imply%20that%20laser,as%20drip%20and%20sprinkler%20irrigation.

[42] https://www.frontiersin.org/articles/10.3389/fsufs.2020.437086/full.

[43] https://ui.adsabs.harvard.edu/abs/2012JHyd..450....1D/abstract.

[44] https://www.sciencedirect.com/science/article/abs/pii/S0012825217300090.

6. Future Hotspots of Adaptation Opportunity: Two Portfolios of Investments

In this phase of the analysis, the hotspots of adaptation opportunity are identified. These are the areas where the benefits of landscape restoration have the greatest potential to offset ongoing trends in land degradation. The areas are selected to optimize the potential return on ecosystem services that each land parcel of agricultural landscapes in Uzbekistan could offer. The potential return on ecosystem services is estimated using biophysical models that consider climate change[45] that could be achieved through implementing landscape restoration in Uzbekistan's productive landscapes (see Annex 1).

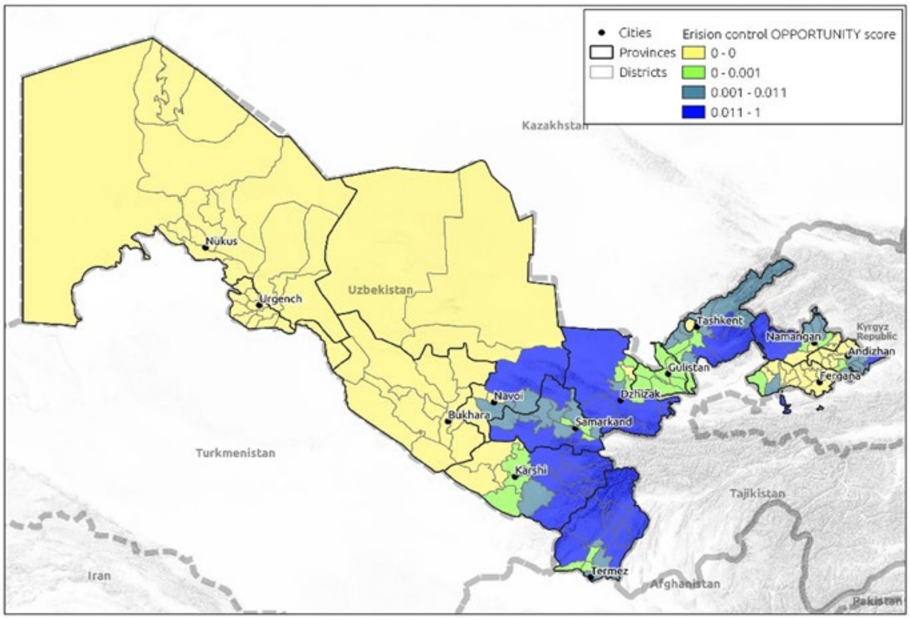
The opportunity scores by ecosystem service are built for optimization of the following ecosystem services: (a) erosion control, (b) water regulation, (c) slope stability and landslide mitigation, and (d) carbon sequestration. Maps ranking the districts of Uzbekistan according to the optimization of each service are presented below for each ecosystem service, aggregating them in a composite index for the future hotspots of opportunity in Uzbekistan.

The biophysical models were run for the BAU / No-action and the landscape restoration–adaptation scenario considering climate change conditions to 2050. The three climate scenarios—optimistic, moderate, and pessimistic—were modeled at 2050 on top of each land management scenario. This involved changing the land use/vegetation condition input to the model (to reflect land degradation or restoration) and the monthly mean rainfall, rainfall frequency, and potential evapotranspiration (to reflect temperature and precipitation change). The 50th percentile of the ensemble values for each scenario was used in the biophysical modeling of ecosystem services potential for landscape restoration (see Annex 1).

6.1. Erosion Control: Future Opportunity Score

This map presents an opportunity score for each district that could be achieved by controlling erosion and reducing soil loss, thereby preventing further losses in the productivity of croplands, pastures, and forests. Erosion control potential is estimated by reducing soil loss due to laminar erosion, representing soil conservation activities and improved vegetation cover management expected from implementing the technology packages. The areas or pixels with higher reductions in soil loss or prevented soil losses are considered

Figure 11. Erosion control opportunity score



Source: Original elaboration for this publication.

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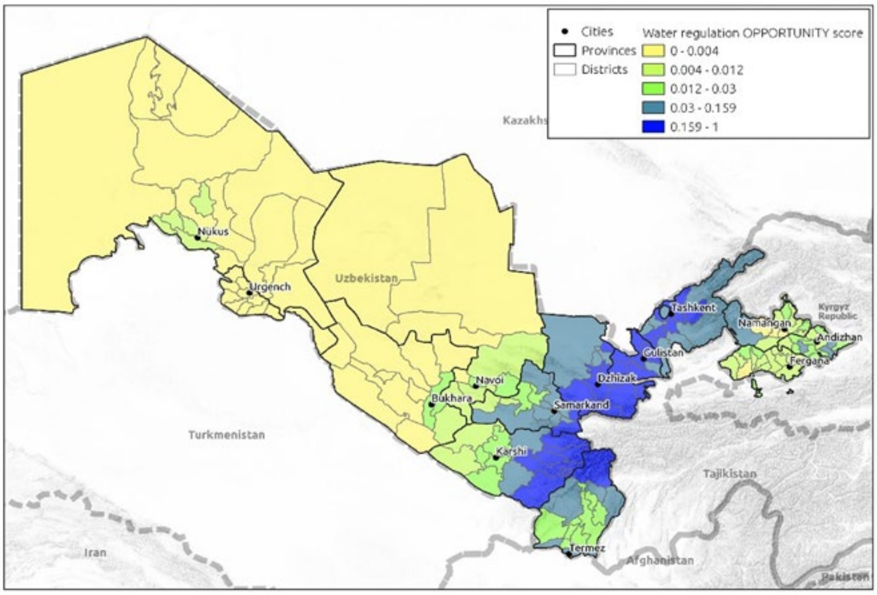
[45] The return is the difference between the offer of ecosystems services in the BAU - Inaction scenario and the offer if the technology packages of sustainable production are implemented (Sustainable - Counterfactual scenario).

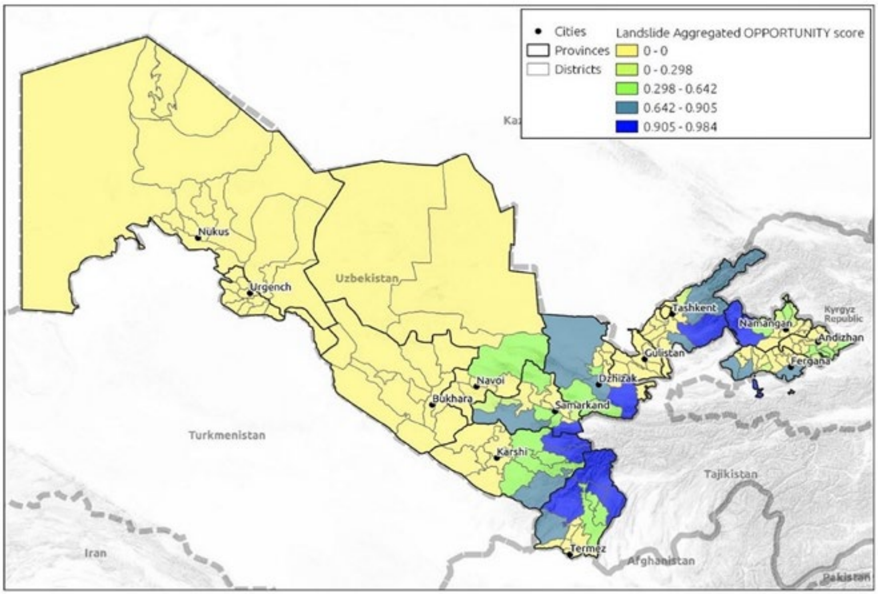
areas with higher potential benefits. This service also includes an increase in sediment retention due to improved vegetation cover by implementing a source-transport-deposition routine that tracks the flow of eroded soil from the sources in the landscape until it reaches streams or water bodies as sediment or solid in the water (Figure 11). Areas that show a higher increase in the amount of eroded soil that is retained and deposited by vegetation and that is boosted by implementing the technology packages are considered areas with higher potential benefits. Water regulation (surface runoff and baseflow): future opportunity score.

Figure 12. Water regulation opportunity score



Source: Original elaboration for this publication.

Figure 13. Aggregated landslide opportunity score



Source: Original elaboration for this publication.

6.2. Water Regulation Future Opportunity Score

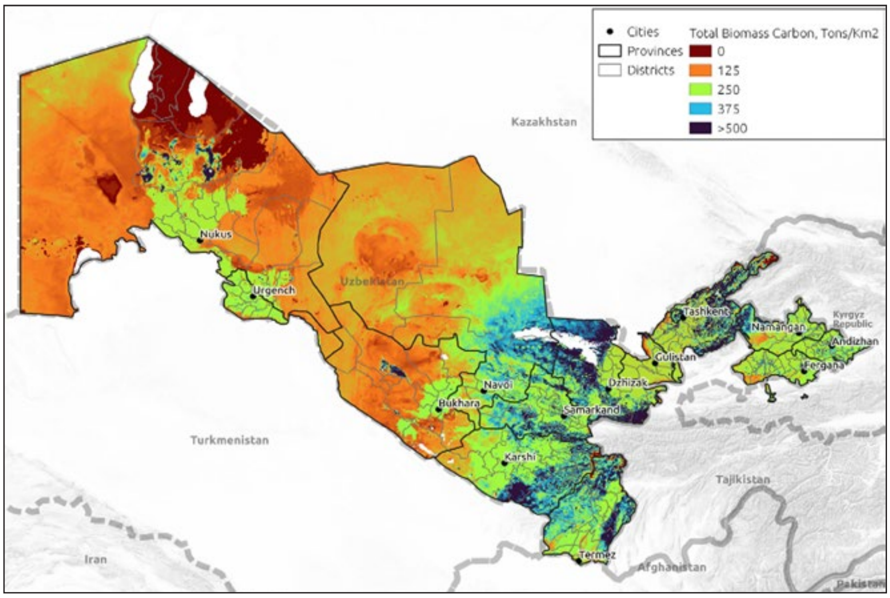
This map presents an opportunity score for each district that could be achieved by improving rainfall-runoff dynamics, thereby reducing peak flows and increasing base flows. Reduction of surface runoff and peak flow intensity is likely with the increase in vegetation cover from more sustainable land management practices. The areas with higher potential benefits produce a greater reduction in surface runoff with the implementation of the technology packages. The increase in local recharge reflects baseflow enhancement, and baseflow contribution is introduced through the implementation of technology packages that increase the proportion of water available for infiltration into the soil. The models define this water as a local recharge and are available for other users downstream. When the local water balance is positive, vegetation does not consume water and contributes to baseflow downstream (Figure 12). In the regions where the water balance is positive, this reduction in water losses directly affects water availability. The areas where this increase in local recharge is higher are considered areas with higher potential benefits.

6.3. Slope Stability and Landslide Mitigation: Future Opportunity Score

Figure 13 presents an opportunity score for each district that could be achieved by improving slope stability and decreasing the risk of small to medium-size landslides. In steeper landscapes where grazing and sustainable pastures technologies are implemented, soil root cohesion is expected with an increase in vegetation vigor. This improvement above ground has the benefits described before (increased rainfall interception, reduced surface runoff, and reduced soil erosion) and the below-ground benefit of an increase in root density. The slope stability model represents the additional sheer resistance from increased and deeper root density as additional soil cohesion that can help stabilize landslide-prone slopes (Figure 13). While not all slopes can be stabilized by vegetation management, the model identifies areas where the additional root cohesion can effectively reduce landslide risk. Those are considered areas with higher potential benefits.

6.4. Carbon Storage Future Adaptation Opportunity Hotspots

Figure 14. Estimated total carbon stock in Uzbekistan by 2022



Source: Original elaboration for this publication.

Figure 14 presents the sum of all above- and below-ground carbon in ecosystems of Uzbekistan, which is more dense to the east of the country. Using the GPP trend as an indicator to estimate carbon stock, the implementation of integrated landscape restoration technologies would stop or reverse carbon stock reduction. Total carbon is the sum of all above- and below-ground carbon in each province. In 2030, the expected carbon stock for the BAU scenario is estimated at 92.8 million MtC. In the same year, the maximum possible increase of carbon stock by implementing technological packages in suitable areas in the country is estimated at 1 percent of the carbon stock under BAU. Not all carbon stock loss is recoverable due to technology packages because only a fraction of Uzbekistan is suitable for the technological packages developed for Uzbekistan. In adaptation opportunity hotspots, implementing technological packages would at least maintain the carbon stock in each selected area.

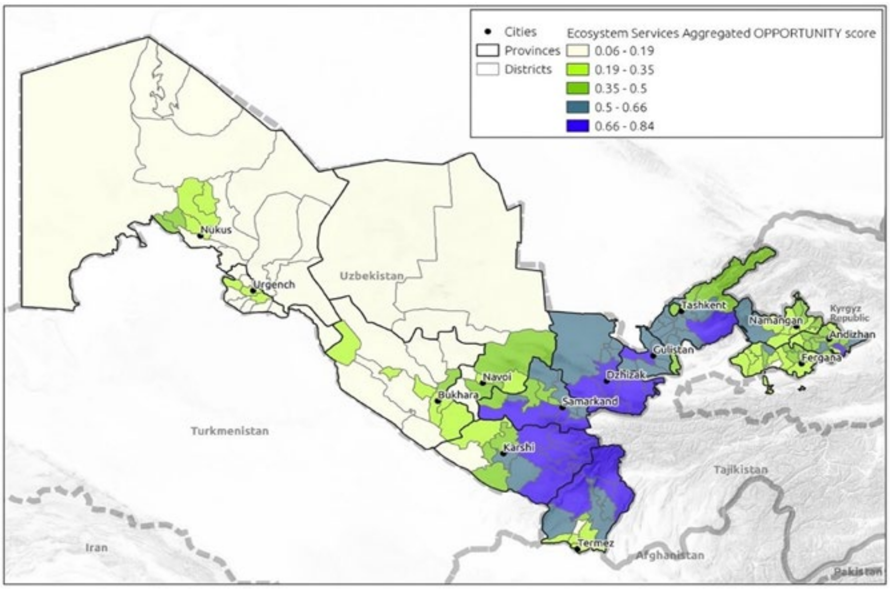
In addition to ecosystem services, potential increases in agricultural productivity have been included as factors to estimate landscape restoration scores. GPP was used as a proxy for agricultural productivity. GPP of croplands, pastures, and forested areas was analyzed using remote sensing from the last 20 years. Areas with significantly low values of GPP are interpreted as areas in severe degradation conditions. Because the effectiveness and productivity gains of the technology packages depend on the initial condition of the land where these are implemented, the areas with average and higher productivity values were prioritized.

To maximize the social benefits of implementing integrated technology packages, rural population density was used as an additional criterion for identifying opportunity areas. The implementation of these packages benefits the rural population directly (for example, higher agricultural yields) and indirectly (for example, job creation and supply chains). Areas with higher rural population densities are considered areas with higher potential beneficiaries from adaptation policies. The potential combined benefits of landscape restoration in hotspots are estimated per district, and the districts with greater improvements from baseline/BAU conditions are assigned a higher opportunity score (18). Trends in a potential increase of agricultural productivity (risk scores) are reflected in Figure 6, and population density is shown in Figure 8.

7. Multi-Criteria Future Hotspots of Adaptation Opportunity

Identification of the future hotspots of opportunity is based on building a composite score for each district in Uzbekistan for the restored ecosystem services, increased agricultural productivity, and population density as presented above. Restored ecosystem services include restoration of provisioning functions (produced on the land for immediate consumption, for example, grain and straw on crop fields, wood and timber on forestlands, and hay and leafy biomass from pastures), regulatory functions (watershed, soil protection, and nutrient recycling and carbon sequestration), and cultural functions (aesthetic and spiritual values) of landscapes. Ranking of districts in Uzbekistan based on the combination of the three ecosystem services, agricultural productivity (as measured by GPP), and population density allows us to identify multi-criteria adaptation opportunity hotspots. The districts are ranked in Figure 15 in terms of the landscape restoration opportunities in the entire national territory. While investing in resilient landscape restoration increases the production of ecosystem services everywhere in Uzbekistan, the greatest future opportunities are in the eastern part of the country, as illustrated in Figure 15 with the dark blue shade.

Figure 15. Composite index of adaptation opportunity



Source: Original elaboration for this publication.

Note: Districts with higher scores show greater potential benefit from investments in landscape restoration, based on ecosystem services of erosion control, water regulation, and landslide mitigation.

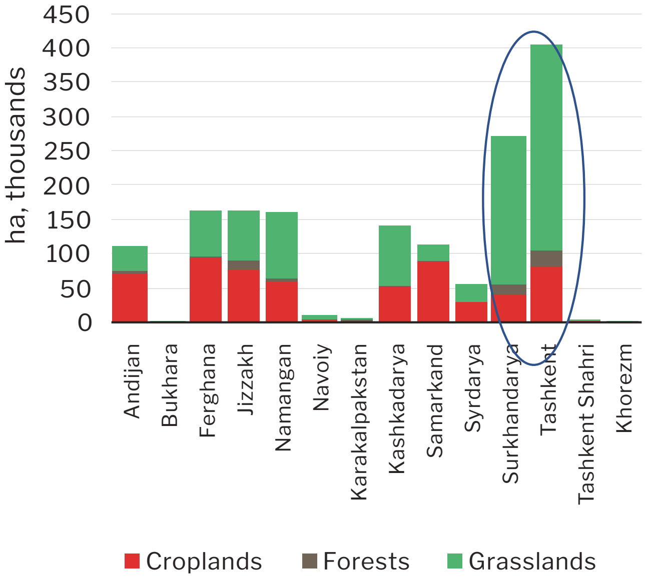
7.1. Feasibility of the Landscape Restoration: Two Portfolios

Given that the cost of investing in the entire national land is significant and financial resources are limited, the two portfolios for landscape restoration are identified for prioritizing the most cost-efficient investments. These hotspots cover about 20 percent of severely degraded lands in forests, rangelands, and crops (1.6 million ha in adaptation opportunity hotspots from 8.3 million ha of severely degraded lands in the same biomes). The two different portfolios of investment encompass a combined total of 1.6 million ha each and maintain an identical distribution of ha per biome/technological package. Each approach represents different ways of investing in 1.6 million ha to maximize benefits.

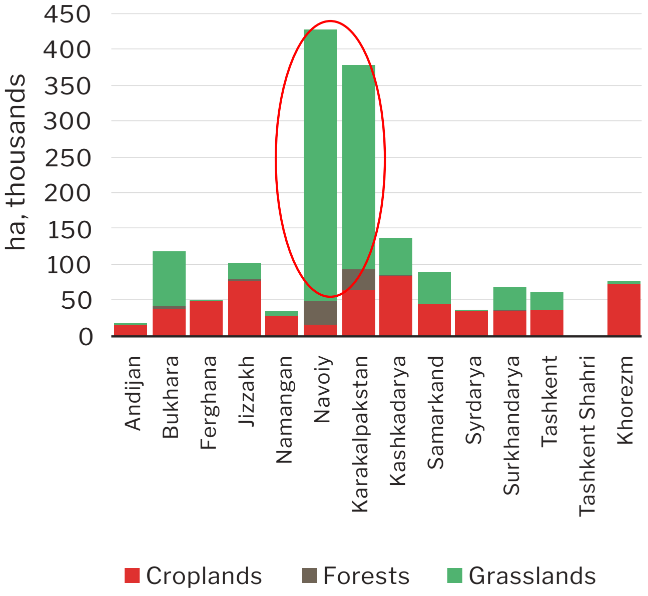
The first approach is the National Optimized 1.6 million ha Portfolio (Future Portfolio 1), which considers the possibility to invest everywhere in the country for a total of 1.6 million ha, allowing the optimization function to identify the best locations in terms of maximizing ecosystem services, including agricultural productivity and population density as described above. This approach maximizes adaptation benefits at the national level by concentrating investments in areas with the highest potential for benefits. The approach maximizes benefits and does not consider an equitable distribution between different provinces of Uzbekistan. Consequently, the distribution of investments between different provinces can vary greatly. The nationally optimized portfolio results in prioritizing investments in eastern Uzbekistan with a higher concentration of benefits in fewer provinces, as seen in Figure 17. The eastern areas nationally have the highest multi-criteria future opportunity scores (Figure 16).

Figure 16. Adaptation opportunity hotspots for land restoration: Two approaches

Approach 1: Nationally Optimized Portfolio



Approach 2: Province Optimized Portfolio



Source: Resource Investment Optimization System (RIOS) modeling (this study).

The second approach, the Province-Optimized 1.6 million ha Portfolio (Future Portfolio 2), considers the optimization in each province separately, maximizing ecosystem services, including agricultural productivity and population density per province. In contrast to the first approach, this approach seeks to ensure more equitable investment, thereby ensuring access to adaptation benefits across all provinces.

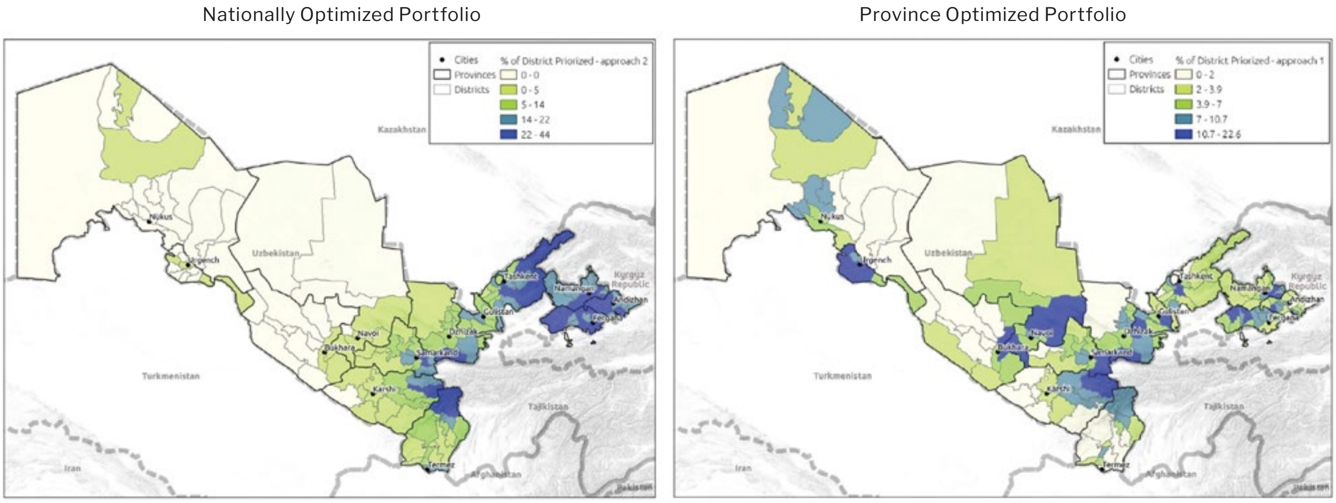
For the nationally optimized portfolio, hotspots of opportunities are concentrated in the east, with Ferghana, Jizzakh, Namangan, Surkhandarya, and Tashkent accounting for 59 percent, 80 percent and 80.5 percent of the 1.6 million ha for cropland, forestland, and grassland, respectively. This part of the country has the highest population densities, and thus, adaptation efforts stand to benefit a large part of the population. This, coupled with other elements of the multi-criteria index, accounted for the allocation of more land for investments in climate-resilient technologies for adaptation.

Since the province-optimized portfolio considers the need to distribute the benefits in each region, the benefits of the intervention are lower overall than the nationally optimized portfolio as benefits are not maximized based on highest returns at the national level, but rather at the provincial level. However, the benefits are distributed across provinces more evenly than in the nationally optimized portfolio. A detailed description of the portfolios can be found in Annexes 1–4.

The resulting portfolio of priority investment areas is shown in Figure 16 and Figure 17, comparing the two portfolios. Figure 16 provides the areas for restoration per province for each portfolio. Provincial optimization means that the areas (ha) that maximize ecosystem services, including socioeconomic factors like population per province, will be prioritized. This means a redistribution of the 1.6 million ha to all provinces. Provinces with the largest area, such as Karakalpakstan and Navoiy, account for 50 percent of the 1.6 million ha because they account for 61 percent of the national area.

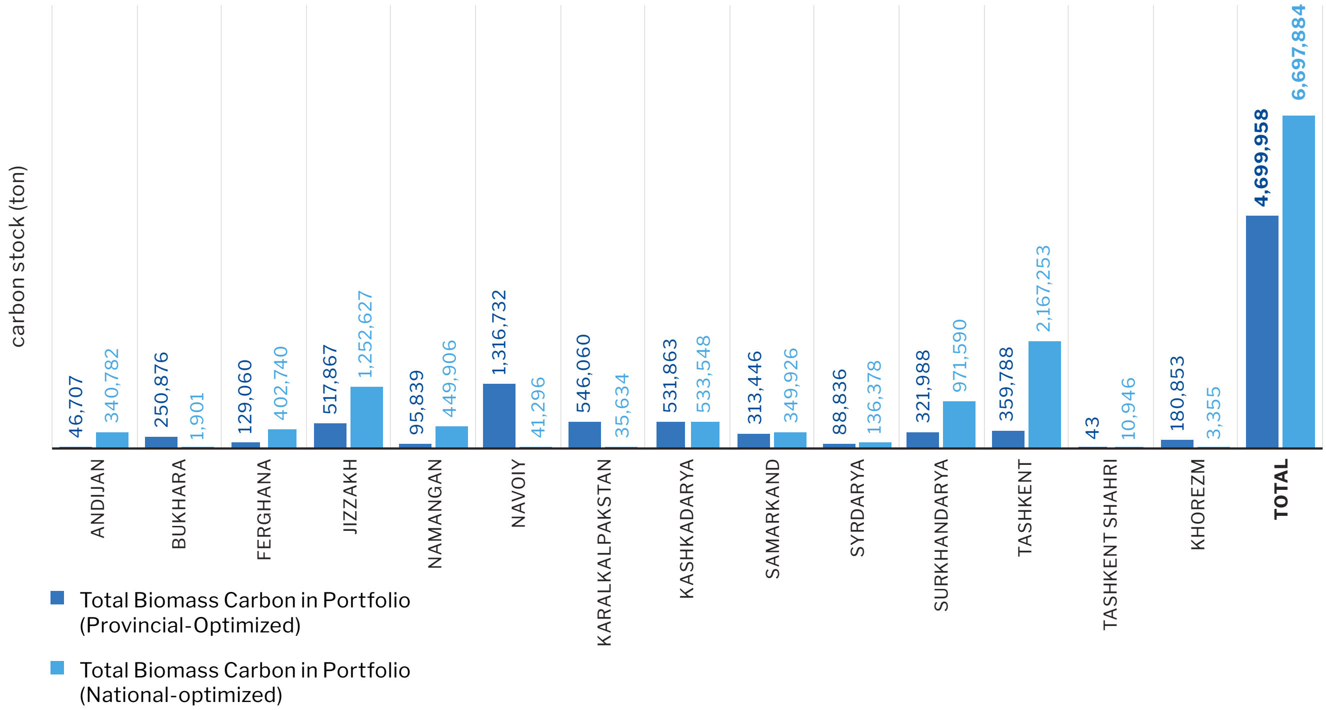
In terms of carbon stock, by 2050, the nationally optimized portfolio will stock 30 percent more carbon after implementing recommended technologies than the province-optimized portfolio. **Because the nationally optimized portfolio identifies the best areas within the national territory for maximizing ecosystem services, land restoration within the identified areas will sequester more carbon (Figure 18). Provincial optimization maximizes ecosystem services at the provincial level, which is suboptimal relative to national optimization, resulting in lower levels of carbon storage (Figure 18).**

Figure 17. Carbon stock - nationally optimized and province-optimized portfolios



Source: Original elaboration for this publication.

Figure 18. Composite index of adaptation opportunity, comparison between portfolios 1 and 2



Source: Original elaboration for this publication.

Note: Districts with higher scores show greater potential benefit from investments in landscape restoration, based on ecosystem services of erosion control, water regulation, and landslide mitigation.

7.2. Costs of Action (Investments) and Benefit: Cost Analysis

Benefit-cost analysis is a powerful tool that allows prioritizing investments in adaptation for a resilient landscape restoration for combating land degradation in the identified hot spot areas to capture the advantages of adopting economically and environmentally efficient and wsustainable technologies, thereby helping the country transition into a green growth model. The benefits of action versus the costs of action have been estimated for each investment portfolio. For the benefits of action, the objectives were to evaluate how changes in land use, agriculture, urbanization, and climate can affect the watershed hydrology water resource cycles, with direct effects on water availability, and for benefits of agricultural productivity (crop production), forage, and timber productivity, additional carbon sequestration will translate into benefits of actions on the adaptation hotspots.

7.2.1. Costs of Action

A literature review on approaches, available technologies, innovations, and conducive policy and institutional enabling conditions needed to move toward greening the agriculture, water, and forest sectors estimates the investment needs to adopt adaptation technologies in the hotspots of opportunity. Based on the results from the benefits and costs of action, a financial analysis of investment in greening the agriculture, forestry, and water sectors of Uzbekistan was completed, considering an indicative investment in 1.6 million ha of degraded lands prioritized for landscape restoration using the ecosystem service modeling approaches described in the previous sections. The approach used different market and nonmarket valuation systems to monetize the estimated costs of inaction and the benefits of action. Costs and benefits are projected out to 10 years, and all costs and benefits during the 10-year planning horizon are discounted to current US dollar values. These estimates are then used to provide estimates of BCRs by province and by biome. A more detailed description of the data and methods used and assumptions made in the report is provided in Annex 4.

Table 3. **Cost of an integrated technological suite to restore ecosystem services by province in Uzbekistan (US$/ha)**

Province	Crops	Water	Natural pastures	Forests
Andijan	254	487	23	195
Bukhara	660	707	23	190
Ferghana	296	377	23	190
Jizzakh	141	302	23	190
Namangan	524	436	23	190
Navoiy	560	285	23	190
Karakalpakstan	343	428	23	190
Kashkadarya	454	334	23	190
Samarkand	650	300	23	190
Syrdarya	439	533	23	191
Surkhandarya	236	364	23	190
Tashkent	506	289	23	190
Khorezm	766	738	23	190

The costs of the recommended technologies per ha of productive land are summarized in Table 3. The average costs per ha of applying recommended technologies differ for croplands, water, natural pastures, and forests. Natural pastures are the cheapest to restore, followed by forests, crops, and water. The highest cost per ha is in Bukhara and Khorezm, and the lowest is in Jizzakh, Surkhandarya, Ferghana, and Andijan.

The investment needs for the nationally optimized portfolio are about 14.5 percent lower than for the province-optimized one. For the nationally optimized portfolio, investment needs are estimated at about US$489 million (US$304 per ha), which is 0.7 percent of GDP in 2021. For the province-optimized portfolio, investment needs for the opportunity hotspots are estimated at US$560 million (US$340 per ha) to implement the recommended technological, institutional, and policy changes, which is 0.8 percent of GDP in 2021. In both portfolios, technologies in cropland and water sectors account for a large share of this investment requirement, averaging 48 percent and 45 percent, respectively, while forest and natural pastures follow with 3 percent and 4 percent, respectively. Most of the machinery and equipment that are needed to implement the recommended technologies have design periods (lifetime) of at least 10 years, so these investments will need to be made only once every 10 years.

7.2.2. Benefits of Action and Benefit-Cost Ratio

The total value of all the benefits of action to control land degradation in hot spot areas is estimated at between US$10.7 billion (for the nationally optimized portfolio) and US$8.9 billion (for the province-

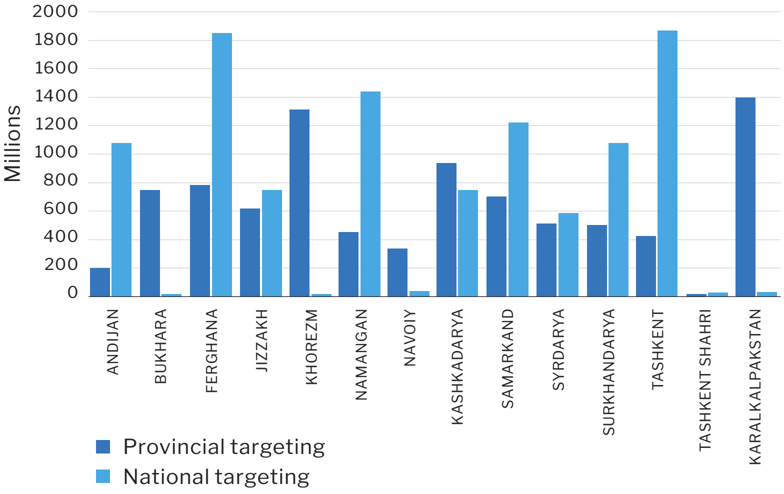
optimized portfolio) over 10 years[46] (US$1.5–1.8 billion annually or 2.4–2.9 percent of GDP). The value of benefits of landscape restoration in the optimized national and provincial portfolios is estimated in the future adaptation hotspots with a total area of 1.6 million ha. Implementing more sustainable land management and adaptation technologies in degraded landscapes can greatly reduce land degradation and possibly reverse the process in some cases, reducing the loss of ecosystem services and generating additional ecosystem services.

In the province-optimized portfolio, the largest benefits (51 percent and 42 percent) will come from investments in croplands and water. Karakalpakstan, Khorezm, and Kashkadarya, in descending order, being the top three provinces, will enjoy these benefits. In contrast, the nationally optimized portfolio shifts investments toward more valuable and productive croplands in the east, where the benefits from croplands (47 percent) and water (49 percent) are greatest in Tashkent, Ferghana, and Namangan (Figure 19).

Although investments in both portfolios are efficient, the BCR for the nationally optimized portfolio is 20 percent higher than for the provincially optimized one. Based on the above estimates of ecosystem service benefits in a 10-year planning period and the costs of implementation, the BCR for portfolio 1 (nationally optimized) is 19.0 (nationally optimized portfolio), and the BCR for portfolio 2 (province-optimized portfolio) is 15.8 (province-optimized portfolio).

Figure 19. Total 10-year benefits from investing in adaptation technologies, comparing two allocation approaches

	Nationally-optimized portfolio	**Province-optimized portfolio**
Total benefits, over 10 years (US$, billions)	10.7	8.9
Annual benefits (US$, billions)	1.8	1.5
Equivalent to GDP (%)	2.9	2.4
Investment needs over 10 years (US$, billions)	0.49	0.56



Source: Original elaboration for this publication.

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[46] Total value of benefits estimated over a 10-year planning period using a discount rate of 12.7 percent, which is the 10-year average of the recent past discount rates published by the National Bank of Uzbekistan, and rates of growth in GPP for the different biomes based on remote sensing data. Any discount rate lower than 12.7 percent, including 6 percent recommended to use for economic analysis in the World Bank, will increase BCR estimated for the integrated landscape restoration investments.

8. Bringing It All Together: Recommendations for Land Investments to Restore Ecosystem Services and Livelihoods in Uzbekistan

In investing in adaptation opportunity hotspots to restore ecosystem services and improve livelihoods, Uzbekistan could implement a framework to facilitate adoption of and create an enabling environment for the planning and financing of landscape restoration projects.

Overcoming institutional and policy barriers

Uzbekistan's landscape restoration efforts face several challenges due to institutional and policy issues. These include limited data and research, a fragmented approach to land use management, outdated planning, and inconsistent regulations. The legal framework for land and forest management is complex, creating confusion and hindering an effective resource allocation. Competing interests among stakeholders, such as farmers, herders, and conservationists, also pose challenges. Social risks arise from changes in land-use practices, potentially restricting access to traditional resources for local communities. Initiatives like the World Bank's Uzbekistan Resilient Landscapes Restoration Project pilot address these issues by promoting data collection, cross-sector collaboration, and inclusive planning.

- **Develop landscape restoration as an element of a broader framework for the national adaptation plan so that initiatives are anchored to this broad goal.** Landscape restoration initiatives are ongoing in a fragmented manner in Uzbekistan, and it's not anchored as a central policy within the framework of a broader national adaptation plan. However, better cross-sectoral implementation, monitoring, evaluation, and coordination are needed. According to the country's Third National Communication to the UNFCCC (TNC), although adaptation measures and actions are being implemented and planned in national and sectoral plans, Uzbekistan has yet to develop a national program for landscape restoration within the framework of its national adaptation plan. Therefore, Uzbekistan's National Adaptation Plan (NAP) will need to be underpinned by the National Strategy for Sustainable Development (NSSD) and closely aligned with the development strategy. Most measures have a sectoral emphasis and are integrated with sector-specific economic development strategies. Different ministries and agencies focus on other aspects of climate change without a formal structure to incorporate climate change-related concerns into national development programs and policies. No single institution is responsible for coordinating adaptation measures or implementing a national adaptation strategy for Uzbekistan. Some environmental policies and programs cover a range of sectoral activities, though the policies and programs are fragmented and uncoordinated.

- **Coordinate adaptation in water resources and irrigation sectors and develop rural integrated land use plan by district.** Increase the efficiency of water use in irrigation by promoting the adoption of water- and energy-efficient technologies in combination with complementary measures and climate-aligned agriculture policies. The implementation of many of the water- and pasture-related technologies require institutional strengthening or reform, including in the case of water, functional water user associations (WUAs) that can generate sufficient income to invest in technology (even when technology is farm level, the WUAs are likely to have a role in supporting the adoption) and in the case of pastures, some form of community decision on stocking rates and rotational grazing of pasture (likely requiring a reduction in stocking rates or a shorter grazing period which is very challenging). **Strengthen economic incentives for investments in climate-smart agriculture and forest landscape restoration** by strengthening land tenure security, liberalizing land use policies, and promoting land conservation investments through: (a) economic incentives such as repurposing of harmful agricultural subsidies into incentives for landscape restoration and introduction of payments for ecosystems services (PES) not only to farmers but also to organizations (WUAs or similar) responsible for natural resources management; (b) advising and training of farmers; (c) introduction of financing tools specifically designed to support farmers in adopting the improved technology in cases where there are short-term losses before the full benefits kick in.

- **Create an enabling environment for innovations in landscape restoration through public-private partnerships (PPPs) for climate research and development (R&D).** PPPs are needed to foster collaboration between the public and private sectors to drive technological innovations in landscape restoration. To improve collaboration further between the private and public sectors, partnerships between technology providers, agribusinesses, start-ups, and government agencies could leverage each other's expertise, resources, and networks.

Enhancing the Adoption of Technologies

Landscape restoration technologies can be applied across large land surfaces and different land uses; they can be very context specific, and thus, different innovations may be required in different contexts. Additionally, the same innovation may be applied in different contexts, but the application's parameters may differ. Hence, knowledge sharing on regulating parameters between different contexts is required. The knowledge-sharing platforms are currently lacking, which adversely affects the uptake of innovations. Some options to tackle the technological barriers are summarized as follows:

- **Create knowledge exchange and networking platforms on successful application of technologies in different contexts, with options for scaling up in similar contexts.** Knowledge exchange and networking platforms should be established and promoted to facilitate sharing experiences, best practices, and lessons learned in technological innovations for landscape restoration. In conjunction with this platform, exchange forums, conferences, and workshops should be promoted where stakeholders can convene, showcase their innovations, and learn from each other's successes and challenges. Developing such initiatives will establish communities and spaces of practice for ongoing collaboration and information sharing.
- **Develop a government program and increase extension services capacity in the integrated landscape restoration to help farmers improve their technology as a tool for increasing agriculture, water use, and energy efficiency.** This report has highlighted existing inefficiencies in current practices related to resource saving and energy efficiency. Technologies such as conservation agriculture, drip irrigation, raised beds, and improved high-yielding crop varieties that are tolerant to various biotic and abiotic stresses have been proposed. There is a need to develop programs where technologies to alleviate these issues can be distributed among farmers. Such programs are important in the short- to medium term to address existing inefficiencies, and in the long term to prepare farmers for the adoption of other technologies referenced above.
- **Develop a national strategy to support integrating national, regional, and local landscape management at the project level with the participation of the private sector.** To improve landscape management capabilities and ensure the implementation of landscape management best practices across policy and legal frameworks across Uzbekistan, there is a need for a national strategy that addresses the issue of landscape management. A national strategy will act as an enabling tool for implementing best practices across different sectors, developing a shared vision across government levels and units to foster synergies.

8.1. Prioritizing Investments for Landscape Restoration

The analysis presented in this report highlights priority areas for landscape restoration, costs of action, and benefits of action; these findings are also very relevant for national landscape restoration initiatives.

Large-scale landscape restoration projects such as the Uzbekistan Resilience Landscape Restoration project (RESILAND) and the 'Yashil Makon' (Green Nation) initiative should prioritize opportunity hotspots. By prioritizing investments in these hotspots, the country gains more per dollar spent in terms of increased productivity of landscapes and ecosystem services, thus permitting higher returns for further expanding into other areas in the medium to long term.

Under the sustainable and efficient use of natural resources of the presidential decree on the transition to a 'green' economy and ensuring 'green' growth in the Republic of Uzbekistan until 2030, the findings of this report propose actions that inform the following aspects of the decree:

- **Developing and implementing agricultural solutions that feed a growing population while ensuring food security and conserving water resources.** The hotspots identified in cropland and pastureland should be prioritized at the national and regional levels because they permit an increase in agricultural productivity and thus have implications for food security.
- **Introducing practices based on sustainable landscapes, forest restoration, and sustainable use of natural resources.** The report provides a suite of technologies for sustainable landscapes that can be used for landscape restoration and thus enhance the move toward a green economy.
- **Harmonization of crop diversification and the introduction of water-saving agricultural technologies with landscape restoration measures.** Crop diversification options and water-saving propositions with cost and benefits have been highlighted in this report; widespread application of these technologies will help support the sustainability of landscapes.
- **Landscape restoration.** Prioritize investments in adaptation, forest, and landscape restoration based on the potential for adoption of climate-smart technologies, the speed of investment recovery, and socioeconomic factors.

8.2. Mobilizing Finance for Landscape Restoration

Mobilizing at least US$0.5 billion for landscape restoration and overcoming potential financial barriers are essential. To adequately leverage mobilized finance for landscape restoration, the following two key categories of barriers need to be addressed:

- Systemic barriers that emerge because environmental and social benefits of landscape restoration have no market value, also, because direct incentives to degrade land outweigh incentives to restore land. Payments for ecosystem services, repurposing carbon tax as subsidies for landscape restoration are some of the solutions.
- 'Scaling up' barriers that emerge from that fact that many restoration projects are too small to attract private finance or require a long investment time horizon (10-20 years) and thus are often considered a risky investment (with limited data on financial returns). To mobilize finance for landscape restoration in Uzbekistan, actions and strategies must be put in place to overcome these barriers for public and private investments.

The following is recommended for mobilizing finance for landscape restoration.

Solutions to address public finance barriers:

- **Develop landscape restoration portfolios targeting each region's unique landscape degradation challenges to prioritize spending based on where the highest benefits are achievable.** In the face of limited funds for landscape restoration, there is a need for targeted investments into the interventions that have the most benefits for the local community. To improve spending efficiency, one could establish landscape restoration portfolios on the province level to target spending better. Such a policy would allow Uzbekistan to achieve substantial positive outcomes in the face of financial barriers.
- **Integrated approach within client governments to increase budget for restoration from different sectors:** Convene multi-donor roundtables for large-scale resource mobilization for landscape restoration**.** The opportunity hotspots and investment needs identified for the two scenarios (the national and provincial) provide a scope for different donors and actors to make investments in different provinces and sectors (agriculture, water, or forests). This offers a collaboration space among donor organizations for pooling funds for investment in opportunity hotspots while leveraging the investment synergies .

- Use **Public Expenditure Review** as a key instrument to optimize public spending, ensuring that investments in landscape restoration contribute effectively to building resilient and sustainable landscapes. The instrument identifies areas where public funds may not be used efficiently, allowing for reallocation to more impactful initiatives. It can highlight how different policies and expenditures across various sectors and government levels integrate to support landscape restoration efforts.
- Develop a **carbon credits framework** to provide a financial incentive to restore landscapes. The revenue from carbon credits can be used to fund further restoration activities, creating a sustainable funding mechanism that supports ongoing resilience efforts. Quality carbon credits require building realistic and credible baseline on the jurisdictional level, providing permanent greenhouse gas (GHG) emission reductions that are ensured by robust monitoring and verification. Solid benefit-sharing mechanism could help engage local communities. As the demand for carbon credits grows, it can lead to the development of new markets and financial instruments that support restoration activities. This can increase the flow of capital into the FOLU sector and promote the adoption of best practices for resilient landscapes.
- **Develop architecture for Green Finance:** Promote the use of green finance (private and public) for investing in landscape restoration through carbon credits, PES, green bonds, cross-sectorial platforms for budget planning, PPPs, and so on.

Solutions to address private finance barriers:

- **Develop a green taxonomy to encourage investment in landscape restoration projects.** A green taxonomy is a standardized green classification system that translates environmental objectives into criteria for specific economic activities for investment purposes. Green taxonomy is a tool for policymakers to encourage sustainable activities, to prevent ‘greenwashing’ and to direct private sector’s investments towards sustainable activities that achieve environmental objectives. Uzbekistan is already working on the development of a green taxonomy. The combination of a taxonomy and a national strategy on landscape restoration will create a framework for green private investments.
- **Mainstream investing in landscape restoration:** Uzbekistan can attract impact investors for landscape restoration projects by: (a) highlighting the environmental and social benefits; (b) partnering with research institutions to estimate long-term financial returns associated with agricultural productivity, reduced disaster risks, and eco-tourism attributed to landscapes restoration; (c) building trust and transparency through a strong legal framework; (d) implementing a streamlined investment process; (e) establishing standardized contracts; (f) engaging stakeholders through community involvement and ensuring communities’ buy-ins; and (g) and encouraging PPPs. By implementing these strategies, Uzbekistan can attract significant investment in its landscape restoration projects.
- **Issue restoration bonds:** Uzbekistan can attract restoration bonds for landscape restoration projects by developing a comprehensive national restoration strategy, quantifying the expected environmental and social benefits, ensuring bond issuance viability, and enhancing creditworthiness through international organizations or foundations. To address investor concerns, Uzbekistan should implement robust monitoring and evaluation frameworks, define exit strategies for bond investors, target impact investors with a strong track record in environmental or sustainable investing, and publicly demonstrate Uzbekistan’s commitment to landscape restoration through government policies, budget allocations, and partnerships with environmental NGOs. By demonstrating these steps, Uzbekistan can build trust with potential bond issuers and investors, making restoration bonds a more attractive option for financing landscape restoration projects.
- **Reduce private sector risk through guarantees:** Uzbekistan can attract investors by offering guarantees for landscape restoration projects. Partial government guarantees can cover a portion of the investor’s losses if the project fails to meet predetermined benchmarks. Performance-based guarantees can be tied to the project’s success, providing full payout if it achieves environmental and social goals. Guarantees against specific risks, such as political instability or currency fluctuations, can make investment more attractive. Ecosystem

service payments can be guaranteed at a minimum price, ensuring investors receive a return on their investment. However, guarantees come with costs, transparency, and a robust monitoring system. A balanced risk-sharing model should be created to incentivize responsible investment. Alternative solutions include collaborating with insurance companies to mitigate risks and establishing trust funds to provide financial backing for restoration projects.

9. Conclusion

Given the importance of the agriculture, forest, and water sectors in meeting targets highlighted in the NDC and the Uzbekistan green growth strategic framework, there is a consensus within the Government of Uzbekistan on the need to reverse degradation trends and adapt to climate change. By adopting a green growth model in its agriculture, forest, and water sectors, Uzbekistan can **enhance** the natural capital and, as a result, garner several social, biophysical, and environmental benefits. The issue is no longer if but rather when and how greening these sectors should be prioritized considering their investment returns. This study attempts to provide full or partial answers to these questions.

By investing in climate adaptation and landscape restoration, Uzbekistan can not only prevent the loss of substantial amounts of ecosystem services, including crop production, water, soil, and the associated amounts of emissions, but also can increase ecosystem services in 5–10 years—thereby enhancing the efficient use and sustainability of the natural capital. In terms of the returns on investment, the study used the conservative estimation of the costs of inaction (in terms of the amounts of various ecosystem services that are being lost) and the corresponding benefits of action. It has demonstrated that by introducing the recommended technological changes, the investment in greening the agriculture, forest, and water sectors, specifically in the prioritized land degradation hot spot areas of Uzbekistan, has a BCR of 19.03 (nationally optimized portfolio) and 15.81 (province-optimized portfolio). This indicates that the long-run benefits of investing in landscape restoration are at least 15 times the investment cost.

Uzbekistan's pivot toward greener agriculture, forest, and water sectors will require introduction of a suite of policy, institutional, and technological changes and overcoming of a set of corresponding barriers to introduce these changes. Several technological, institutional, and policy options are available for Uzbekistan to reduce degradation of the natural capital in the agriculture, forest, and water sectors. Restoration of degraded landscape will become an element of a broader framework for the national adaptation plan so that initiatives are anchored to this overarching goal. An enabling environment will include relevant policies and institutions to strengthen economic incentives for investments in climate-smart agriculture and forest landscape restorations and innovations in landscape restorations through PPPs for climate R&D . In parallel, innovative technologies should be deployed. This could be achieved by establishing knowledge exchange and networking platforms on application of technologies and developing a national program to help farmers improve their technologies to increase agriculture, water use, and energy efficiency.

Finally, to mobilize finance for landscape restoration in Uzbekistan, the government could take a lead in developing landscape restoration portfolios targeting each province's unique landscape degradation challenges to prioritize spending based on where the highest benefits are achievable. It could convene multi-donor roundtables for large-scale resource mobilization for landscape restoration; develop architecture for carbon credits markets, Green Finance and green taxonomy; mainstream impact investing for landscape restoration; issue restoration bonds; and reduce private sector risk through guarantees.

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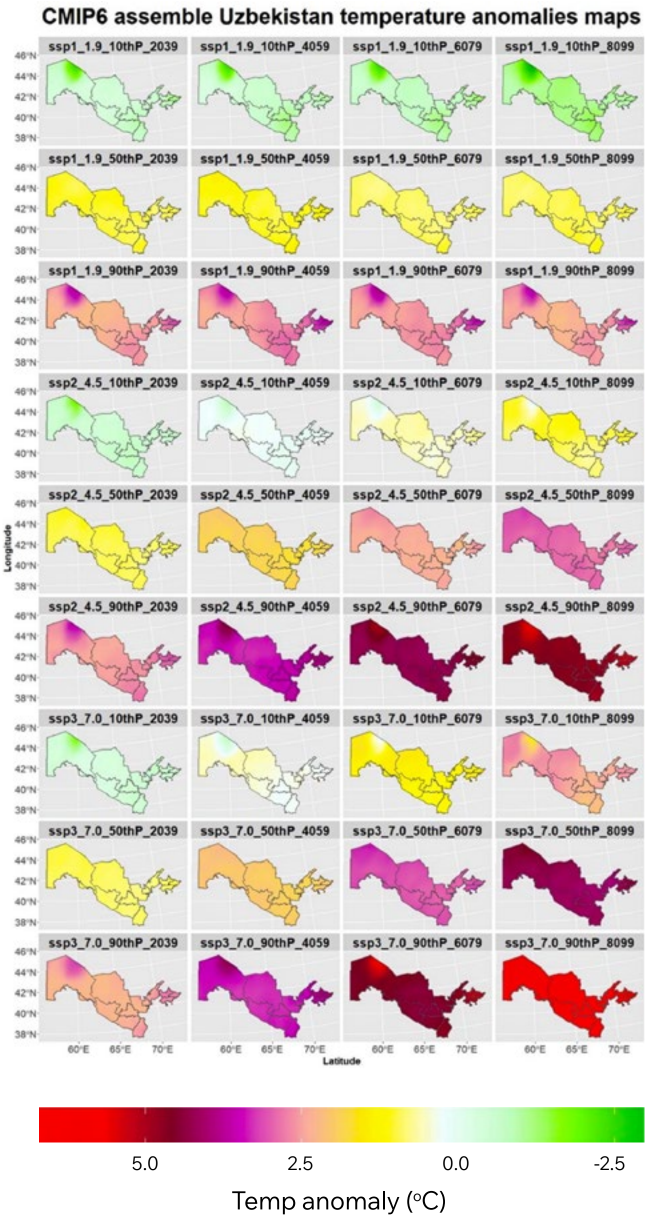
Annex 1. Methods to Assess Drivers of Change and Identify Hotspots of Land Degradation

Climate Risk Analysis

In this study, the Coupled Model Inter-comparison Project (CIMP6) climate change data from the World Bank Climate Change Knowledge Portal (WBCCKP) were processed using the model ensemble approach for optimistic, moderate, and pessimistic scenarios (SSP1-1.9, SSP2-4.5, and SSP3-7.0) and for two different time horizons (2030 and 2050).

For the further identification of risk hotspots, a climate change risk score was calculated for each district based on the projected magnitude of change in four climatology-derived variables that directly affect the provision of ecosystem services from landscapes: standardized precipitation evapotranspiration drought anomaly (an indicator of drought risk), Rx1 day anomaly (an indicator of flood risk), precipitation (Pr) anomaly (an indicator of changes in rainfall), and growing season length (GSL) anomaly (an indicator of risks to productivity). For each model ensemble and variable considered, the 10th, 50th, and 90th percentile values were considered to reflect the range of conditions that Uzbekistan might face in the coming decades. The climate risk score for each district was estimated as the averaged multi-scenario deviation of future climate variables from baseline (2021) observed conditions, where the districts with the greatest deviation in future climate are assigned the highest risks scores. See Table 1.1 for more details on the climatology-derived variables used in the climate risk calculation.

Figure A1.1. Spatial pattern of predicted temperature anomalies for three climate scenarios (SSP1-1.9, SSP2-4.5, and SSP3-7.0), three percentiles of model ensemble predictions (10th, 50th, and 90th), and four time periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099)



Source: Original to this publication.

Figure A1.2. Spatial pattern of predicted rainfall anomalies for three climate scenarios (SSP1-1.9, SSP2-4.5, and SSP3-7.0), three percentiles of model ensemble predictions (10th, 50th, and 90th), and four time periods (2020–2039, 2040–2059, 2060–2079, and 2080–2099

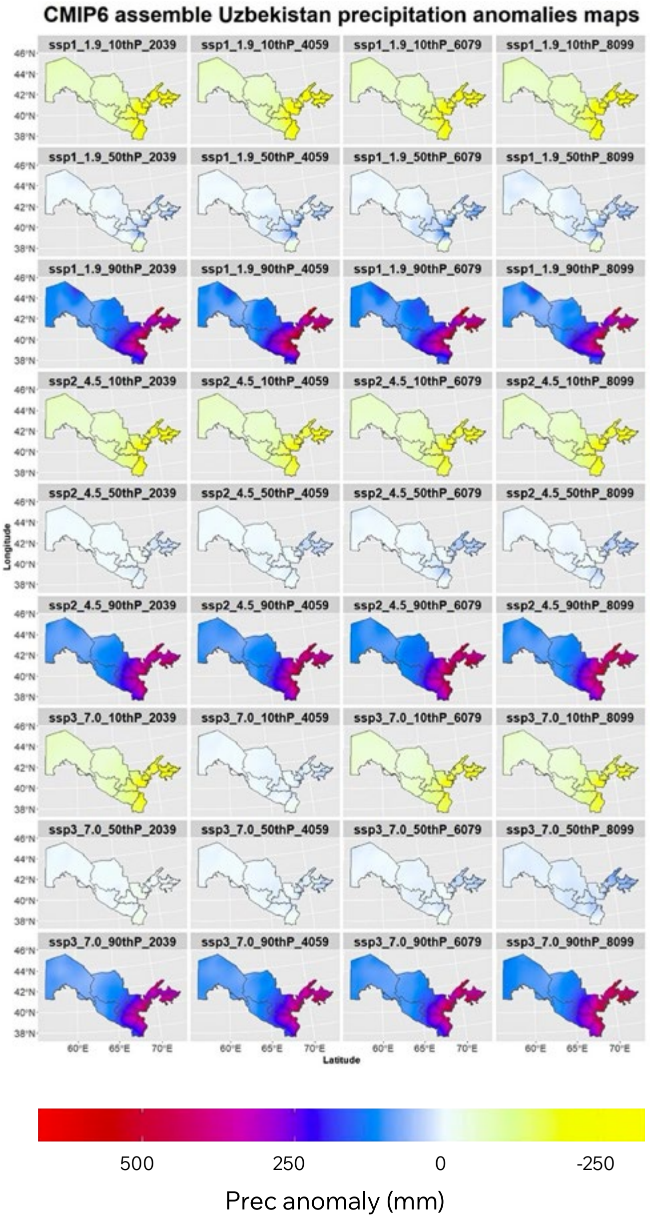


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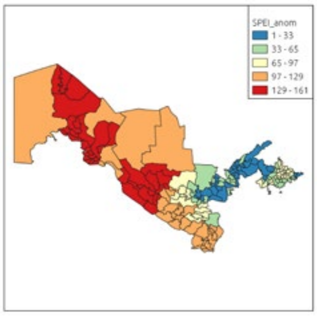
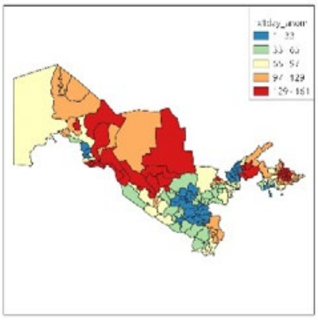
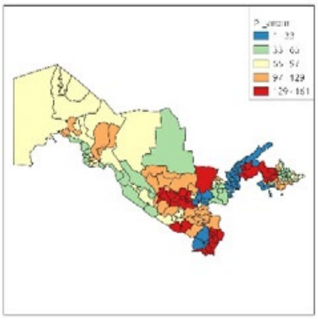
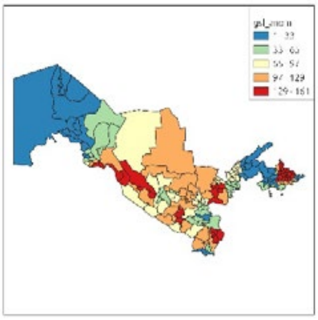
Table A1.1. Details on climate-derived variables used in the calculation of the climate change risk score for districts in Uzbekistan

Variable	Rationale	Score approach	Result
Standardized precipitation evapotranspiration (SPEI) drought anomaly	SPEI is a multi-scalar drought index based on climatic data. Negative SPEI values are indicators of drought. Anomalies are the deviation of current climate conditions from present observed climate data.	The average SPEI anomaly across multiple scenarios (pessimistic, moderate, and optimistic) and Percentiles (10th, 50th and 90th) for both time horizons (2030 and 2050) are tabulated for each district. Higher scores are assigned to lower SPEI anomalies, indicating severe drought condition in the future	
Rx1 day anomaly	Rx1 Day is the maximum daily precipitation event depth. Higher Rx1 values are associated with the triggering of natural disaster events such as landslides and floods.	The average Rx1 Day anomaly across multiple scenarios (pessimistic, moderate, and optimistic) and percentiles (10th, 50th, and 90th) for both time horizons (2030 and 2050) are tabulated for each district. Higher scores are assigned to higher Rx1 Day anomalies, indicating increase in extreme rain events depth.	
Pr anomaly	Pr is the total annual precipitation depth. Pr anomaly is the increase/decrease in precipitation from current observed data. Negative values indicate reduction in rainfall inputs.	The average Pr anomaly across multiple scenarios (pessimistic, moderate, and optimistic) and percentiles (10th, 50th, and 90th) for both time horizons (2030 and 2050) are tabulated for each district. Higher scores are assigned to lower Pr anomalies, indicating reduction in total annual rainfall.	
GSL anomaly	GSL anomaly indicates the additional days per year when crops and other plants will grow successfully in the future. A lengthening growing season implies a greater potential demand of freshwater resources. GSL increase also means pests spawning multiple generations per season, increasing their negative impacts on crop productivity.	The average GSL anomaly across multiple scenarios (pessimistic, moderate, and optimistic) and percentiles (10th, 50th, and 90th) for both time horizons (2030 and 2050) are tabulated for each district. Higher scores are assigned to districts with higher GSL anomalies, indicating a greater exposure to increased water resources demand and pests increase.	

Source: Original to this publication.

Modeling Land Degradation

Spatial patterns and trends in land degradation are evaluated using the time series of the National Aeronautics and Space Administration (NASA) Moderate Resolution Imaging Spectroradiometer (MODIS) GPP in agricultural landscapes. GPP is an indicator of biomass productivity in Uzbekistan's croplands, pastures, and forests, and while it varies year to year with annual weather patterns, it can also exhibit an increasing or decreasing trend through time. In this study, the European Space Agency (ESA) WorldCover 10 m 2021 product was used as a starting point, and then, trends in GPP as an indicator of improving or declining vegetation vigor were used to further classify land use land cover (LULC) into condition classes: good, fair, or poor.

The average value of GPP is calculated for each district and for each year from 2001 to 2020 and the trend slope estimated using pixel-wise linear regression. The linear regression parameters were then used to project GPP in each pixel forward in 20-year increments. For future scenarios, GPP per district is tabulated using the same 20-year time windows but centered on 2030 and 2050. This time window approach reduces the potential to overestimate or underestimate average GPP due to extrapolating based only on one or two very wet or very dry years, for example.

The resulting land use and vegetation condition rasters correspond to a categorical land cover classification with additional information on vegetation condition, based on projected GPP. Any given pixel can have the same GPP in the future as in the baseline (stable condition pixel), higher GPP (improving condition pixel), or lower GPP (degrading condition pixel). Vegetation covers from ESA were then classified into vegetation condition classes (poor, fair, and good). This classification was based on the mean and standard deviation (SD) in the baseline GPP measurements for each natural vegetation cover class (forests, pastures, and croplands), such that 'fair' was assigned to pixels within mean ± 0.5 SD, 'poor' was assigned to pixels < mean – 0.5 SD, and 'good' was assigned to pixels > mean + 0.5 SD. If the GPP trend for a given pixel is strong enough, as a result of the scenario assumptions, that pixel GPP value might change enough by 2050 to move from one bin (for example, fair) to another (for example, poor or good). Note that land uses themselves did not change in the projected futures, only the relative condition.

Projections of future land use and vegetation conditions without land management interventions were developed for the BAU/No-action scenario, based on linear extrapolation of historical trends in land degradation as described above. For the adaptation scenario, landscape restoration actions were reflected as a one-step improvement in the pixel-level vegetation condition class. For example, a given pixel of pastureland cover projected to be in 'poor' condition as a result of GPP trends would be changed to 'fair' condition as a consequence of restoration activities implemented in the adaptation scenario.

Population Change

Population growth was projected using a gridded regression model based on historical population density data from WorldPop (Tatem 2017). Population density grids for 2000, 2005, 2010, 2015, and 2020 were used to derive the slope and y-intercept of the linear regression, which was then applied to each pixel in the country at 1 km resolution. The resulting regression parameters were used to propagate into the future the observed trends in population data from 2000 to 2020. The resulting population density raster, in terms of total inhabitants per km^2, for 2030 was used along with trends in land degradation (GPP) and composite climate risk scores to generate an aggregate risk score and to identify land degradation risk hotspots.

Population density is used in this analysis as a driver of change and as a variable for assessing the impacts of adaptation actions. First, population density is used to define the areas where the implementation of adaptation technologies and nature-based solution (NBS) strategies would be viable and meaningful. Since the desired impact of adaptation strategies is the benefit of people living in these rural landscapes, the presence of people is the deciding factor. For this, an arbitrary threshold of >10 inhabitants per km^2 is used to identify the areas for the implementation of adaptation measures.

Next, population density is used as a variable for impact analysis, providing information on the potential direct beneficiaries of the implementation on the adaptation technologies and strategies. It is used directly as the total population present in areas where ecosystem services change between scenarios as a result of landscape management actions. The effect is that potential changes in ecosystems in areas that benefit a greater number of people return higher scores in the mapping of adaptation opportunity hotspots.

Annex 2. Methods to Model Ecosystem Services and Identify Hotspots of Adaptation Opportunity

The objective of the analysis is to identify hotspots of adaptation opportunity, that is, areas where the implementation of adaptive technologies can show the greatest improvement in

- Controlling erosion and reducing soil loss, thereby preventing further losses in the productivity of croplands, pastures, and forests;
- Improving rainfall-runoff dynamics, thereby reducing peak flows and increasing base flows; and
- Improving slope stability and decreasing the risk of small to medium-size landslides.

To this end, spatially explicit ecosystem services models were applied to estimate the potential improvement that could be achieved through implementing landscape restoration in Uzbekistan's productive landscapes. Each of these ecosystem service models is described briefly in the following sections.

To model the potential benefits of land restoration and adaptation technologies, this analysis assumes such activities would be implemented in productive lands—those classified as croplands (cultivated and managed vegetation), grazing areas (pastures and herbaceous vegetation), or forests. Adaptation potential was estimated using the InVEST Sediment Delivery Ratio (SDR) and Seasonal Water Yield (SWY) models and a landslide/slope stability model (described below).

To reflect changes in land condition due to adaptation actions, our approach assumed that land restoration would have the effect of improving a land parcel's condition class from 'poor' to 'fair' or from 'fair' to 'good'. Model parameters reflecting this change in land condition for each scenario were developed and used as input to the erosion control, water regulation, and slope stability models.

In addition to modeling changes in land condition due to degradation or restoration, the magnitude and direction of changes in rainfall and temperature were also used to evaluate the impacts of climate change on these ecosystem services outcomes, as described in the following sections. To reflect climate changes, only the 50th percentile values from each SSP's model ensemble were used. For each model, results were averaged across the three SSP scenarios.

Model results were then used to estimate the benefits of restoration in Uzbekistan's productive lands (croplands, pastures, and forests). Benefits of restoration are calculated for each district as the percent change in the total sediment export, total annual baseflow, total storm surface runoff, and total extent of land with unstable slopes between the BAU/No-action scenario and the scenario where adaptation practices are implemented.

Erosion Control

Soil erosion is the movement or displacement of the upper layer of soil, and it is a naturally occurring process that affects all landforms. Certain human activities greatly enhance this process and contribute to a substantial soil loss. This is significant because topsoil contains the highest amount of organic matter and is best suited for agricultural activities.

In this study, the InVEST SDR model (Natural Capital Project 2022) was utilized to estimate the potential impacts of climate, land degradation, and restoration on erosion and sedimentation. The spatially explicit SDR model estimates for each pixel the average amount of erosion per year and then integrates information on the landscape context (land cover and land use upslope and downslope of the pixel) to estimate the amount of sediment thereafter retained on the landscape or washed away in streams. The model is based on an implementation of the Revised Universal Soil Loss Equation (RUSLE1) (Renard 1997) for the calculation of annual soil loss and includes a sediment delivery function as a function of the hydrological connectivity of each pixel in the landscape. Data for the SDR model include biophysical parameters for the calculation of erosion dynamics, sediment export, and retention across the landscape, including data on elevation, LULC, rainfall erosivity, soil erodibility, topography, vegetation cover, and management practices.

The three climate scenarios—optimistic, moderate, and pessimistic—were modeled at 2050 on top of each land management scenario. This involved changing the land use/vegetation condition input to the model (to reflect land degradation or restoration), as well as the rainfall erosivity input (to reflect climate change).

The primary climate input to the SDR model is rainfall erosivity. Future rainfall erosivity values were obtained by using the multiple regression formula below:

$$EI_{30} = -25185 - 136MFI + 28P + 27223SI$$

where

EI = Rainfall erosivity, in MJ mm ha^{-1} h^{-1} yr^{-1}

MFI = Modified Fourier Index, derived from average monthly rainfall from 2010 to 2020

SI = Seasonal Index, derived from average monthly rainfall data from 2010 to 2020.

The coefficients for the multiple regression were obtained by fitting the historical rainfall data set at 50 km against the high-resolution (1 km) data set of rainfall erosivity from the European Soil Data Center (Panagos et al. 2017). The multiple regression was used to project future rainfall erosivity, and then the anomalies between projected and historical values were used to adjust the high-resolution rainfall data set used as input to the SDR model. The reason to use the anomalies between historical and projected erosivity instead of directly using the future estimations of rainfall erosivity is to maintain the spatial heterogeneity present in the high-resolution product, where mountain ranges and precipitation shadows are mapped.

Pixel-level model results for sediment export were totaled for each district, and the difference between the BAU/No-action scenario and the adaptation scenario was used as an indicator of the benefit of land restoration for sediment retention.

Water Regulation: Baseflow and Flood Control

The water regulation ecosystem services considered include the infiltration of water and flow through the subsurface, contributing to baseflow, and surface runoff, which can contribute to flood risk. The InVEST SWY model (Natural Capital Project 2022) was utilized to estimate the potential impacts of climate, land degradation, and restoration on these water regulation services. The model estimates the amount of water produced by a watershed that arrives in streams over the course of a year. The two primary outputs of the model are quick flow and baseflow—quick flow represents the amount of precipitation that runs off the land directly, during and soon after a rain event, and baseflow is the amount of precipitation that enters streams more gradually through subsurface flow, including during the dry season. Data inputs to the SWY model include rainfall, potential evapotranspiration, topography, soil, and land cover.

The SWY model requires monthly rasters from multiyear averages of rainfall depth, potential evapotranspiration, and number of rain events. A temporal reduction of daily time series of precipitation and potential and actual evapotranspiration was applied to Climate Hazards InfraRed Precipitation with Stations (CHIRPS) (Funk et al. 2015), TerraClimate (Abatzoglou et al. 2018), and MODIS 16A2 (Running, Mu, and Zhao 2017) databases using Google Earth Engine. The reduction algorithm computed rainfall depth, number of rain events, and potential and actual evapotranspiration for each pixel from 2001 to 2020 to extract the monthly averages. Vegetation water use coefficients (Kc) for the SWY model were derived by taking the ratio of actual to potential evapotranspiration over the same period. Soil physical properties were based on SoilGrids and reclassified into hydrologic soil groups. Curve numbers (CNs) for each LULC were assigned following the United States Department of Agriculture (USDA) Soil Conservation Service (SCS) procedures (USDA-NRCS 2004) (Table A2.1).

Table A2.1. Selection of CN parameter values based on USDA SCS guidance

LULC	USDA SCS CN and Condition Criteria
Evergreen Broadleaf Forests	USDA cover type: Woods Condition: Fair Condition description: Woods are grazed, but not burned, and some forest litter covers the soil.
Savannas: tree cover 10–30%	Derived CN as a combination of 70% grasslands and 30% evergreen broadleaf forests
Grasslands: dominated by herbaceous annuals	USDA cover type: Grasslands Condition: Fair Condition description: 50–75% ground cover and not heavily grazed
Permanent wetlands	Same as evergreen broadleaf forests.
Croplands	USDA cover type: Row crops Cover description treatment: Straight row (SR) Hydrologic condition: Good Condition description: • Density and canopy of vegetative areas: HIGH • Percent of residue cover on the land surface (good >20%): HIGH • Conservation tillage good hydrologic condition, more than 20 percent of the surface is covered with residue (greater than 750 pounds per acre for row crops or 300 pounds per acre for small grain).
Urban, built-up or exposed soil	USDA cover type: Developing urban areas Condition: Newly graded areas (pervious areas only, no vegetation)
Cropland/natural vegetation mosaics	Same as croplands
Water bodies	CN does not apply.

The SWY model was run for the baseline (2021) condition and both the BAU/No-action and the landscape restoration scenarios considering climate change conditions to 2050. The three climate scenarios — optimistic, moderate, and pessimistic — were modeled at 2050 on top of each land management scenario. This involved changing the land use/vegetation condition input to the model (to reflect land degradation or restoration), as well as the monthly mean rainfall, rainfall frequency, and potential evapotranspiration (to reflect climate change). The 50th percentile of the ensemble values for each SSP scenario was used to drive the SWY model, generating six scenarios (three SSPs for each of the two land management scenarios). The average results for the three SSP scenarios were taken as the representative outcome and were used in further calculation steps. As with the sediment data, no field-based observation data on water flows were available for model calibration, so results should be interpreted in terms of relative, rather than absolute, flow values.

Pixel-level model results for baseflow and surface runoff were totaled for each district, and the differences between the BAU/No-action scenario and the adaptation scenario were used as indicators of the benefit of land restoration for baseflow improvement and flood mitigation, respectively.

Slope Stability and Landslide Mitigation

Estimates of landslide hazard and mitigation potential were generated using the Factor of Safety (FS) approach (Selby 1993), which relates slope, depth of soil, soil water saturation, and soil cohesion along with other soil properties to estimate an FS that reflects the probability of slope failure. This approach is widely used in geotechnical engineering for slope failure prediction and is the same model that was used in the landslides risk modeling in Kali Gandaki Case Study, Nepal (World Bank 2019). This model produces a raster that represents the ratio of resisting forces to driving forces (FS) on a potential shear plane where FS below 1 is considered unstable and FS greater than 1 is stable. FS is calculated as follows:

$$FS_i = \frac{c_i + \delta c_i + (\gamma_s - \gamma_w * m_i) * z_i * \cos^2 \alpha_i * \tan \phi_i}{\gamma_s * z_i * sin\alpha_i * cos\alpha_i}$$

where

z_i: *soil depth, assumed to be the depth of a potential failure plane [m]*
α_i: *slope angle [degl*
φ_i: *soil internal angle of friction*
c_i: *soil cohesion [kPa]*
δc_i: *Sc;: added cohesion because of plant roots [kPa]*
γ_s: *Y: unit weight of soil [kN/m3]*
γ_w: *Y: unit weight of water [kN/m3]*
m: *m: soil water saturation [-]*

The FS model was applied at the country level, using the inputs and parameters given in Table 2.2. Soil water saturation, in the traditional use of the FS calculation, is fixed for a certain amount, usually saturation capacity of soil profile between 0.4 and 0.5, or for a reference storm event. The soil saturation was estimated for baseline and each SSP scenario as a function of the maximum 1-day rainfall parameter (Rx1; see Table A1.1). Percent soil water saturation was assumed to scale linearly with Rx1 up to a threshold of 100 mm, above which 100 percent saturation is assumed.

Table A2.2. FS landslide hazard model inputs and parameters

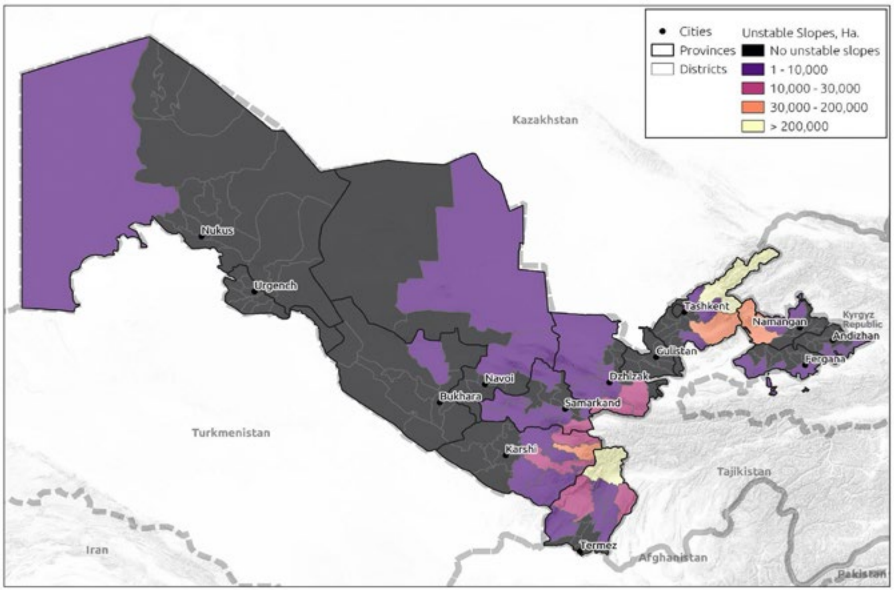
Model	Inputs and parameter sources
FS	• DEM: SRTM 30 – EPSG:32735 • Soil thickness: depth to R horizon, from SoilGrids (1.2 ~ 2 m) • Soil water saturation: based on linear scaling using Rx1 Day variable from WBCCKP • Soil friction angle: 16 ~ 33 degrees, according to soil classes • Soil bulk density: from SoilGrids (0.83 ~ 1.4) • Cohesion: inorganic soils = 0 kPa; for forest covers derived from GPP, 0 ~ 10 kPa

Outputs from the baseline landslide hazard FS model were then summarized such that each pixel with a value of FS equal to or less than 1 was considered 'unstable', and assigned a landslide hazard value = 1, and each pixel with a value of FS greater than 1 was considered 'stable' and assigned a hazard value = 0.

Modeling Impacts of Restoration on Slope Stability

As discussed in World Bank (2019), soil cohesion factor from plant roots can be used to evaluate not only the ecosystem services of landslide risk reduction given current landscape configuration but also the potential of landscape management practices to further reduce it. It can also be applied in climate change scenarios analysis by modifying the soil water saturation to account for changes in rainfall intensity/depths. This approach therefore allows for estimating the contribution of root cohesion to slope stability by adding additional cohesion to the baseline cohesion of soils based on physical soil texture and other properties. This additional cohesion afforded by greater root density is expected from the implementation of activities oriented toward the improvement of vegetation that increases vegetation productivity and soil cover.

Figure A2.1. Results of baseline assessment of slope stability, showing the total extent of unstable slopes (ha) per district in Uzbekistan



Source: Original to this publication.

From a civil and geotechnical engineering standpoint, a failure of natural slopes is a consequence of unstable slopes usually triggered by excessive rains, physical cuts on slope profiles due to infrastructure construction (that is, roads), or loss of soil cohesion properties such as vegetation removal. In the case of shallow seated slope instability, which occurs within 2 m deep and following a rotation movement, root tensile strength from vegetation covering the soil can directly contribute to improving stability and increasing slope resistance to heavy rainfalls (Coppin and Richards 1990). Water is the single most important factor affecting slope stability, and the presence of vegetation can affect the groundwater level and the pore pressure within the soil mass. Vegetation reduces the surface runoff and increases the percolation. More significantly, vegetation can decrease the pore water pressure as a result of evapotranspiration. Evapotranspiration also gives rise to an increase in the effective soil cohesion due to soil suction, and the reinforcement effect of the root matrix further enhances the effective soil cohesion. Where the roots are of sufficient size and length to cross the potential failure slip surface, they also provide a tensile force which is an additional restraint on the potential slip plane (Freer 1991; Freer et al. 1997). These mechanical and hydrological benefits of vegetation, whether from grasslands, shrublands, or trees, are expressed as shear strength in the form of additional soil cohesion of the soil profile, and the planned use of vegetation to reduce slope instability is called Biotechnical Stabilization (Gray and Sotir 1996).

We evaluate the potential for vegetation management to mitigate erosion and landslide hazards by simulating two future scenarios under climate change and comparing them with the baseline condition: one with vegetation cover fully intact (adaptation) and another with little to no vegetation cover (BAU/No-action). For this high-level screening analysis, we do not make any assumptions about the specific land management practices employed; rather, we assume the outcome of improved vegetation cover and structure. We assume that the most locally appropriate technologies will be selected and implemented, and the result will be an enhancement of vegetation cover and root cohesion.

The infinite slope FS algorithm based on the Mohr–Coulomb failure criterion (Fredlund, Morgenstern, and Widger 1978), as modified by Selby (1993), was used in this report to evaluate the contribution of root cohesion to mechanical slope stability. Root cohesion contribution to slope stability and shallow landslide risk reduction is simplified in infinite slope analysis by adding additional cohesion, in Pascals, to the effective cohesion of soil that is a function of their texture. A modified FS equation to account for additional soil cohesion from roots (World Bank 2019) can be expressed as:

$$\mathrm{FS} = (\mathrm{C} + \mathbf{dC} + (\mathrm{Ys} + \mathrm{Yw} * \mathrm{M}) * \mathrm{Z} * \cos(\mathrm{A})\hat{}2 * \tan(\mathrm{I}))\ ) \\ /\ (\mathrm{Ys} * \mathrm{Z} * \sin(\mathrm{A}) * \cos(\mathrm{A})),$$

where

C: Soil cohesion, from physical soil texture or properties, in kPa

***dC:** Additional soil cohesion, from vegetation roots, in kPa*

Ys: Unit weight of soil, in kN/m^3

Yw: unit weight of water, in kN/m^3

M: Soil water saturation, unitless, 0 ~ 1

Z: Soil depth to potential failure plane, in m

A: Slope angle

I: Soil internal angle of friction.

Physical parameters for the equation above are calculated by the algorithm implementation of factor of safety(FS) in SAGA[47] from soil texture properties and topography. Unit weight of soil is derived from bulk density, internal angle of friction from soil textural class, and slope profiles from the digital elevation model.

Additional root cohesion, **dC** in the equation, varies between vegetation type and age, topography, soil profile depth, and meteorological regime. Root cohesion is an emerging property of the vegetation in each ecosystem and biome. In geotechnical guidelines, considering the factors mentioned above, root cohesion from deep rooted trees is considered to add an additional tensile strength of 10–40 kPa to the soil (Look 2007). Ji et al. (2012) found that root cohesion in mono-specific cultures vary as a function of the physiological properties of different families of trees, being higher in Fabaceae than Cupressaceae.

These physiological differences affect root depth, root profile, density, architecture, and lignin content, thus making root cohesion vary between 5 kPa and 90 kPa. Mao et al. (2012), after a systematic review of 90 species of grasses, shrubs, and trees, found, on average/minimum, tensile strength of

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[47] SAGA is a GIS module that can classify soil texture using the USDA scheme.

25/2, 28/3 and 32/10 kPa for each plant functional group, respectively. However, these values are greatly reduced with soil profile depth, decreasing from 75 to less than 2 kPa for trees when soil depth goes beyond 1 m depth. Schmidt et al. (2001) found that management activities have an impact on root cohesion similar to dominant vegetation functional groups, when in tree-dominated land parcels with root cohesion values between 6 and 25 kPa the use of herbicides or other understory vegetation suppression activities significantly decreased root cohesion around 10 kPa. Chiaradia, Bischetti, and Vergani (2012) found that observed landslides events in northern Italy, independently of vegetation functional group, occurred in areas where root cohesion was less than 5 kPa.

The inclusion of root cohesion in spatially distributed modeling of slope stability is simplified using tensile strength averages for functional vegetation classes (evergreen forest, deciduous forest, and so on), assuming average tree densities, diameters, and ages, and simplifying the exponential loss of root cohesion as a function of soil depth. In the absence of data for forested landscapes in Uzbekistan, an average for forestland cover, based on the literature reviewed, of **10 kPa** was used. This value is somewhat lower than values reported in the literature for other temperate and tropical regions and reflects Uzbekistan's semiarid climate and relatively sparse natural forest density. Other land cover classes range from 1 kPa to 10 kPa in estimated baseline root cohesion.

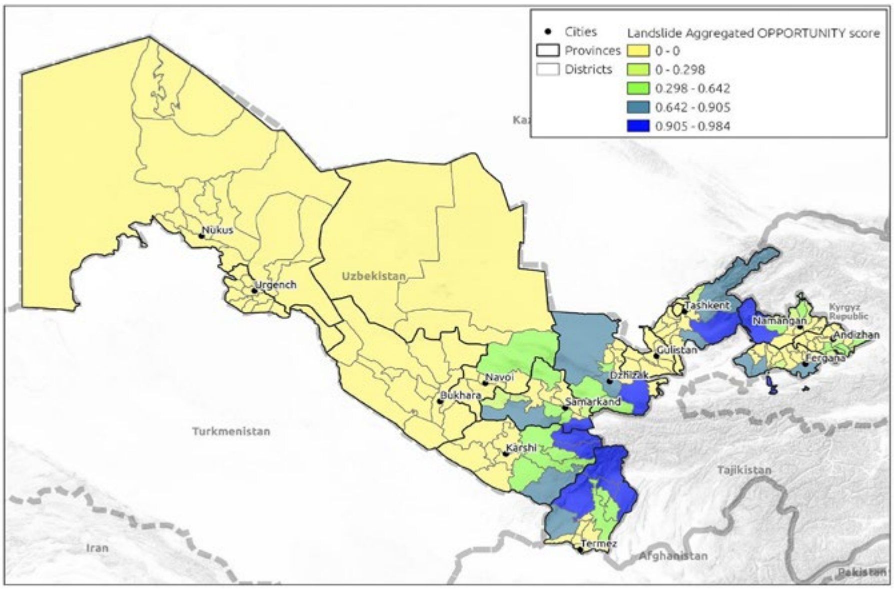
The slope stability model was used to estimate FS values for the baseline condition and the scenarios of land degradation and adaptation—comparing landslide risks with versus without investments in improving vegetation cover—to identify areas where these activities would most effectively mitigate such hazards. For the scenario analysis, the adaptation technologies are assumed to increase root density by a conservative 33 percent over baseline, resulting in an average of +3 kPa of additional soil cohesion. Positive effects of increased vegetation cover on additional soil cohesion have been reported in the literature of adding between 5 and 10 kPa, even up to 20–50 kPa in moist regions and dense forested areas. However, given the arid and semiarid condition of Uzbekistan's natural woodlands and steppe landscapes, a more conservative approach was chosen in this study.

The assumed conservative increase in root cohesion was applied in agricultural landscapes where implementation was assumed to be possible: accessible areas, above a minimum threshold of population density of 10 persons/per km2, and located in agricultural landscapes (either pasture, cropland production, or forestry activities). This additional root cohesion factor was applied on top of the BAU/No-Action scenario land conditions inside the slope stability model. The effect is the reduction of slope instability in some areas where the natural topographical factors that cause instability can be mitigated by the increase in root cohesion. On top of the land restoration scenarios, increased maximum daily rainfall depths for 2050 were used to reflect predicted climate changes in the model, based on the Rx1 day variable derived from WBCCKP.

Composite Indicators of Landslide Hazard

Landslide hazards can have serious impacts, not only on productive landscapes but also on human lives and infrastructure. Therefore, the biophysical model outputs for the unstable slope areas for the three scenarios (baseline, BAU and adaptation) are combined with additional data sets to assess the impacts of agricultural productivity, road infrastructure, and population. Three indexes of landslide risk are then defined, depending on the assets exposed to unstable slopes: **(a)** ***agricultural/productive landscapes risk,*** measured as the change in the extent of agricultural lands with unstable slopes between the baseline and the two land management scenarios, in which the districts with greater changes are at the most risk; (b) ***road network risk,*** where higher risk scores are assigned to districts with the greatest change in the proportion of major roads on unstable slopes between the baseline and each of the two scenarios; and ***(c) population risk,*** where higher scores are assigned to districts where the percentage change in people living on unstable slope areas increases the most between baseline and the two scenarios. Finally, ***an aggregated landslide risk score*** was calculated that combines the effect on productive lands, road network infrastructure, and population living in unstable slope areas. Higher scores are assigned to districts where the combined effects of vulnerable topography, climate change, and land degradation dynamics will increase this natural hazard's negative impacts on productivity, infrastructure, and people. This aggregated risk score can be used for the identification of landslide risk hotspots.

Figure A2.2. Aggregated opportunity score - landslides



Source: Original to this publication.

Generating Composite Hotspots of Adaptation Opportunity

Results from the erosion control, water regulation, and landslide models were combined into composite *adaptation opportunity scores* at the district level. This result helps visualize where investments in landscape restoration and adaptation actions have the greatest potential to help agricultural landscapes in the country adapt to future conditions, district by district.

Next, to complement the district-level opportunity scores, a prioritization exercise was undertaken to further zoom in and identify priority hot spot areas at a pixel level. This was done by applying the RIOS model—developed by the Natural Capital Project and The Nature Conservancy (TNC)—which targets investments in soil and water conservation activities with the goal of achieving the greatest ecosystem service returns toward multiple objectives (Vogl et al. 2015). The output of the RIOS model is a map of the locations of selected interventions, chosen based on ranked cost-effectiveness scores to achieve one or more ecosystem services objectives.

RIOS calculates a score for each pixel on the landscape, indicating how effective an activity is expected to be for improving the desired objective, relative to other places. RIOS then combines scores across objectives via weighted summation. Once defined landscape and feasibility constraints are met, selection of priority areas is driven by estimated ecosystem services benefit as determined by relative rankings. RIOS then selects priority areas by choosing the highest ranked pixels in order, until the defined area or budget is allocated. The output of this prioritization process is a map showing a recommended portfolio of investments and their locations.

RIOS was run considering a total of 1.6 million ha of land to be allocated for investment. This number was determined based on the results of this report and considering (a) the estimated level of adoption of the individual technologies in each crop/biome; (b) the area suitable/amenable for the particular technology; (c) socioeconomic factors, such as food security, speed of cost recovery, investment requirement, expected returns, expected adoption of the technologies/innovations, the gravity of land degradation, and the opportunities to intervene before it is too late; and (d) a feasible level of investment considering implementation costs at around US$350/ha. The 1.6 million ha is presented as a test case to demonstrate the effectiveness of the recommended technological, policy, and institutional interventions in improving the biophysical, environmental, and economic well-being of the country while also achieving sizeable benefits for the country. These same hot spot areas prioritized for intervention are used in subsequent benefit-cost analyses, as described in the next section.

Objectives to maximize in the RIOS model portfolio selection included erosion control, baseflow enhancement, flood mitigation potential, improvement in slope stability, land productivity, and 2030 population density. Investment portfolios were generated using two different approaches. The first allocates priority opportunity hotspots across the country based on the expected improvements in these five ecosystem services dimensions. The second allocates priority opportunity hotspots given a minimum number of ha per province and per biome within each province. The minimum ha per province / biome emerged from the application of the above criteria (adoption rates, socioeconomic factors, and so on).

Table A2.3. Summary of data sources for identification of hotspots and ecosystem services modeling

Data set	Source	Additional information
Analysis units 1: Administrative units	GADM 4.x, level 2	link
Analysis units 2: Watersheds	World Wildlife Fund (WWF) HydroBasins, level 7	link
Population	WorldPop project; Number of people per pixel with country totals adjusted to match UN population estimates.	Periods: 2000, 2010, and 2020 Resolution: 1 km link
LULC	ESA Land Cover product	Year: 2021 Resolution: 10 m link
Livestock	Gridded Livestock of the World (GLW3) is a spatial data set that shows the global distribution of the major types of livestock. Sum of the total number of buffaloes, cattle, goats, and sheep	Year: 2010 Resolution: 1 km link
Digital elevation model	WWF Hydrosheds conditioned and filled DEM	Resolution: 90 m link
Soil texture	OpenLandMap project, developed by Envirometrix Ltd. Soil texture classes (USDA system) for 6 standard soil depths (0, 10, 30, 60, 100, and 200 cm) at 250 m. Derived from predicted soil texture fractions using the soil texture package in R. Used to derive USLE C soil erodibility factor	Resolution: 250 m link
Rainfall erosivity	This map provides a complete rainfall erosivity data set for the whole world based on 3,625 precipitation stations and around 60,000 years of rainfall records at high temporal resolution (1 to 60 minutes). Gaussian Process Regression (GPR) model was used to interpolate the rainfall erosivity values of single stations and to generate the R-factor map. Measurement unit: MJ mm ha^{-1} h^{-1} yr^{-1}	Resolution: 1 km link
Net primary production	The MOD17A3HGF V6 product provides information about annual Net Primary Productivity (NPP) at 500 m pixel resolution. Annual NPP is derived from the sum of all 8-day Net Photosynthesis (PSN) products (MOD17A2H) from the given year. The PSN value is the difference of the GPP and the Maintenance Respiration (MR) (GPP-MR) Period 2001–2021. Annual averages and linear trend	Resolution: 500 m link
Hydrological quality and erosion control ecosystem services	InVEST SDR model	Resolution: 100 m link
Climate and weather	WBCCKP data sets; historical reference period and CMIP6 mean projections; 3 SSP (SSP1-1.9, SSP2-4.5, and SSP3-7.0); and 10th, 50th and 90th percentiles	link
PAs	World Database of Protected Areas	
Biomes	WWF	
Irrigated croplands		

Annex 3. Description of Data, Assumptions, and Procedures Used in Estimation of Ecosystem Services Lost to Land Degradation

In this study, we assembled data on the total area under each crop/biome type (particularly for cotton, potatoes, forests, and pastures) and for broad crop categories (such as cereals, legumes, vegetables, and fruits) and the corresponding average yield figures in each province from official statistics of the Statistics Committee. Unlike the other biomes, provincial-level data on pastures were not readily available. Therefore, expert estimates of production and yield were made based on the district-level data provided by the cadastral agency. Data on the percentage of provincial land area for each crop (or crop category) falling under three (low, moderate, and severe) land degradation levels were obtained from experts in different local institutions, including national and regional research institutions. The classification was based on a combination of several criteria listed in Tables 3.1 – 3.8. For productivity analysis, the shares of lands which experience low, moderate, and severe degradation are, respectively, 38 percent, 32 percent, and 30 percent, which add up to 100 percent. This report is focusing only on the 30 percent lands which are severely degraded. However, in the estimation of soil and soil carbon loss, only about 13.12 percent of the total land area in the country is estimated to be currently experiencing active erosion out of which 12.2 percent, 0.92 percent, and 0.1 percent, respectively, are experiencing low, moderate, and severe erosion.

We then used the Solver utility in the Excel software of the MS Office suite to disaggregate the provincial average yield figures obtained from the official statistics into the average yields in the low, moderate, and severe classes of soil degradation for each crop/biome by using the following constraints:

- The difference between yields in the low and moderate and between moderate and severe degradation levels is 10 percent. Even though we know that the yield losses due to land degradation are much higher, we decided to use a conservative 10 percent yield difference to arrive at the minimum cost of land degradation.
- For each province, the weighted average of the yields in the three classes of land degradation for each crop/biome must be equal to the provincial average yield.
- A larger study which includes all lands falling under the three different land degradation classes was completed in 2022 under another project which is a predecessor to this project. This study focusses only on areas identified as land degradation hotspots in Uzbekistan. For this analysis, the study team has agreed to include only the lands classified as having 'severe land degradation' in each of the 13 provinces of Uzbekistan as areas representing the land degradation hot spot areas in the country. Therefore, the results, conclusions, and recommendations apply only to these hot spot areas.
- Separate data on the percentage of provincial land area for each crop (or crop category) falling under four (slight, low, moderate, and severe) soil erosion levels were obtained from the InVEST SDR model and remote sensing-based work of Vogl and Leon (2022) (Figure 3.1 and Figure 3.2). To avoid confounding errors arising from the difference in classifications with the data obtained from local experts (described above), the data from Vogl and Leon (2022) were exclusively used for the estimation of the total soil eroded and the associated carbon released to the atmosphere.

Table A3.1. Summary of methods and tools, indicator variables, and data sources used by activity/theme

Activity	Method and tools	Specific data/details	Source of data
Cost of inaction			
• **Provide analysis on how changes in land use, deforestation, agriculture, urbanization, and climate can affect the watershed hydrology and water resource cycles, with direct effects on water availability.** • **Provide analysis of land and forest degradation from livestock and grazing management.**	• This will heavily draw on the literature to find estimates of losses in ecosystem services per unit area of agricultural and forestland due to in action. If data are available, this will be done for different extents of degradation. Then, using national statistics and expert estimates of the percentage share of land falling under the different levels of degradation, we will make estimates of total loss in each category and then a single national estimate for each ecosystem service using the percentage shares as weights	• Data on yield loss (for major crops and pasture), forest biomass loss, morbidity/mortality rates associated with land degradation, natural resource depletion (soil, water, and forest) and so on	• Vogl and Leon (2022) • Published and unpublished literature, government documents, key informant interviews, national statistics, and so on
Benefit of action			
• **Provide an analysis of the advantages of adopting economically and environmentally efficient and sustainable technologies thereby helping the country transition into a green growth model.**	• Provide an analysis of the technological, management innovations, policy, and institutional options and human and financial capacity needs for mitigating barriers to a green transition.	• Literature review on approaches and available technologies and innovations and conducive policy and institutional environment toward greening the agriculture, water, and forest sectors • Data on the country's national accounts; global, regional, and national databases on past and projected foreign direct investment prospects; human resources by discipline and education level; private sector participation; and the country's creditworthiness	• Vogl and Leon (2022) • National, regional, and global databases; literature review; and key informant interviews

Activity	Method and tools	Specific data/details	Source of data
Cost-benefit analysis			
- **Based on the results from costs of inaction (item 1) and benefits of action (item 2), provide a financial analysis of investment in greening the agriculture, forestry, and water sectors of Uzbekistan.**	- Use different market and nonmarket valuation systems to monetize the costs of inaction and benefits of action estimated in sections 1 and 2, respectively. This will involve projection of costs and benefits for the next 10 years during which most of the major investments will need to be made only once. All costs and benefits during the 10-year planning horizon are discounted to current US dollar values. These estimates are then used to provide estimates of BCRs by province and by biome.	- Costs of inaction and benefits of action estimated in sections 1 and 2 above, official discount factors obtained from national accounts, and area and production figures obtained from the Statistics Committee	- All sources listed above
Conclusions and recommendations			
- **Make conclusions based on the findings.** - **Make technological, innovation, policy, and institutional recommendations for enhancing private sector opportunities; improving options for adaptation and ecosystem functionality; integrating landscape solutions; generating employment; enhancing sustainable use of resources; and improving the livelihoods of people engaged in the forestry, agriculture, and water sectors.**	- Conclusions will be made based on the findings of the above analyses. - Recommendations will be made based on the assessment of the available opportunities and expected challenges for greening the agriculture, water, and forest sectors of Uzbekistan and the review other countries' experiences.	- Analysis of all the data listed above will provide the basis for drawing conclusions and making recommendations.	- All data sources listed above

Table A3.2. Classification of soil erosion levels

Erosion rate (ton/ha)	Classification	
	Singh et al. (1992)	This study
0–5	Slight	Slight
5–10	Moderate	Low
10–20	High	Low
20–40	Very high	Moderate
40–80	Severe	High
>80	Very severe	High

Table A3.3. Degree of stone in the soil

Small particles less than 3 mm, %	Level of stoned soil
<0.5	Non-stoned
0.5–5	Low stoned
5–10	Medium stoned
>10	Strong stoned

Table A3.4. Soil salinity level (%)

Salinity level	Types of salinity					
	Sulfate	Chloride-sulfate		Sulfate-chloride		Chloride
	Dry residue	Dry residue	Chlorine	Dry residue	Chlorine	Chlorine
Nonsaline	<0.3	<0.1	<0.01	<0.1	<0.01	<0.01
Low saline	0.3–1.0	0.1–0.3	0.01–0.05	0.1–0.3	0.01–0.04	0.01–0.03
Medium saline	1.0–2.0	0.3–1.0	0.05–0.20	0.3–0.6	0.04–0.2	0.03–0.1
Strong saline	2.0–3.0	1.0–2.0	0.20–0.30	0.6–1.0	0.2–0.3	0.1–0.2
Very strong saline	>3.0	>2.0	>0.3	>1.0	>0.3	>0.2

Table A3.5. Degree of gypsuming of the soil (%)

Level of gypsum	The amount of gypsum, % ($CaSO_4$*$2H_2O$)
Non-gypsuming of soil	<10
Low gypsuming of soil	10–20
Medium gypsuming of soil	20–40
Strong gypsuming of soil	>40

Table A3.6. Grouping of soils by amounts of mobile nitrogen, phosphorus, potassium, and humus, mg/kg

Soil supply	N-NO_3	P_2O_5	K_2O	humus, %
Very low	<20	<15	<100	<05
Low	20–30	15–30	100–200	0.5–1.0
Medium	30–50	30–45	200–300	1.0–1.5
High	50–60	45–60	300–400	1.5–2.0
Very high	>60	>60	>400	>2.0

Table A3.7. Water erosion

Erosion degree	Loss of soil material	
	t/ha/year	mm/year
Weak	< 10	< 0.6
Medium	10–50	0.6–3.3
Strong	50–200	3.3–13.3
Very strong	> 200	> 13.3

Table A3.8. Wind erosion

Degree	Blown soil surface, cm
Low	<5 cm
Medium	5–10 cm
Strong	>10 cm

To estimate the amount of carbon that is released to the atmosphere due to soil erosion, we made the following assumptions:

- Conversion factor from percentage humus to percentage of C of 0.58 percent
- Average soil layer depth of 30 cm
- Average soil bulk density of 1.5 g/cm^3.

To estimate the diesel equivalents from carbon emissions, we used a conversion factor of 1.38 which was derived using data from two sources (Source 1 and Source 2).

Estimation of Irrigation Water Loss

The main challenges in managing and ensuring the sustainability of surface water and groundwater resources in agriculture, the ideal measurement indicators, and suggested methods of estimation for the ecosystem services lost due to inaction are presented in Table 3.9. Availability of data posed a major challenge for making estimation of the ecosystem services lost due to irrigation water degradation. This is more so because of the specificity and level of details that are needed for each variable.

To this effect, official statistics were obtained for the quantity of water from surface sources allocated to each province, and expert estimates sought for the quantity of groundwater actually extracted from groundwater sources and amount of water lost during conveyance and field application. While water lost due to leakage during conveyance may percolate down and help in recharging groundwater and in increasing baseflow, the fact that this water may not be available for crop production during the same cropping season makes it lost at least for that season. Therefore, with this caveat, we assume this water is lost. The expert estimations were based on district-level data from water consumers associations that are available up until 2021. The data showed that a total of 18.1 billion m^3 of irrigation water is available annually for use in Uzbekistan out of which 17.9 billion m^3 is allocated from surface water resources while the remaining 183.4 million m^3 is abstracted from groundwater. Out of the total supply of 45.9 billion m^3, only 30.1 billion m^3 (66 percent) is delivered to the field and only 60 percent utilized by the crops (Table A3.10).

Table 3.11 presents data on current average yield levels, average yield potential based on experimental data, yield gap, and potential yield gains which are based on the following conservative assumptions:

- Only 50 percent of the yield gap in each biome, crop, or crop category can be closed by introducing the optimal path (that is, by introducing the recommended suite of technological, policy, and institutional changes) in 10 years.
- The yield increases are uniform in percentage terms across all degradation classes.

Table A3.9. Challenges related to irrigation water resources and estimation of their impacts

Challenge	Impacts / manifestations	Impact indicator	Suggested estimation approach	Estimated in this study?
Reducing water availability downstream due to diversion and/or higher use upstream (transboundary)	Water shortage downstream	Reduction in the amount of water flowing to the country	Difference in long-term annual flows after discounting the reduction in precipitation upstream	No. Ignored because it is beyond the scope of this study
Transboundary water issues and water disputes and governance (up/down stream) including regional discrepancies in irrigation development	Conflicts, political instability, civil unrest, and moral issues	• Number of conflicts • Number of political upheavals		No. Ignored because these are beyond the scope of this study.
Salinity and later logging	Degradation of soil biophysical properties and crop loss	Change in soil salinity	Least saline soils in irrigated areas of the country to be considered as reference	Yes, but only the monetary values of salinity from the literature.
Increasing costs of irrigation	Economic loss	Cost of pumping	Irrigation costs of farms with well-designed irrigation infrastructure and with leveled and lined canals will be used as reference.	No. Data for this are not available.
Leakage due to old age of lined canals, reservoirs, and distribution networks and seepage in earthen canals, reservoirs, and distribution networks	• Loss of water • Shortage of water • Economic cost	• Amount of water lost • Amount of money lost	Loss in new lined ones will be used as the reference.	Yes
Evaporation in open canals, reservoirs, and distribution networks	• Loss of water • Shortage of water • Economic loss	• Amount of water lost	Loss in closed canals and distribution networks will be used as the reference.	No. Data for this are not available.
Poorly designed irrigation infrastructure (canals and hydraulic structures)	• Water wastage • Shortage of water • Economic loss	• Amount of water lost	Loss in well-designed systems will be used as reference.	No. Data for this are not available.
Increased siltation (canals and reservoirs)	Danger of dam damage, reduced reservoir capacity, overflow of water, and shortage of water during dry season	• Amount of water lost • Opportunity cost of not being able to save water for later during the year	Estimates of the amount of overflowing water from the literature (if available)	No. Data for this are not available.

Challenge	Impacts / manifestations	Impact indicator	Suggested estimation approach	Estimated in this study?
Lack of trained personnel (for example, irrigation engineers)	Poor advice to farmers and hence poor management of scarce resource; poor design of irrigation infrastructure and hence loss or inefficient use of water	Water use efficiency	Estimates of water use efficiency if available from the literature	No. Data on this are not available.
Contamination / mineralization of water resources	• Leaching of fertilizers and pesticides from farms • Negative effect on health of farmers and consumers	• Number of people suffering from water-related health problems • Treatment cost for such people	Estimates from the literature and expert consultations	No. Data on this are not available.
Overirrigation and hence low water use inefficiency	Salinity, lower productivity, and wastage of scarce resource	Yield loss and opportunity cost of water lost	• Estimates of yield in low-salinity lands will be used as reference. • Use marginal value product of water to estimate total value of application in excess of the crop requirement.	• No. Data on this are scanty. • No. Data to estimate production functions are not available.
Poor/inappropriate crop choices (for example, cotton versus wheat)	Unoptimized use of scarce water resources	Total area planted to the wrong crop(s)	• System-level bio-economic simulation model	• No. To the best of our knowledge, such a model is not readily available.
Low water table (increased capillary effect and possible salinization of soils)	Damage of underground infrastructure and foundations of housing units (economic loss)	Cost of reconstruction of infrastructure and buildings damaged by salinity	• Based on literature review	No. Too complex for a small project like this.
Poor / insufficient groundwater recharge	Decreasing availability of water and hence shortage of water for current and/or future generations	• Change in the amount of water available per ha	• Estimates from the literature and/or from remote sensing	Yes, but a simplistic estimation using runoff data.
Groundwater overexploitation	Water shortage for current and/or future generations	• Changes in the average depth of wells	• Literature review	No. Ground water use is negligible and hence ignored.

Table A3.10. Amount of water (m³, millions) allocated from surface water, abstracted from groundwater and utilization

	Annually allocated amount of surface water or abstracted ground water for irrigation (million m³) by source:				**Annually delivered to the field (million m³) by source:**				**Amount of water utilized by crops (million m³) by source:**			
Province	Location (Upstream, Middle, Downstream)	Surface water resources	Ground water resources	Total	Surface water resources	Ground water resources	Total	Delivered to thefield as % of total supply	Surface water resources	Ground water resources	Total	Utilization as % of total supply
Bukhara	Downstream	4,012.90	59.60	4,072.50	2,648.51	39.34	2,687.85	66%	2,138.26	31.76	2,170.02	53%
Khorezm	Downstream	3,854.60		3,854.60	2,235.67	-	2,235.67	58%	2,136.63	-	2,136.63	55%
Karakalpakstan	Downstream	6,104.88		6,104.88	3,907.12	-	3,907.12	64%	3,109.00	-	3,109.00	51%
Jizzakh	Middle	2,764.70	37.80	2,802.50	2,128.82	29.11	2,157.93	77%	2,038.98	27.88	2,066.86	74%
Navoiy	Middle	1,388.72	38.60	1,427.32	847.12	23.55	870.67	61%	783.98	21.79	805.77	56%
Samarkand	Middle	3,608.20	42.00	3,650.20	2,489.66	28.98	2,518.64	69%	2,160.99	25.15	2,186.15	60%
Syrdarya	Middle	3,266.60	14.20	3,280.80	1,992.63	8.66	2,001.29	61%	2,317.16	10.07	2,327.24	71%
Tashkent	Middle	3,737.80	14.00	3,751.80	2,541.70	9.52	2,551.22	68%	2,338.17	8.76	2,346.93	63%
Andijan	Upstream	2,329.20	35.40	2,364.60	1,490.69	22.66	1,513.34	64%	1,453.95	22.10	1,476.05	62%
Ferghana	Upstream	3,137.20	81.30	3,218.50	2,352.90	60.98	2,413.88	75%	1,855.01	48.07	1,903.09	59%
Namangan	Upstream	3,127.70	53.90	3,181.60	2,064.28	35.57	2,099.86	66%	2,025.82	34.91	2,060.73	65%
Kashkadarya	Upstream	5,312.40	87.60	5,400.00	3,506.18	57.82	3,564.00	66%	3,456.63	57.00	3,513.63	65%
Surkhandarya	Upstream	2,805.10	16.00	2,821.10	1,570.86	8.96	1,579.82	56%	1,670.86	9.53	1,680.39	60%
Total Uzbekistan		**45,450.00**	**480.40**	**45,930.40**	**29,776.14**	**325.13**	**30,101.27**	**66%**	**27,485.45**	**297.02**	**27,782.48**	**60%**

For estimating the benefits of the introduction of the optimal changes in terms of soil erosion reduction, we relied on data from Wuepper et al. (2020) where it is reported that the Kyrgyz Republic has about 3 ton/ha less erosion rate than its neighbors including Uzbekistan. Considering the socioeconomic, topographic, climatic, and agroecological similarities between Uzbekistan and the Kyrgyz Republic, we assumed that by introducing the recommended policy, institutional, and technological changes, Uzbekistan can reduce its erosion rate from its current rate of 4.3 ton/ha to the level in the Kyrgyz Republic, that is, Uzbekistan can realistically reduce erosion rate by 3 tons/ha to bring it down to 1.3 ton/ha in all lands under all biomes except forests which mostly include steep slopes for which the target is increased to 7.5 ton/ha thereby making the national average target to be 1.71 ton/ha.

Table A3.11. Current average yield levels, average yield potential based on experimental data, yield gap, and yield gap that can realistically be closed in 5–10 years with the introduction of the optimal interventions

Biome	Current Yield (ton/ha)	Average yield potential (if all policy, institutional, and technological problems are solved)	Yield gap (%)	Yield that some top-performer farmers in Uzbekistan have already achieved (ton/ha)	Yield level that can realistically be achieved if the optimal technological, policy, and insti-tutional changes are introduced (ton/ha)	Reference for yield potential
Cereals	**4.30**	**7.37**	**71.30**		**5.84**	
Wheat	5.60	9.00	60.71	10.00	**7.30**	Khalikulov et al. 2015
Barley	1.80	3.50	94.44	8.00	**2.65**	Dr. Aziz Nurbekov, personal communication
Corn	5.16	15.00	190.70	15.00	**10.08**	CACILM-2 project results in Bukhara province
Rice	4.57	12.00	162.49	13.00	**8.29**	Director Rice Research Institute, personal communication
Rye	2.80	3.50	25.00	5.00	**3.15**	D. Juraev from South Agricultural Research Institute, 2021
Legumes	**1.34**	**2.90**	**116.47**		**2.12**	
Chickpea	1.15	2.80	143.48	3.20	**1.98**	Nurbekov et al., 2018
Common bean	1.26	3.28	160.32	3.50	**2.27**	Khalilov et al., 2015
Mung bean	1.34	2.70	101.49	3.00	**2.02**	Nurbekov et al., 2019
Soybean	0.90	2.70	200.00	3.30	**1.80**	Nurbekov et al., 2017
Cotton	**2.88**	**4.85**	**68.15**	**6.40**	**3.87**	Sh. Nomozov, personal communication
Potatoes	**33.70**	**55.30**	**64.09**	60.20	**44.50**	Director Scientific Research Institute of Vegetables Crops, Melons and Potatoes, personal communication (DSIVCMP), personal communication
Vegetables	**46.00**	**73.81**	**60.46**	68.90	**59.91**	DSIVCMP, personal communication
Tomatoes	33.10	54.36	64.23	61.50	**43.73**	DSIVCMP, personal communication
Cucumbers	33.70	60.60	79.82	65.40	**47.15**	DSIVCMP, personal communication

Biome	Current Yield (ton/ha)	Average yield potential (if all policy, institutional, and technological problems are solved)	Yield gap (%)	Yield that some top-performer farmers in Uzbekistan have already achieved (ton/ha)	Yield level that can realistically be achieved if the optimal technological, policy, and insti-tutional changes are introduced (ton/ha)	Reference for yield potential
Onions	35.50	80.70	127.32	90.80	**58.10**	DSIVCMP, personal communication
Carrots	76.60	105.60	37.86	110.60	**91.10**	DSIVCMP, personal communication
Cabbages	51.10	67.80	32.68	74.50	**59.45**	DSIVCMP, personal communication
Fruits	**13.36**	**19.74**	**47.80**	21.90	**16.55**	
Apple	8.48	12.61	48.66	15.60	**10.55**	Director Research Institute of Horticulture, Viniculture and Wine-marking (DRIHVW), personal communication
Grape	12.54	30.27	141.48	34.60	**21.40**	DRIHVW, personal communication
Apricot	10.90	14.60	33.98	15.30	**12.75**	DRIHVW, personal communication
Pear	13.43	18.60	38.51	18.10	**16.01**	DRIHVW, personal communication
Cherries	11.10	17.90	61.33	19.40	**14.50**	DRIHVW, personal communication
Others	6.36	8.60	35.29	9.60	**7.48**	DRIHVW, personal communication
Other crops	**13.12**	**19.87**	**51.42**	21.90	**16.50**	DRIHVW, personal communication
Alfalfa	12.90	25.60	98.45	28.30	**19.25**	Deputy Director Research Institute of Animal Husbandry, Poultry and Fish Culture, personal communication
Sunflower	1.59	2.70	69.81	1.80	**2.15**	D. Juraev from South Agricultural Research Institute, 2021, personal communication
Forests	**0.01**	**0.02**	**141.88**	0.03	**0.01**	
Permanent Pastures (natural grasslands)	**0.25**	**0.90**	**266.53**	1.30	**0.57**	Abdulla Rabbimov, Research Institute of Karakul and Desert Ecology, personal communication

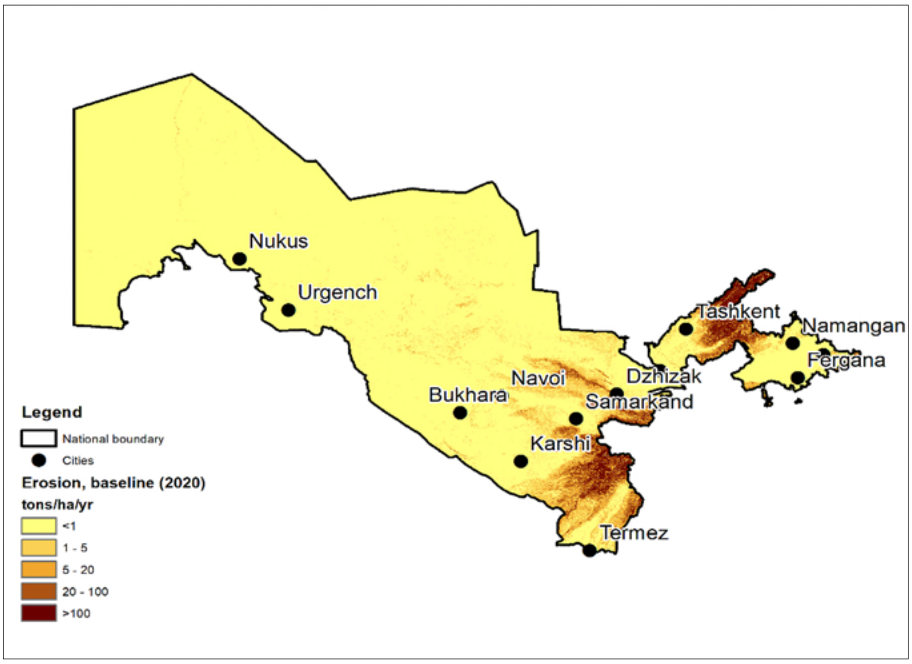
Table A3.12. Land area (ha) by biome and by degradation classification

	Area (ha) of area under forests and shrubs by degree of land degradation				Area (ha) of area under permanent pastures by degree of land degradation			
Province	**Low**	**Modest**	**Severe**	**Total**	**Low**	**Modest**	**Severe**	**Total**
Andijan	3,432	390	78	3,900	8,242	6,923	5,934	21,100
Bukhara	174,016	140,551	20,079	334,645	1,341,954	629,041	587,105	2,558,100
Fergana	9,928	3,650	1,022	14,600	12,852	6,242	4,406	23,500
Jizzakh	80,262	73,710	9,828	163,800	392,008	166,306	178,185	736,500
Khorezm	25,239	23,628	4,833	53,700	51,774	34,516	23,011	109,300
Namangan	13,862	7,648	2,390	23,900	57,769	55,458	36,972	150,200
Navoiy	457,524	610,032	203,344	1,270,900	3,473,945	2,501,241	2,918,114	8,893,300
Kashkadarya	78,816	70,606	14,778	164,200	650,907	356,949	398,943	1,406,800
Samarkand	7,800	4,420	780	13,000	249,000	199,200	348,600	796,800
Syrdarya	2,058	1,848	294	4,200	6,041	7,463	6,396	19,900
Surkhandarya	119,034	102,696	11,670	233,400	271,645	293,376	260,779	825,800
Tashkent	54,674	22,849	4,080	81,602	145,865	121,555	178,280	445,700
Karakalpakstan	343,298	557,860	171,649	1,072,807	1,726,278	1,333,942	2,197,081	5,257,300
Total Uzbekistan	**1,369,943**	**1,619,887**	**444,825**	**3,434,655**	**8,388,280**	**5,712,212**	**7,143,807**	**21,244,300**
Share in total (%)	**40**	**47**	**13**	**100**	**39**	**27**	**34**	**100**

	Area (ha) of area under other-lands by degree of land degradation				Total crop area (ha) by degree of land degradation			
Andijan	53,913	55,547	53,913	163,374	177,199	47,040	17,387	241,626
Bukhara	286,058	294,726	286,058	866,842	100,297	115,858	45,893	262,048
Fergana	106,873	110,111	106,873	323,857	169,487	89,632	54,925	314,043
Jizzakh	264,810	272,834	264,810	802,454	159,057	169,216	89,972	418,246
Khorezm	68,870	70,957	68,870	208,698	56,357	92,258	84,687	233,302
Namangan	112,056	115,452	112,056	339,564	122,511	75,301	32,524	230,336
Navoiy	275,788	284,145	275,788	835,721	44,099	46,518	18,967	109,584
Kashkadarya	264,989	273,019	264,989	802,998	197,789	189,876	95,337	483,002
Samarkand	144,496	148,875	144,496	437,867	201,111	176,962	51,260	429,333
Syrdarya	66,491	68,506	66,491	201,489	84,014	78,857	39,540	202,411
Surkhandarya	209,752	216,108	209,752	635,612	139,601	136,931	38,656	315,188
Tashkent	225,034	231,853	225,034	681,920	205,625	101,944	42,209	349,778
Karakalpakstan	3,318,886	3,419,459	3,318,886	10,057,231	75,625	119,223	76,813	271,662
Total Uzbekistan	**5,398,017**	**5,561,593**	**5,398,017**	**16,357,626**	**1,732,771**	**1,439,617**	**688,171**	**3,860,559**
Share in total (%)	**33**	**34**	**33**	**100**	**45**	**37**	**18**	**100**

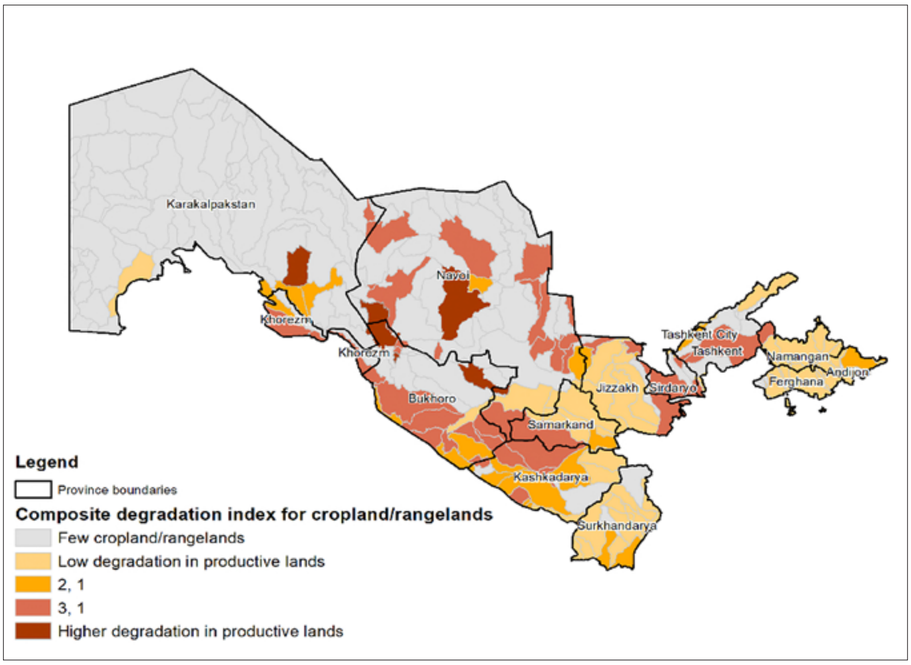
Source: Original estimates for this publication based on remote-sensed data.

Figure A3.1. Soil erosion rates in Uzbekistan



Source: Original to this publication.

Figure A3.2. Composite degradation index for crop and rangelands



Source: Vogl and Leon (2022).

Annex 4. Detailed Results of Cost-Benefit Analysis of Landscape Restoration

Table A4.1. Minimum amount of production (tons) lost annually due to soil erosion in areas identified as land degradation hotspots in Uzbekistan: by crop type, by province, and national aggregates

	Minimum amount of annual production lost (tons) due to land degradation by crop type								As a % of total provincial or national production	Average loss in the province or country (ton/ha)
	Cereals	Legumes	Cotton	Potatoes	Vegetables	Fruits	Other crops	Total for croplands		
Andijan	11,191	390	2,381	4,695	19,933	8,871	17,982	**65,442**	**1.42**	0.01
Bukhara	15,074	210	11,629	9,578	31,701	21,871	30,389	**120,452**	**3.55**	0.04
Ferghana	23,432	972	9,850	12,497	42,212	21,214	30,596	**140,773**	**3.63**	0.04
Jizzakh	27,859	1,215	13,335	4,015	20,697	5,698	22,408	**95,226**	**4.27**	0.04
Khorezm	21,030	150	26,885	10,044	46,516	15,389	37,056	**157,071**	**6.66**	0.07
Namangan	13,180	1,095	5,070	7,490	21,464	10,735	14,347	**73,381**	**2.62**	0.03
Navoiy	7,924	230	3,372	2,210	7,741	5,116	11,305	**37,897**	**3.10**	0.03
Kashkadarya	25,986	276	19,810	10,287	28,385	14,808	21,682	**121,234**	**4.17**	0.04
Samarkand	10,825	1,636	9,970	28,667	66,302	41,247	12,012	**170,660**	**3.50**	0.04
Syrdarya	13,299	884	8,466	2,731	12,217	2,400	23,828	**63,825**	**3.57**	0.04
Surkhandarya	10,885	329	8,224	10,388	31,128	8,160	13,902	**83,015**	**2.52**	0.03
Tashkent	12,480	260	5,730	8,777	23,998	5,050	15,027	**71,324**	**2.38**	0.02
Karakalpakstan	16,552	370	3,827	4,565	15,157	3,638	32,339	**76,448**	**5.29**	0.05
Total Uzbekistan	**209,716**	**8,018**	**128,549**	**115,944**	**367,451**	**164,198**	**282,872**	**1,276,748**	**3.38**	0.03
Share of each crop in total crop loss (%)	**16.43**	**0.63**	**10.07**	**9.08**	**28.78**	**12.86**	**22.16**	**100.00**		
Rank (high to low)	**3**	**7**	**5**	**6**	**1**	**4**	**2**			

Note: Here, percentage losses are calculated in reference to the provincial/national total (not as percentage of the hot spot areas only). Land degradation in this analysis includes soil erosion, nutrient mining, acidity, poor soil structure, and soil salinity.

Table A4.2. Summary of annual costs of inaction to control land degradation on all croplands in the land degradation hotspots of Uzbekistan (in US$ and as % of GDP)

Crop type	Minimum cost (US$/year) of land degradation in the form of loss of					As % of GDP
	Consumptive uses	Non-consumptive uses	Indirect uses	Nonuse values	Total cost (US$)	
Cereals	100,088,123	4,197,545	2,472,009	15,631,554	**122,389,232**	0.20
Legumes	2,535,604	149,638	64,227	214,775	**2,964,244**	0.00
Cotton	222,323,953	7,671,848	3,447,966	11,361,764	**244,805,530**	0.40
Potatoes	40,447,493	561,096	257,438	3,020,919	**44,286,946**	0.07
Vegetables	127,712,296	2,688,711	876,519	10,841,050	**142,118,576**	0.23
Fruits	236,545,150	1,204,299	781,243	26,652,158	**265,182,850**	0.43
All other crops	271,913,392	1,767,091	744,550	4,137,917	**278,562,950**	0.45
Total Uzbekistan	**1,001,566,010**	**18,240,228**	**8,643,951**	**71,860,138**	**1,100,310,326**	**1.78**
As % of GDP	**1.62**	**0.03**	**0.01**	**0.12**	**1.78**	

Table A4.3. Total amount of diesel used for tillage operations and the associated carbon emissions under current working conditions in the land degradation hotspots of Uzbekistan

Province	Quantity of diesel used for field work and other farm activities under conventional tillage (tons)								Total carbon emitted (ton)
	Cereals	Legumes	Cotton	Potatoes	Vegetables	Fruits	Other crops	Total	
Andijan	858	14	995	139	252	83	309	**2,649**	**1,906.97**
Bukhara	1,129	16	6,053	339	750	70	848	**9,206**	**6,626.23**
Ferghana	2,064	25	4,340	567	867	405	660	**8,928**	**6,426.06**
Jizzakh	4,797	225	6,625	151	475	115	1,568	**13,956**	**10,044.96**
Khorezm	1,974	27	12,733	488	937	180	1,183	**17,522**	**12,612.05**
Namangan	1,382	31	2,309	244	322	311	371	**4,970**	**3,577.57**
Navoiy	807	11	1,553	96	129	117	334	**3,048**	**2,193.70**
Kashkadarya	4,170	77	10,273	473	739	136	968	**16,835**	**12,117.19**
Samarkand	1,457	106	4,570	877	1,383	145	757	**9,295**	**6,690.20**
Syrdarya	1,654	19	4,557	111	238	52	458	**7,088**	**5,101.52**
Surkhandarya	1,088	10	4,375	432	511	219	475	**7,110**	**5,117.39**
Tashkent	1,819	36	2,647	286	550	169	1,020	**6,528**	**4,698.46**
Karakalpakstan	3,414	126	5,477	455	762	84	1,957	**12,275**	**8,834.98**
Total Uzbekistan	**26,614**	**721**	**66,506**	**4,659**	**7,914**	**2,087**	**10,909**	**119,409**	**85,947.27**

Table A4.4. Amount of forage lost (tonWs) due to land degradation on permanent (natural) pasturelands by province and national aggregates in the land degradation hotspots of Uzbekistan

Province	Loss (tons/year)	Value (US$)	As % of total provincial or national supply	Loss of pastureland (tons per ha)
Andijan	313	15,149	5.30	0.0148
Bukhara	17,384	841,376	4.25	0.0068
Ferghana	219	10,594	3.45	0.0093
Jizzakh	8,906	431,066	4.48	0.0121
Khorezm	1,196	57,897	3.91	0.0109
Namangan	2,015	97,501	4.63	0.0134
Navoiy	137,999	6,679,033	6.21	0.0155
Kashkadarya	20,897	1,011,400	5.31	0.0149
Samarkand	22,822	1,104,553	8.42	0.0286
Syrdarya	390	18,891	6.12	0.0196
Surkhandarya	13,386	647,865	6.00	0.0162
Tashkent	10,931	529,050	7.66	0.0245
Karakalpakstan	101,188	4,897,406	8.02	0.0192
Total Uzbekistan	**337,647**	**16,341,781**	**6.47**	**0.0167**

Table A4.5. Amount of water (m^3, millions) lost due to inaction to control degradation in irrigation water resources in the land degradation hotspots of Uzbekistan

	Annually allocated amount of surface water or abstracted ground water for irrigation (million m^3) by			Annually delivered to the field (million m^3) by source:				Amount of water utilized by crops (million m^3) by source:				Annually lost water (million m^3) by:					Total	% share of loss in total provincial or national supply
												Source		Point of loss				
Province	Surface water resources	Ground water resources	Total	Surface water resources	Ground water resources	Total	Delivered to the filed as % of total supply	Surface water resources	Ground water resources	Total	Utilization as % of total supply	Surface water resources	Ground water resources	Conveyance losses	Storage losses	Field-level losses		
Andijan	278.09	4.23	282.32	177.98	2.70	180.68	%64	173.59	2.64	176.23	%62	104.50	1.59	64.27	36.07	5.75	106.09	37.58%
Bukhara	288.76	4.29	293.05	190.58	2.83	193.41	%66	153.86	2.29	156.15	%53	134.89	2.00	68.27	57.50	11.13	136.90	46.72%
Fergana	612.84	15.88	628.72	459.63	11.91	471.54	%75	362.37	9.39	371.76	%59	250.47	6.49	144.90	92.51	19.55	256.96	40.87%
Jizzakh	594.74	8.13	602.87	457.95	6.26	464.21	%77	438.62	6.00	444.62	%74	156.12	2.13	115.17	36.40	6,68	158.25	26.25%
Khorezm	675.07	-	675.07	391.54	-	391.54	%58	374.20	-	374.20	%55	300.87	-	156.06	117.34	27.47	300.87	44.57%
Namangan	383.60	6.61	390.21	253.17	4.36	257.54	%66	248.46	4.28	252.74	%65	135.14	2.33	86.43	42.62	8.43	137.47	35.23%
Navoiy	504.10	14.01	518.11	307.50	8.55	316.05	%61	284.58	7.91	292.49	%56	219.52	6.10	120.81	87.99	16.82	225.62	43.55%
Kashkadarya	641.07	10.57	651.64	423.10	6.98	430.08	%66	417.12	6.88	424.00	%65	223.94	3.69	144.97	72.84	9.82	227.64	34.93%
Samarkand	509.49	5.93	515.42	351.55	4.09	355.64	%69	305.14	3.55	308.69	%60	204.35	2.38	119.03	74.42	13.27	206.73	40.11%
Syrdarya	565.40	2.46	567.85	344.89	1.50	346.39	%61	401.06	1.74	402.81	%71	164.33	0.71	114.84	41.26	8.95	165.05	29.07%
Surkhandarya	793.15	4.52	797.68	444.17	2.53	446.70	%56	472.44	2.69	475.14	%60	320.71	1.83	181.43	109.66	31.45	322.54	40.44%
Tashkent	737.78	2.76	740.55	501.69	1.88	503.57	%68	461.52	1.73	463.25	%63	276.27	1.03	168.54	94.28	14.48	277.30	37.45%
Karakalpakstan	1,067.71	-	1,067.71	683.34	-	683.34	%64	543.75	-	543.75	%51	523.96	-	245.95	230.54	47.47	523.96	49.07%
Total Uzbekistan	**7,651.79**	**79.40**	**7,731.18**	**4,987.09**	**53.60**	**5,040.68**	**%65**	**4,636.72**	**49.10**	**4,685.82**	**%61**	**3,015.07**	**30.30**	**1,730.68**	**1,093.43**	**221.25**	**3,045.37**	**39.39%**

Table A4.6. Estimates of total energy used for pumping irrigation water in the land degradation hotspots of Uzbekistan

Province	Share of area under severe land degradation (%)	Total energy used for pumping in kWh	Total carbon emitted due to pumping (tons)
Andijan	12	5,771,625	435.48
Bukhara	7	5,993,000	452.18
Ferghana	20	12,719,104	959.67
Jizzakh	22	12,343,446	931.33
Khorezm	18	14,010,685	1,057.12
Namangan	12	7,961,319	600.69
Navoiy	36	10,462,208	789.39
Kashkadarya	12	13,304,961	1,003.87
Samarkand	14	10,574,162	797.83
Syrdarya	17	11,734,461	885.38
Surkhandarya	28	16,461,420	1,242.03
Tashkent	20	15,312,301	1,155.33
Karakalpakstan	17	22,159,751	1,671.98
Total Uzbekistan	**18**	**158,808,443**	**11,982.00**

Table A4.7. Volume of forest and shrub biomass lost annually in tons, ton per unit area, and as percentage of national total loss by province in the land degradation hotspots of Uzbekistan

Province	Forest and shrub biomass		
	Forest and shrub biomass lost (tons)	Loss as % of total provincial or national forest biomass stock	Forest biomass loss per unit area (ton/ha)
Andijan	–	–	–
Bukhara	5,465.68	0.56	0.27
Ferghana	–	–	–
Jizzakh	–	–	–
Khorezm	1,788.69	0.77	0.37
Namangan	363.79	0.32	0.15
Navoiy	18,073.52	0.18	0.09
Kashkadarya	–	–	–
Samarkand	61.76	0.16	0.08
Syrdarya	–	–	–
Surkhandarya	–	–	–
Tashkent	–	–	–
Karakalpakstan	38,114.40	0.46	0.22
Net - Uzbekistan	**63,867.84**	**0.30**	**0.16**

Table A4.8. Minimum amount of soil (tons) lost annually due to erosion by crop/biome type and by province and national aggregates in the land degradation hotspots of Uzbekistan

	Total soil erosion (ton) in Uzbekistan												As % of total soil loss in crop areas	As % of total national soil stock in all biomes	Loss (ton per ha) of total severely degraded land area
Province	Cereals	Legumes	Cotton	Potatoes	Vegetables	Fruits	Other crops	Forests and shrubs	Permananet Pastures (grass lands)	Other lands	Total for all crops	Total for all biomes			
Andijan	518	8	476	51	134	197	137	-	32,208	1,028	1,521	34,758	1.55%	1.2199%	54.90
Bukhara	-	-	-	-	-	-	-	-	-	-	-	-	0.00%		
Fergana	1,507	22	1,086	153	327	710	351	-	328	4,286	4,156	8,770	4.23%	1.9518%	87.83
Jizzakh	1,467	96	494	16	70	118	375	-	27,119	5,057	2,636	34,812	2.68%	4.8604%	218.72
Khorezm	-	-	-	-	-	-	-	-	-	-	-	-	0.00%		
Namangan	629	17	476	52	97	231	135	-	11,379	2,413	1,637	15,429	1.67%	1.8367%	82.65
Navoiy	-	-	-	-	-	-	-	-	-	-	-	-	0.00%		
Kashkadarya	-	-	-	-	-	-	-	2,423	147,971	-	-	150,394	0.00%	2.0341%	91.54
Samarkand	8,454	615	3,428	715	1,604	2,001	3,434	-	7,041	20,653	20,251	47,945	20.60%	1.9966%	89.85
Syrdarya	-	-	-	-	-	-	-	-	180	-	-	180	0.00%	0.6844%	30.80
Surkhandarya	-	-	-	-	-	-	-	-	36,666	-	-	36,666	0.00%	2.4987%	112.44
Tashkent	26,725	752	14,690	1,687	4,708	6,776	10,777	5,172	54,202	128,896	66,115	254,385	67.26%	2.8339%	127.52
Karakalpakstan	742	33	636	49	118	45	350	-	-	73,116	1,975	75,091	2.01%	3.5302%	250.00
Total Uzbekistan	**40,041**	**1,543**	**21,287**	**2,723**	**7,058**	**10,080**	**15,559**	**7,594**	**317,094**	**235,450**	**98,290**	**658,429**	**100.00%**	**2.4165%**	**108.74**
Loss (ton per ha) of total land in this biome	**68.53**	**65.80**	**69.23**	**67.88**	**68.44**	**68.68**	**68.65**	**154.80**	**119.15**	**158.72**	**68.69**	**108.74**			
Share of each crop in total soil loss (%)	**6.08**	**0.23**	**3.23**	**0.41**	**1.07**	**1.53**	**2.36**	**1.15**	**48.16**	**35.76**	**14.93**	**100.00**			

Table A4.9. Minimum amount (tons) of carbon released to the atmosphere due to soil erosion by biome/crop type and by province and national aggregates in land degradation hotspots of Uzbekistan

Province	Total amount of carbon released annually to the atmosphere (ton/ha) in Uzbekistan											
	Cereals	Legumes	Cotton	Potatoes	Vegeta-bles	Fruits	Other crops	Forests	Permanent pastures (grasslands)	Other lands	Total for all crops	Total for all biomes
Andijan	1.50	0.02	1.38	0.15	0.39	0.57	0.40	—	93.40	2.98	**4.41**	**100.80**
Bukhara	—	—	—	—	—	—	—	—	—	—	**—**	**—**
Ferghana	4.37	0.06	3.15	0.44	0.95	2.06	1.02	—	0.95	12.43	**12.05**	**25.43**
Jizzakh	4.25	0.28	1.43	0.05	0.20	0.34	1.09	—	78.64	14.67	**7.64**	**100.95**
Khorezm	—	—	—	—	—	—	—	—	—	—	**—**	**—**
Namangan	1.82	0.05	1.38	0.15	0.28	0.67	0.39	—	33.00	7.00	**4.75**	**44.74**
Navoiy	—	—	—	—	—	—	—	—	—	—	**—**	**—**
Kashkadarya	—	—	—	—	—	—	—	11.24	429.12	—	**—**	**440.36**
Samarkand	24.52	1.78	9.94	2.07	4.65	5.80	9.96	—	20.42	59.89	**58.73**	**139.04**
Syrdarya	—	—	—	—	—	—	—	—	0.52	—	**—**	**0.52**
Surkhandarya	—	—	—	—	—	—	—	—	106.33	—	**—**	**106.33**
Tashkent	77.50	2.18	42.60	4.89	13.65	19.65	31.25	24.00	157.18	373.80	**191.73**	**746.71**
Karakalpakstan	2.15	0.10	1.85	0.14	0.34	0.13	1.01	—	—	212.04	**5.73**	**217.76**
Total Uzbekistan	**116.12**	**4.48**	**61.73**	**7.90**	**20.47**	**29.23**	**45.12**	**35.24**	**919.57**	**682.81**	**285.04**	**1,922.66**

Table A4.10. Additional annual production that can be realized due to the introduction of the recommended policy, institutional, and technological changes in the land degradation hotspots of Uzbekistan

	Total annual production gains (tons) due to the introduction of the policy, institutional, and technological changes							Provincial or National Total	As % of total provincial or national production	Average yield gain (ton/ha)
Province	Cereals	Legumes	Cotton	Potatoes	Vegetables	Fruits	Other - crops			
Andijan	3,504	7,075	1,060	2,038	6,128	264	3,932	24,001	0.52%	0.10
Bukhara	5,077	7,094	10,020	6,759	37,867	1,478	7,725	76,021	2.24%	0.29
Fergana	11,362	18,022	4,677	9,290	35,539	3,830	11,841	94,562	2.44%	0.30
Jizzakh	18,507	12,116	11,221	3,369	26,427	1,454	11,557	84,650	3.79%	0.20
Khorezm	11,059	5,205	20,010	6,676	50,062	4,668	10,231	107,911	4.57%	0.46
Namangan	7,574	10,814	3,655	6,937	7,974	1,326	7,484	45,765	1.64%	0.20
Navoiy	4,317	4,716	2,533	1,023	4,927	470	5,420	23,406	1.91%	0.21
Kashkadarya	16,569	5,718	15,625	8,336	39,080	3,205	8,577	97,109	3.34%	0.20
Samarkand	6,272	13,017	7,124	11,802	36,730	4,819	8,806	88,571	1.82%	0.21
Syrdarya	7,290	16,461	7,288	2,292	30,216	555	8,628	72,730	4.07%	0.36
Surkhandarya	4,550	14,056	6,589	8,018	12,030	2,224	6,669	54,136	1.64%	0.17
Tashkent	5,580	4,126	3,582	6,605	10,983	696	7,629	39,202	1.31%	0.11
Karakalpakstan	10,801	3,739	3,714	4,475	33,007	840	12,360	68,935	4.77%	0.25
Total Uzbekistan	**112,463**	**122,161**	**97,098**	**77,619**	**330,970**	**25,829**	**110,859**	**876,999**	**2.32%**	**0.23**
Gain as % of current production in one season (%)	**1.55**	**30.42**	**3.17**	**2.47**	**3.30**	**0.58**	**1.17**	**2.32**		
Share of each crop in total volume of production to be gained (%)	**12.82**	**13.93**	**11.07**	**8.85**	**37.74**	**2.95**	**12.64**	**100.00**		
Rank	**3**	**2**	**5**	**6**	**1**	**7**	**4**			

Note: Here, percentage losses are calculated with reference to the provincial/national total (not as percentage of the hot spot areas only).

Table A4.11. Minimum amount of soil that will be prevented from being eroded from croplands due to the introduction of the recommended changes in the land degradation hotspots of Uzbekistan

	Total soil ersosion (ton) prevented prevented annually due to the introduction of the recommended changes														
Province	Cereals	Legumes	Cotton	Potatoes	Vegetables	Fruits	Other-crops	Forests	Permananet Pastures (grass lands)	Other lands	Total for all crops	Total for all biomes	as % of total provincial or national soil stock	saving in all crop areas (Ton per	Average saving (Ton per ha) in all biomes
Andijan	188.72	3.10	173.60	18.69	48.88	71.70	49.84	-	14,821.91	374.94	554.53	15,751.38	0.55%	12.90	24.88
Bukhara	-	-	-	-	-	-	-	-	-	-	-	-			
Fergana	595.96	8.52	429.59	60.40	129.35	280.93	138.95	-	139.87	1,695.07	1,643.70	3,478.64	0.77%	12.16	34.84
Jizzakh	535.91	34.91	180.51	5.73	25.63	43.23	136.87	-	24,172.67	1,847.25	962.80	26,982.72	3.77%	4.54	169.53
Khorezm	-	-	-	-	-	-	-	-	-	-	-	-			
Namangan	274.73	7.44	208.15	22.66	42.28	101.13	59.05	-	7,173.70	1,054.69	715.42	8,943.81	1.06%	9.62	47.91
Navoiy	-	-	-	-	-	-	-	-	-	-	-	-			
Kashkadarya	-	-	-	-	-	-	-	1,273.37	97,326.64	-	-	98,600.02	1.33%		60.01
Samarkand	2,718.55	197.78	1,102.32	229.99	515.71	643.50	1,104.28	-	3,853.32	6,641.57	6,512.12	17,007.01	0.71%	4.85	31.87
Syrdarya	-	-	-	-	-	-	-	-	21.09	-	-	21.09	0.08%		3.60
Surkhandarya	-	-	-	-	-	-	-	-	26,755.92	-	-	26,755.92	1.82%		82.05
Tashkent	12,020.81	338.29	6,607.33	758.72	2,117.51	3,047.97	4,847.50	2,886.76	36,373.58	57,976.81	29,738.13	126,975.28	1.41%	7.34	63.65
Karakalpakstan	333.73	15.06	286.29	22.22	53.29	20.39	157.35	-	-	32,887.15	888.33	33,775.48	17.23%	0.53	775.26
Total Uzbekistan	**16,668.41**	**605.10**	**8,987.78**	**1,118.40**	**2,932.65**	**4,208.86**	**6,493.83**	**4,160.13**	**210,638.71**	**102,477.47**	**41,015.04**	**358,291.35**	**1.42%**	**2.01**	**63.69**
Loss (ton per ha) of total land in this biome	**28.53**	**25.80**	**29.23**	**27.88**	**29.59**	**28.68**	**28.65**	**84.80**	**79.15**	**69.08**	**28.76**	**63.69**			**4.29**
Share of each crop in total soil loss (%)	**41**	**1**	**22**	**3**	**7**	**10**	**16**				**100**			**0**	
Rank	**1**	**7**	**2**	**6**	**5**	**4**	**3**								

Table A4.12. Annual additional forage production due to the recommended changes in pasturelands in the land degradation hotspots of Uzbekistan

Province	Additional annual forage production (tons)	Additional forage production as percentage of total provincial or national forage production (%)	Average gain in forage production (ton/ha)
Andijan	**551.90**	9.34	0.08
Bukhara	**16,250.03**	3.97	0.05
Ferghana	**493.63**	7.78	0.06
Jizzakh	**7,057.33**	3.55	0.07
Khorezm	**888.64**	2.90	0.06
Namangan	**1,459.08**	3.35	0.07
Navoiy	**113,619.59**	5.11	0.10
Kashkadarya	**15,523.56**	3.94	0.08
Samarkand	**14,834.18**	5.48	0.14
Syrdarya	**258.54**	4.06	0.10
Surkhandarya	**10,523.89**	4.72	0.10
Tashkent	**7,172.82**	5.03	0.12
Karakalpakstan	**86,443.42**	6.85	0.13
Total Uzbekistan	**275,076.62**	**5.27**	**0.10**

Table A4.13. Summary of annual benefits from interventions to control land degradation on all crop lands in the land degradation hotspots of Uzbekistan (in US$ and as % of GDP)

	Total Benefits (in US$) by Benefit Category				
	Consumptive uses	Non-consumptive uses	Indirect uses	Non-use values	Total benefits of intervention
Andijan	26,711	—	3,914	393	**31,018**
Bukhara	786,486	—	129,065	11,581	**927,132**
Ferghana	23,891	—	3,265	352	**27,508**
Jizzakh	341,568	—	244,875	5,030	**591,473**
Khorezm	43,009	—	31,623	633	**75,265**
Namangan	70,618	—	14,935	1,040	**86,593**
Navoiy	5,499,078	—	739,409	80,976	**6,319,463**
Kashkadarya	751,325	—	174,017	11,063	**936,406**
Samarkand	717,960	—	114,963	10,572	**843,495**
Syrdarya	12,513	—	1,081	184	**13,779**
Surkhandarya	509,346	—	144,049	7,500	**660,896**
Tashkent	347,158	—	80,919	5,112	**433,188**
Karakalpakstan	4,183,778	—	997,222	61,607	**5,242,607**
Total Uzbekistan	**13,313,442**	**—**	**2,679,336**	**196,044**	**16,188,823**
As % of GDP	**0.02**	**0.00**	**0.00**	**0.0003**	**0.03**

Table A4.14. Total annual volume and monetary value of woody biomass prevented from being lost due to deforestation or gained due to afforestation (tons)

	Volume of additional woody biomass produced (tons)	Monetary value (US$) of benefits by benefit category				
		Consumptive uses	Non-consumptive uses	Indirect uses	Non-use values	Total benefits
Andijan	178	10,390	—	2,333	1,060	13,784
Bukhara	45,709	2,674,675	—	625,654	272,987	3,573,316
Ferghana	2,327	136,140	—	30,570	13,895	180,605
Jizzakh	22,374	1,309,183	—	295,589	133,620	1,738,392
Khorezm	11,002	643,801	—	153,556	65,709	863,066
Namangan	5,441	318,370	—	73,526	32,494	424,390
Navoiy	462,914	27,087,335	—	6,196,615	2,764,633	36,048,582
Kashkadarya	33,642	1,968,569	—	443,891	200,919	2,613,379
Samarkand	1,776	103,903	—	23,711	10,605	138,219
Syrdarya	669	39,164	—	8,830	3,997	51,991
Surkhandarya	26,567	1,554,555	—	350,510	158,664	2,063,728
Tashkent	9,288	543,510	—	122,656	55,473	721,638
Karakalpakstan	390,760	22,865,281	—	5,334,796	2,333,714	30,533,791
Total Uzbekistan	**1,012,646**	**59,254,876**	**—**	**13,662,237**	**6,047,770**	**78,964,883**
As % of GDP		**0.09603**	**0.00**	**0.0221**	**0.01**	**0.128**

Table A4.15. Minimum amount of water that can be saved due to the introduction of the recommended policy, institutional, and technological changes

Province	Total water supply (m^3, millions)	Delivered to the field as % of total supply	Field - level utilization as % of total supply	Loss as % of total supply (current)	Loss as % of total supply (after recommended changes are introduced)	Amount of water (m^3, millions) annually saved from being lost due to the introduction of the recommended policy, institutional, and technological changes			
						During conveyance	During storage	During field application	Total
Andijan	170.15	82	81	38	19	19.37	10.87	1.73	31.97
Bukhara	713.23	83	77	47	23	83.08	69.97	13.54	166.59
Ferghana	562.90	88	80	41	20	64.87	41.41	8.75	115.03
Jizzakh	602.87	89	87	26	13	57.59	18.20	3.34	79.12
Khorezm	1,399.19	79	78	45	22	161.73	121.60	28.47	311.81
Namangan	449.25	83	82	35	18	49.75	24.53	4.85	79.14
Navoiy	247.05	81	78	44	22	28.80	20.98	4.01	53.79
Kashkadarya	1,065.88	83	83	35	17	118.57	59.57	8.03	186.17
Samarkand	435.81	85	80	40	20	50.32	31.46	5.61	87.40
Syrdarya	640.89	81	85	29	15	64.80	23.28	5.05	93.14
Surkhandarya	345.99	78	80	40	20	39.35	23.78	6.82	69.95
Tashkent	452.74	84	81	37	19	51.52	28.82	4.42	84.77
Karakalpakstan	1,726.18	82	75	49	25	198.81	186.36	38.37	423.55
Total Uzbekistan	**8,812.13**	**83**	**80**	**40**	**20**	**988.57**	**660.85**	**133.00**	**1,782.42**

Table A4.16. Cost of inaction to control land degradation in hot spot areas of Uzbekistan (in US$ per year)

	Cost (in million US$) of land degradation per year:							
Type of Value	**In all crop lands**	**In natural forests**	**In natural pastures**	**Water**	**In abandoned crop lands**	**Infrastructure damage and economic losses induced by extreme weather and emergency**	**In the form of health problems**	**Total (US$/year)**
1. Use value	1,028,450,189	10,131,805	92,551,062	1,103,198,952	360,226,046	90,674,006	38,255,206	2,723,487,265
1.1 Direct use value	1,019,806,238	2,183,330	16,341,781	1,103,198,952	360,226,046	90,674,006	22,953,123	2,615,383,476
1.2 Indirect use value	8,643,951	7,948,476	76,209,281	-	-	-	15,302,082	108,103,789
2. Non-use value	71,860,138	-	240,638	439,350	-	-	38,255,206	110,795,331
Total	**1,100,310,326**	**10,131,805**	**92,791,700**	**1,103,638,302**	**360,226,046**	**90,674,006**	**76,510,411**	**2,834,282,596**
As a % of GDP	**1.78**	**0.02**	**0.15**	**1.79**	**0.58**	**0.15**	**0.12**	**4.59**

Note: Due to lack of data and difficulty of estimation, many aspects of nonuse value are not included in the estimation for which in our estimates, more than 96 percent of the total cost of inaction comes from use value out of which over 91 percent is direct use value.

Table A4.17. Recommended suite of technological, institutional, and policy interventions to reduce land degradation and enhance yields in croplands in land degradation hotspots of Uzbekistan

Province	Best-bet technologies (for both irrigated and rain-fed areas)	Best-bet institutional and policy changes
All 13 provinces	1. Conservation agriculture practices 2. Crop diversification (including crop rotations and agroforestry) 3. Improved high-yielding, water-efficient, and disease-resistant crop varieties with appropriate agronomic practices 4. Planting wheat on standing cotton	1. State policy must incorporate both farm enterprises (as the users of the largest land areas) and dehkan farms (as the producers of most food and the major users of pasture areas). To date, policy has been overly focused on large farm enterprises and their predecessors. 2. Market-based institutions (such as land exchanges) must be introduced. 3. Incentive structures must be shifted to encourage sustainable use of land and water resources. 4. Extension services must be improved involving a participatory approach that combines the local knowledge of farmers with the technical knowledge of researchers and other experts.

Note: The improved varieties for

- Bukhara and Navoiy should be salt and cold tolerant,
- Andijan should be heat tolerant,
- Khorezm should be cold tolerant,
- Namangan should be heat tolerant,
- Kashkadarya should be heat and drought tolerant,
- Syrdarya should be salt tolerant,
- Surkhandarya should be drought tolerant, and
- Surkhandarya should be drought and cold tolerant.

Table A4.18. Recommended suite of technological, institutional, and policy interventions to reduce land degradation and enhance yields in forests in land degradation hotspots of Uzbekistan

Province	Best-bet technologies	Policy and institutional changes
All 13 provinces	1. Reforestation of existing degraded forests and afforestation of marginal lands using appropriate tree/shrub species 2. Protection and management of vegetatio 3. Agroforestry	1. Adequate financing 2. Building institutional capacity 3. Effective collaboration between state organizations

Table A4.19. Recommended suite of technological, institutional, and policy interventions to reduce land degradation and enhance yields in pasturelands in land degradation hotspots of Uzbekistan

Province	Best-bet technologies	Policy and institutional changes
All 13 provinces	1. Ensure rotational grazing and seasonal resting. 2. Establish pastures on poor croplands, or in a mixed farming system, consider alternate components of rotations such as alfalfa and sainfoain (for drought-prone areas).	1. Introduce participatory pasture management principles to prevent pasture degradation.
Bukhara, Navoiy, Kashkadarya, Samarkand, Surkhandarya, Tashkent, and Karakalpakstan	1. Plantation (using airplanes) or transplanting of appropriate grass/shrub species (for example, saxaul and Kokhia) in pasture/rangelands	

Table A4.20. Recommended suite of technological, institutional, and policy interventions to reduce land degradation-induced water losses in land degradation hotspots of Uzbekistan

Province	Best-bet technologies for irrigated and rain-fed areas	Policy and institutional changes
All 13 provinces	**(a) Farm-level technologies** ***(i) Farms with access to irrigation water*** 1. Mechanized Raised Beds (MRBs) 2. Drip Irrigation 3. Sprinkler irrigation 4. Weather-based irrigation scheduling 5. Laser-assisted land leveling ***(ii) Farms with no access to irrigation water*** • Water harvesting technologies in rain-fed areas **(b) Communal technologies - reservoirs, conveyance structures, pump houses, and pumps (the effects of these sets of technologies are not included in the estimation of the loss of ecosystem services)** 1. Design, construction, operation, reconstruction, and repair of large and especially critical water management facilities 2. Leveling and lining of irrigation canals and distribution networks and renovation and lining of major water reservoirs 3. Replacement of old and energy-intensive pumps with solar-powered and energy-efficient pumps	1. Water pricing for irrigation and introducing of penalty for those who overirrigate 2. Provision of subsidies to farmers for the purchase of drip and sprinkler irrigation devises 3. Provision of subsidies to farmers for the purchase of solar panels for irrigation (to minimize emissions and the pressure on electric power) 4. Reduction of cotton area (to save water and avoid salinization of soils)

Table A4.21. Summary of value of ecosystem services added or prevented from being lost due to action in land degradation hotspots of Uzbekistan (in US$ per year)

	Cost (in million US$) of land degradation per year:							
Type of Value	In all crop lands	In natural forests	In natural pastures	Water	In abandoned crop lands	In the form of flood and landslides	In the form of health problems	Total (US$/year)
1. Use value	688,531,910	72,917,113	15,992,778	645,688,878	-	11,504,960	1,254,040	1,435,889,680
1.1 Direct use value	679,497,298	59,254,876	13,313,442	645,688,878	-	11,504,960	752,424	1,410,011,878
1.2 Indirect use value	9,034,612	13,662,237	2,679,336	-	-	-	501,616	25,877,802
2. Non-use value	51,911,076	6,047,770	196,044	-	-	-	1,254,040	59,408,931
Total	**740,442,987**	**78,964,883**	**16,188,823**	**645,688,878**	**-**	**11,504,960**	**2,508,081**	**1,495,298,611**
As a % of GDP	**1.20**	**0.13**	**0.03**	**1.05**	**0.00**	**0.02**	**0.00**	**2.42**

Table A4.22. Investment required (US$) for the implementation of the recommended technological, institutional, and policy changes to combat land degradation in the prioritized land degradation hot spot areas

Item	Province	Crops	Water	Natural pastures	Forests	Total for all biomes
National area under this biome (ha)		3,860,559	3,860,559	21,244,300	3,434,655	44,897,140
National area requiring this investment (ha)		1,821,926	1,753,404	2,771,197	540,958	6,887,484
Hot spot areas recommended for this investment		598,229	598,229	70,060	930,821	1,599,109
Cost of implementing this intervention	**Andijan**	3,901,168	7,482,957	42,680	2,334	11,429,139
	Bukhara	26,079,139	27,925,042	1,770,708	600,856	56,375,745
	Ferghana	14,526,768	18,526,753	37,823	30,583	33,121,927
	Jizzakh	10,965,235	23,588,442	537,407	294,103	35,385,187
	Khorezm	56,110,034	54,057,962	69,400	144,628	110,382,024
	Namangan	14,952,717	12,444,681	111,508	71,521	27,580,428
	Navoiy	9,146,616	4,645,205	8,801,032	6,085,069	28,677,922
	Kashkadarya	37,900,845	27,847,501	1,203,213	442,232	67,393,791
	Samarkand	28,568,358	13,166,973	1,051,378	23,342	42,810,049
	Syrdarya	15,467,465	18,783,763	19,292	8,798	34,279,318
	Surkhandarya	7,925,187	12,236,331	786,509	349,225	21,297,252
	Tashkent	18,362,414	10,481,898	537,692	122,097	29,504,102
	Karakalpakstan	22,464,780	28,019,372	6,626,395	5,136,600	62,247,147
Total Uzbekistan		**266,370,727**	**259,206,879**	**21,595,038**	**13,311,388**	**560,484,032**
Share of each component in total investment (%)		**48**	**46**	**4**	**2**	**100**

Note:

- Hard component includes cost of machinery and equipment; soft component includes cost of policy, institutional, and market changes.
- It is assumed that subsidies of up to 20 percent of the total cost of the hard component will be needed to be given to farmers to promote adoption of the technologies.
- No specific interventions will be made to control landslides and extreme weather and to reduce land degradation-related health problems. However, the interventions made to control land degradation in the different biomes will have impacts (positive externalities) in reducing those problems.

Table A4.23: Hard and soft components of the investment by biome and province in US$

		Crops			Water		
Item	**Province**	**Hard component**	**Soft component**	**Total**	**Hard component**	**Soft component**	**Total**
Cost of implementing this intervention (US$)	**Andijan**	211,555	3,689,614	3,901,168	6,216,788	1,266,169	7,482,957
	Bukhara	1,035,039	25,044,100	26,079,139	23,206,789	4,718,253	27,925,042
	Fergana	781,780	13,744,988	14,526,768	15,384,612	3,142,140	18,526,753
	Jizzakh	503,377	10,461,858	10,965,235	19,592,438	3,996,004	23,588,442
	Khorezm	2,090,893	54,019,142	56,110,034	44,914,481	9,143,481	54,057,962
	Namangan	911,608	14,041,109	14,952,717	10,339,230	2,105,451	12,444,681
	Navoiy	411,247	8,735,369	9,146,616	3,864,664	780,541	4,645,205
	Kashkadarya	2,018,062	35,882,783	37,900,845	23,136,443	4,711,058	27,847,501
	Samarkand	1,361,086	27,207,272	28,568,358	10,938,478	2,228,495	13,166,973
	Syrdarya	638,780	14,828,685	15,467,465	15,611,565	3,172,198	18,783,763
	Surkhandarya	404,728	7,520,459	7,925,187	10,168,788	2,067,543	12,236,331
	Tashkent	760,243	17,602,171	18,362,414	8,715,726	1,766,171	10,481,898
	Karakalpakstan	921,551	21,543,229	22,464,780	23,277,201	4,742,171	28,019,372
Total Uzbekistan		**12,049,950**	**254,320,777**	**266,370,727**	**215,367,203**	**43,839,676**	**259,206,879**
Share in total investment (%)		**5**	**95**	**100**	**83**	**17**	**100**

		Natural Pastures			Forests			Total for all Biomes		
Item	**Province**	**Hard component**	**Soft component**	**Total**	**Hard component**	**Soft component**	**Total**	**Hard component**	**Soft component**	**Total**
Cost of implementing this intervention (US$)	**Andijan**	0	42,680	42,680	0	2,334	2,334	6,428,342	5,000,797	11,429,139
	Bukhara	0	1,770,708	1,770,708	0	600,856	600,856	24,241,828	32,133,917	56,375,745
	Fergana	0	37,823	37,823	0	30,583	30,583	16,166,393	16,955,535	33,121,927
	Jizzakh	0	537,407	537,407	0	294,103	294,103	20,095,815	15,289,373	35,385,187
	Khorezm	0	69,400	69,400	0	144,628	144,628	47,005,373	63,376,650	110,382,024
	Namangan	0	111,508	111,508	0	71,521	71,521	11,250,839	16,329,589	27,580,428
	Navoiy	0	8,801,032	8,801,032	0	6,085,069	6,085,069	4,275,911	24,402,011	28,677,922
	Kashkadarya	0	1,203,213	1,203,213	0	442,232	442,232	25,154,506	42,239,285	67,393,791
	Samarkand	0	1,051,378	1,051,378	0	23,342	23,342	12,299,564	30,510,485	42,810,049
	Syrdarya	0	19,292	19,292	0	8,798	8,798	16,250,345	18,028,973	34,279,318
	Surkhandarya	0	786,509	786,509	0	349,225	349,225	10,573,516	10,723,736	21,297,252
	Tashkent	0	537,692	537,692	0	122,097	122,097	9,475,970	20,028,132	29,504,102
	Karakalpakstan	0	6,626,395	6,626,395	0	5,136,600	5,136,600	24,198,752	38,048,396	62,247,147
Total Uzbekistan		**0**	**21,595,038**	**21,595,038**	**0**	**13,311,388**	**13,311,388**	**227,417,153**	**333,066,878**	**560,484,032**
Share in total investment (%)		**0**	**100**	**100**	**0**	**100**	**100**	**41**	**59**	**100**

Table A4.24. Total 10-year benefits (in US$) of implementing the technological, institutional, and policy interventions in the prioritized hot spot areas of Uzbekistan

Item	Province	Crops	Water	Natural pastures	Forests	Landslides and flooding prevented and reduction of land degradation-induced health problems	Total value of benefits of action
Cost of implementing this intervention	**Andijan**	126,823,544	72,137,012	198,798	12,840	1,934,014	201,106,208
	Bukhara	363,028,150	368,670,140	5,194,659	4,095,579	6,810,362	747,798,890
	Ferghana	503,789,122	262,808,922	173,551	188,575	8,808,505	775,768,676
	Jizzakh	425,279,092	179,323,021	3,652,892	1,807,286	4,446,932	614,509,224
	Khorezm	591,900,811	702,141,360	462,938	875,631	7,834,220	1,303,214,959
	Namangan	264,070,271	173,653,074	544,029	474,965	7,140,020	445,882,359
	Navoiy	131,437,221	118,373,986	36,336,617	41,326,472	5,405,718	332,880,013
	Kashkadarya	510,000,519	405,511,182	5,698,864	2,733,450	9,298,974	933,242,989
	Samarkand	491,531,925	190,860,382	5,176,568	143,714	7,472,679	695,185,268
	Syrdarya	297,031,356	207,279,396	86,242	59,656	3,205,288	507,661,939
	Surkhandarya	328,988,263	149,694,967	3,957,896	2,132,491	10,568,015	495,341,631
	Tashkent	214,616,172	187,701,104	2,623,663	795,728	8,749,715	414,486,383
	Karakalpakstan	307,234,625	1,006,221,151	36,299,782	35,081,916	7,550,360	1,392,387,835
Total Uzbekistan		**4,555,731,073**	**4,024,375,699**	**100,406,501**	**89,728,301**	**89,224,802**	**8,859,466,375**
Share of each component in total benefits (%)		**51.42**	**45.42**	**1.13**	**1.01**	**1.01**	**100.00**

Table A4.25. BCR for investment on introducing the technological, institutional, and policy recommendations in the prioritized land degradation hot spot areas in Uzbekistan

Province	Crops	Water	Natural pastures	Forests	Total for all biomes
Andijan	32.51	9.64	4.66	5.50	17.60
Bukhara	13.92	13.20	2.93	6.82	13.26
Ferghana	34.68	14.19	4.59	6.17	23.42
Jizzakh	38.78	7.60	6.80	6.15	17.37
Khorezm	10.55	12.99	6.67	6.05	11.81
Namangan	17.66	13.95	4.88	6.64	16.17
Navoiy	14.37	25.48	4.13	6.79	11.61
Kashkadarya	13.46	14.56	4.74	6.18	13.85
Samarkand	17.21	14.50	4.92	6.16	16.24
Syrdarya	19.20	11.04	4.47	6.78	14.81
Surkhandarya	41.51	12.23	5.03	6.11	23.26
Tashkent	11.69	17.91	4.88	6.52	14.05
Karakalpakstan	13.68	35.91	5.48	6.83	22.37
Total Uzbekistan	**22.12**	**14.98**	**4.55**	**6.67**	**15.81**

Note:

- *BCR for pastures is low because the current productivity of natural pastures is very low, and we have made a very conservative assumption on yield gains because increasing yields in this biome requires either assigning land titles, which is not easy, or a lot of work in ensuring mutually beneficial collective actions on communal property.*
- BCR for forests is also low because the benefits of forests are not *fully realized in 10 years.*

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