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The role of land restoration for climate change mitigation and biodiversity conservation in Kazakhstan

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ABSTRACT

Land restoration in Kazakhstan plays a pivotal role in addressing both climate change mitigation and biodiversity conservation. The country faces significant challenges related to land degradation, including driven by deforestation and shrubland loss, which has substantial economic and environmental impacts. By restoring forests, Kazakhstan can enhance carbon sequestration, particularly in regions such as Eastern Kazakhstan, which has shown notable gains in carbon sinks from land use and land cover changes. Restoration initiatives also align with Kazakhstan's commitments under the Bonn Challenge, aiming to restore millions of hectares of degraded land by 2030. By analyzing land cover changes from 2001 to 2020, we identified key degradation hotspots and quantified economic losses of approximately 5.6 billion USD, primarily in grasslands and forests. Evaluating three socioeconomic and climatic scenarios—Optimistic, Base, and Pessimistic—revealed that restoration investments ranging from 6.7 to 11.6 billion USD could yield benefit-cost ratios between 1.4 and 4.3, with wetlands and forests restoration emerging as priority areas. These findings highlight the need for an integrated, data-driven approach to align economic viability with environmental sustainability, thereby promoting green growth and enhancing long-term resilience. Land restoration can serve as a cornerstone for achieving Kazakhstan's environmental goals, fostering synergies between climate mitigation, biodiversity protection, and sustainable development.

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1. Introduction

Climate change, biodiversity loss, and land degradation are closely interrelated challenges that cannot be effectively tackled in isolation. In Kazakhstan, as well, climate change is likely to become the dominant factor reducing crop and livestock productivity, lowering agricultural incomes, and accelerating biodiversity loss over the coming decades. Land degradation is already eroding vital ecosystem services and biodiversity through the loss of both above- and below-ground soil carbon and while also contributing to climate change through increased emissions of nitrous oxide. This degradation further influences rainfall patterns and contributes to more frequent and severe extreme weather events such as droughts, floods, and dust storms (Mirzabaev et al., 2019).

Land in Kazakhstan serves as a critical nexus linking climate change, biodiversity loss, and land degradation with agricultural productivity. Agriculture remains a significant part of the national economy through providing livelihoods for a large segment of the workforce. Therefore, integrated and coordinated actions addressing the land-climate-biodiversity-agriculture nexus are essential for achieving sustainable development and a resilient, food-secure future in Kazakhstan. Such an approach promises enhanced efficiency and effectiveness in national land restoration investments, steering the country toward green growth.

Land restoration in Kazakhstan is not only an environmental imperative but also a vital economic and social strategy to combat ecosystem degradation. Kazakhstan's diverse landscapes—from its expansive steppes to its fertile agricultural regions—have suffered from overexploitation, mismanagement, and the impacts of climate change. This degradation undermines biodiversity and ecosystem stability while directly affecting agricultural productivity and the livelihoods of millions who depend on the land.

This paper pursues the following research questions:

- What is the current extent and cost of land degradation in Kazakhstan? Where are the degradation hotspots, and how have these hotspots and associated costs evolved between 2001 and 2020?
- What are the total financing needs for restoring degraded lands in Kazakhstan?
- Which degraded areas in Kazakhstan offer the highest returns on land restoration investments?

1.1. Study Area, Geographic and Institutional Context

Kazakhstan faces significant land degradation challenges that stem from a mix of natural and human-induced factors. Natural aridity, agricultural expansion, deforestation, and overgrazing have collectively driven severe soil erosion, loss of vegetation, and a decline in agricultural productivity. These environmental stresses are further compounded by extreme weather events and natural disasters—which have been intensified by climate change—placing additional strain on local livelihoods. About 46% of Kazakhstan experienced vegetation degradation between 2000 and 2029, with land use change as the predominant contributor, followed by climate change and climate variability (Kolluru et al., 2024).

Historically, Kazakhstan's extensive rangelands have supported nomadic lifestyles and continue to be vital for food production, climate regulation, and soil conservation (Kerven et al., 2021). Yet, these same rangelands are suffering degradation due to climate variability, overgrazing, and the proliferation of unpalatable grass species. Wind erosion plagues the vast plains, while water erosion predominantly affects foothill and mountainous regions (Kalieva et al., 2025), with an estimated 29 million hectares impacted by these erosive processes (Mukhanov, 2024). Up to 60% of Kazakhstan's territory experienced significant vegetation loss in 2000–2004 compared to the 1980–1984 period (Le et al., 2016). Erosion may intensify under current land use and climate trends: areas with high topographic erosion potential were predicted to expand by about 10%, corresponding to an additional 24,000 km^2 of land becoming susceptible to severe erosion by 2030 (Seitkazy et al., 2025). This anticipated increase is driven by both climatic factors (likely more intense rainfall events and desiccating winds) and land use factors (such as insufficient ground cover outside of the growing season). Salinization of agricultural lands is a major problem across the country (Rakhmanov et al., 2024),This loss not only diminishes the land's productive capacity and threatens biodiversity by eroding vital ecosystems and habitats, but it also contributes to greenhouse gas emissions through the reduction of carbon stored both above and below ground.

Desertification was estimated earlier to costs the country approximately 6.2 billion USD (Saigal, 2003), with roughly two-thirds to three-quarters of Kazakhstan's territory is classified as susceptible to desertification (Bissinbayeva et al., 2024), with active desertification taking place on about 3.8% of the territory (Hu et al., 2020). While land use and land cover changes have been linked to annual losses of around 3 billion USD between 2001 and 2009 (Mirzabaev et al., 2016). These figures underscore the substantial economic burden that environmental degradation places on Kazakhstan.

Institutionally, the country grapples with a fragmented framework for land management and restoration. Responsibilities are dispersed among various ministries and agencies—most notably, the Ministry of Ecology and Natural Resources and the Ministry of Agriculture, including the Land Administration Committee —leading to overlapping mandates, inconsistent data collection, and coordination challenges.

The absence of a unified, centralized data management system further exacerbates these issues, resulting in resource duplication and inconsistencies. Additionally, limited involvement from academic and research institutions—hampered by funding constraints, weak collaboration frameworks, and a shortage of technical expertise—impedes the effective monitoring, reporting, and verification of land restoration efforts.

Despite these challenges, Kazakhstan has initiated several efforts to improve land management and restoration over the past decade. There is now an urgent need for comprehensive, data-driven approaches that not only restore degraded lands but also ensure sustainable land use practices. Integrating land restoration with climate and biodiversity action agendas is seen as critical for enhancing the resilience and long-term sustainability of Kazakhstan's landscapes.

On the policy front, Kazakhstan's biodiversity strategies have evolved over time. The National Biodiversity Strategy and Action Plan (NBSAP) completed in 1999 set ambitious goals: the in situ conservation of biological diversity, socioeconomic assessments to balance the use of the country's biological resources, the expansion and safeguarding of the genetic fund—including agricultural crop varieties and livestock—and improving the productivity of agricultural lands. As of 2023, over 29 million hectares have been designated as protected areas, covering 10.77% of the country's land. Furthermore, Kazakhstan's "Concept for Conservation and Sustainable Use of Biodiversity by 2030" identifies key targets for forest and wooded land restoration, focusing on the Aral Sea region and protective tree lines along transportation corridors. This Concept set targets to increase wooded land from 4.7% of the total land area by 2020 to 5% by 2030, primarily through reforestation and afforestation efforts covering 1.5 million hectares. These initiatives include the establishment of fast-growing tree plantations, urban green belts, and the planting of 10,000 hectares of shelterbelts. In line with these ambitious plans, the President of the Republic of Kazakhstan has directed that over two billion trees be planted in forests and an additional 15 million trees in settlements between 2021 and 2025. Although earlier iterations of the NBSAP and the related Concept did not receive parliamentary approval, the Ministry of Ecology and Natural Resources is currently developing a new NBSAP under the "Global Biodiversity Framework – Early Action Support" project funded by the Global Environment Facility (GEF).

In its commitment to combat climate change, Kazakhstan has pledged to reduce greenhouse gas emissions unconditionally by 15% and conditionally by 25% relative to the 1990 base year by the end of 2030 (NDC, 2023). A national emission trading system has also been established. Advanced technologies such as satellite data and artificial intelligence are being employed to monitor changes in land use and forest cover, thereby enhancing the quality of data collection for monitoring, reporting, and verification (MRV). Plans to increase forest cover include the development of private industrial plantations and forest nurseries, supported by the National Action Plan for 2020-2025.

Kazakhstan's Land Degradation Neutrality (LDN) commitments, as outlined in its 2017 national LDN targets, address several key areas. The country aspires to achieve land degradation neutrality by 2030, restore 6.8 million hectares of degraded agricultural lands by 2020, and expand irrigated areas by 40% to reach 2 million hectares by 2020. Additional restoration efforts target 610,000 hectares of irrigated areas and 368,000 hectares of floodplain irrigated areas, alongside initiatives in agroforestry and afforestation aimed at reducing erosion. Comprehensive monitoring and reporting are planned for 33 million hectares each of agricultural lands and pasturelands.

Under the Bonn Challenge (Ministry of Agriculture of the Republic of Kazakhstan, 2018), Kazakhstan has committed to expanding its restoration and afforestation efforts with a target of restoring 1.5 million hectares by 2030. Should additional technical and financial support become available, these efforts could expand to a total of 1.8 million hectares restored and afforested by 2030. Official data reveal that 318,000 hectares were restored between 2018 and 2020, and there is a strong focus on afforestation activities on the dried Aral Sea bottom.

2. Analytical approach

2.1. Costs and benefits of land restoration

Land restoration seeks to revive every function and component of a previously degraded ecosystem, rather than focusing on just one element such as planting trees in a deforested area. Since ecosystems constitute the natural capital that generates services with measurable economic values (MEA, 2005), it is crucial to understand the breadth of benefits they offer. Figure 1 illustrates the global distribution of economic values derived from these services across different ecosystems (Brander et al., 2024). These values fall into three main categories—food and economic services, climate regulation (including carbon sequestration), and environmental and biodiversity services—reflecting each ecosystem's distinct role in supporting human well-being and ecological balance.

Restoring degraded ecosystems entails four major cost components. Establishment costs arise from putting restoration technologies and practices in place, such as site preparation or planting activities. Maintenance costs then cover the ongoing expenses of caring for restored areas over time. Opportunity costs represent the forgone benefits of the land's previous use—for instance, when reforestation replaces cropland, any lost income from agricultural production must be taken into account (Mirzabaev and Wuepper, 2023). Transaction costs, which can make up as much as half of total restoration expenses (Coggan et al., 2010), encompass the processes of identifying suitable restoration sites, planning and negotiating interventions, organizing restoration programs, and monitoring the outcomes. Accurately recognizing and factoring in each of these costs is vital for designing effective, financially sound restoration strategies.

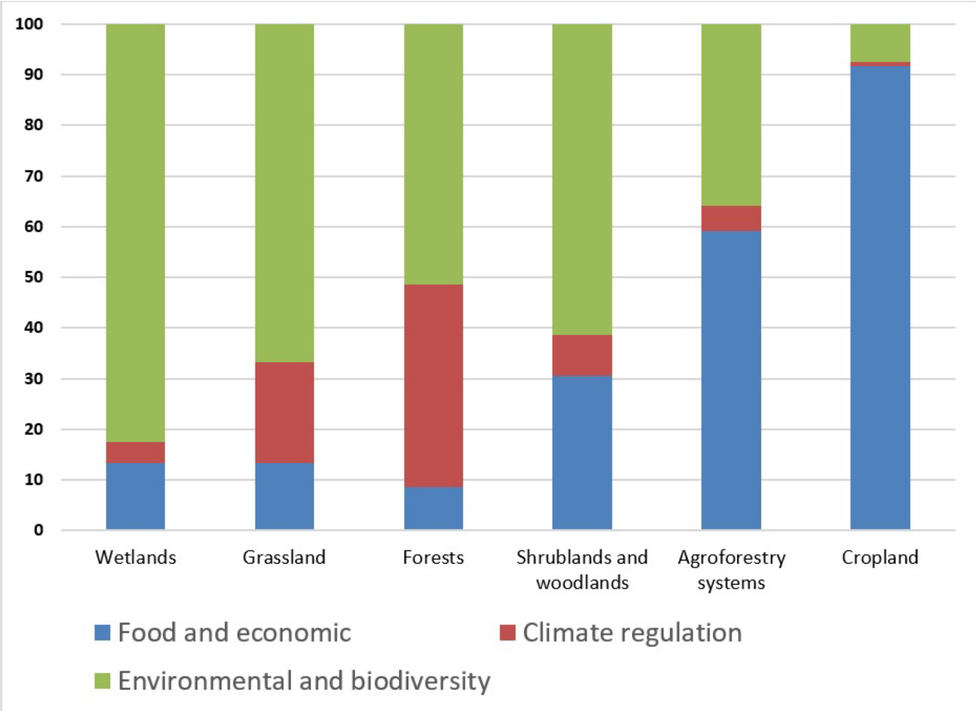

Figure 1. Shares of economic values of ecosystem services in different ecosystems (in percentages), global averages (Foundation for Sustainable Development & Brander Environmental Economics, 2023)

Creating synergies among the various actors involved in land restoration can significantly reduce transaction costs, thereby enhancing both the effectiveness and efficiency of restoration efforts. In practice, when stakeholders coordinate their activities, restoration targets are more likely to be met while minimizing overall costs.

The analytical process illustrated in Figure 2 outlines the steps taken to identify land degradation hotspots, assess the costs of degradation, and evaluate the necessary investments and potential returns from restoration. The analysis started by examining land use and land cover (LULC) changes in Kazakhstan over the period from 2001 to 2020, with 2001 serving as the baseline and 2020 as the endline. Building on these findings, we then analyzed shifts across various ecosystem types—including forests, woodlands, shrublands, wetlands, grasslands, croplands, and barren lands.

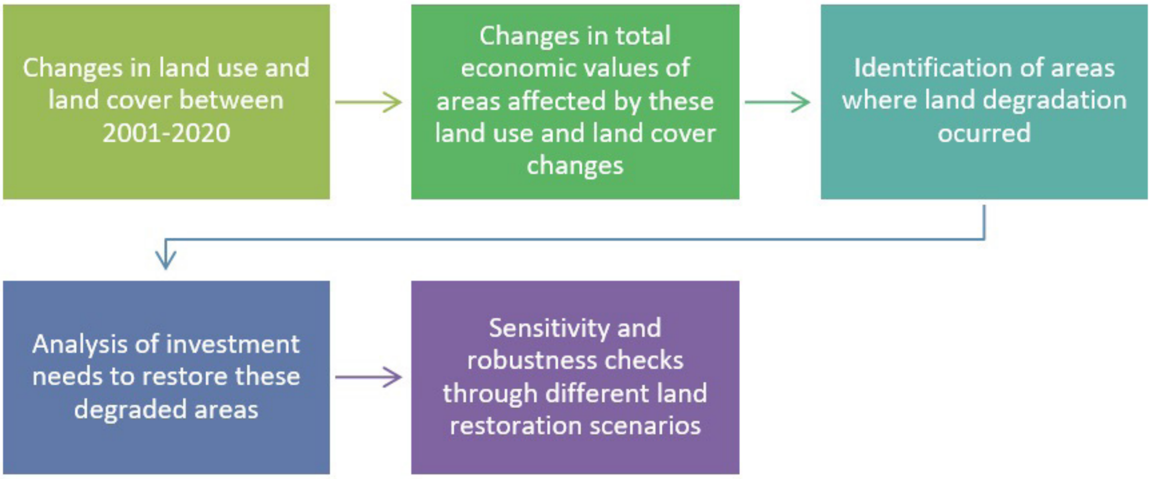

Figure 2. Analytical process for identification of land degradation hotspots, costs of land degradation, investment needs and returns from land restoration

By combining the LULC data with information on the total economic values of each ecosystem (Table I), the study pinpointed locations where declines in total economic value signified land degradation. Finally, the study estimated the investment required to restore these degraded ecosystems, incorporating available data on restoration costs (Table I).

More formally, the analytical process applied involves the calculation of the costs of land degradation includes the total economic values (TEV) of direct use and indirect use ecosystem services obtained from land ecosystems in Central Asia. The costs and benefits of land restoration activities are calculated by their net present value (NPV) in year t for planning horizon T. The costs of land restoration activities are comprised of establishment costs for restoring the degraded biomes, maintenance costs, the opportunity costs of the lower value biome, which is being replaced by the higher value biome, as well as the transaction costs used for implementing land restoration programs.

$$\pi_t^c = \frac{1}{\rho^t} \sum_{t=0}^{T} \left(PY_t^c + IV_t - lm_t^c\right) \qquad (1)$$

where, π_t^c = net present value (NPV) of land restoration in year t for planning horizon T; ρt = 1+r, r = discount rate (10%); Y_t^c= production of direct use provisioning services after land restoration (food, fodder, timber, non-timber products, etc.); P= unit price of Y_t^c; IVt = value of indirect use ecosystem services (e.g. carbon sequestration); lm_t^c = cost of land restoration, including establishment, maintenance, opportunity, and transaction costs. The planning horizon (T) in this study is determined to be 30 years, i.e., between 2020 and 2050.

If Central Asian countries do not undertake land restoration, the NPV is given by:

$$\pi_t^d = \frac{1}{\rho^t} \sum_{t=0}^{T} \left(PY_t^d + IV_t\right) \tag{2}$$

where π_t^d = NPV of the ecosystem services still derived from the degraded biome. Superscript d indicates a degraded biome.

The benefit of land restoration is given by:

$$BA = \pi_t^c - \pi_t^d \tag{3}$$

The difference π_t^c-π_t^d is essential in decision making. If the returns to land restoration, after including land restoration costs, are smaller than the corresponding returns from the degraded biome, it would not make economic sense to conduct land restoration activities.

Analytically, this would mean calculating (4) below. For example, when a forest is cut down and turned into a cropland, this would mean lower values of ecosystem services because forests usually provide higher TEV of ecosystem services than croplands.

$$C_{LULC} = \sum_i^K (\Delta a_1 * p_1 - \Delta a_1 * p_2) \tag{4}$$

where C_{LULC} = cost of land degradation due to land dynamics; a_1= land area of biome 1 being replaced by biome 2; $P_1$and P_2 are TEV biome 1 & 2, respectively, per unit of area.

Hence, by the definition of land degradation, $P_1 > P_2$.

This means, land dynamics that lead to higher TEV, i.e., when $P_1 < P_2$, is not regarded as land degradation but rather as land improvement.

The analysis of land dynamics is based on International Geosphere-Biosphere Programme (IGBP) definitions and comprises the following biomes present in Central Asia: Evergreen Broadleaf Forest, Evergreen Needleaf forests, Mixed Forest, Closed shrubland, Woodlands, Grassland, Permanent wetlands, Cropland, Urban areas, Cropland/Natural Vegetation Mosaics which correspond to agroforestry systems, and barren areas, and Water bodies.

Table I. Ecosystem values and land restoration costs in Central Asian countries

Ecosystem values and land restoration costs (USD/ha)	Forests	Woodlands and shrublands	Wetlands	Croplands	Grasslands
Ecosystem values	7,000	1,700	6,700	132 - 2,539	407 – 2,223
Establishment costs	1,000	300	3,800	500	250
Maintenance costs	250	200	300	100	100

Sources: compiled from numerous sources indicated in Data Section

This investment analysis was conducted under different scenarios—optimistic, base, and pessimistic—to account for uncertainties in ecosystem values, restoration costs, and the future impacts of climate change (Table II).

The Shared Socioeconomic Pathways (SSPs) are scenarios developed to describe different ways in which the world might evolve in terms of social, economic, and environmental conditions over the 21st century. These pathways help analyze potential future outcomes for climate change mitigation and adaptation under different socioeconomic conditions:

- SSP1-2.6 (optimistic): low emission scenario.
- SSP3-7.0 (base): medium emissions scenario.
- SSP5-8.5 (pessimistic): high emissions scenario.

To account for the projected impacts of climate change in land restoration activities, the corresponding values on projected changes in Consecutive Dry Days and Mean Annual Temperatures for SSP3-7.0, SSP5-8.5, SSP1-2.6 were used.

Table II. Scenarios for land restoration investments

Scenarios	Ecosystem values	Establishment and maintenance costs	Time horizon (years)	Discount rate (%)	Survival rates (%)	Transaction costs
Base scenario (SSP3-7.0)	Table I + site-specific impacts of temperature changes due to climate change	Table I	30	10	30%+ site-specific variations due to changing consecutive dry days due to climate change	25%

Table II. Cont.

Pessimistic scenario (SSP5-8.5)	30% lower than in Table I + site-specific impacts of temperature changes due to climate change	30% higher than in Table I	30	10	30%+ site-specific variations due to changing consecutive dry days due to climate change	25%
Optimistic scenario (SSP1-2.6)	30% higher than in Table I + site-specific impacts of temperature changes due to climate change	30% lower than in Table I	30	10	60% + site-specific variations due to changing consecutive dry days due to climate change	25%

The analysis evaluated the net present value (NPV) of the benefits anticipated from land restoration over a 30-year period (2020–2050). A discount rate of 10% is applied, consistent with current interest rates on USD-denominated financial products, and transaction costs are assumed to be 25% of the total implementation costs—a conservative estimate given that such costs can reach up to 50% in ecosystem restoration and environmental projects (Coggan et al., 2010). This 30-year timeframe reflects the long-term nature of ecosystem restoration: young tree saplings must first survive and then mature over several decades before they can deliver the full suite of ecosystem benefits. The recovery trajectory for each biome was modeled by taking into account the time needed for the restored ecosystem to reach its full potential, as well as the gradual increase in benefits following restoration.

Table II presents the various scenarios and associated modeling parameters used to assess both the investment needs and the benefits derived from land restoration, including the impacts of different projected levels of climate change. The analysis considered three distinct scenarios: the Base scenario (SSP3-7.0), the Pessimistic scenario (SSP5-8.5), and the Optimistic scenario (SSP1-2.6). Each scenario incorporates variations in ecosystem values, establishment and maintenance costs, survival rates, and climate factors, thereby providing a comprehensive framework for understanding the potential financial and environmental returns of land restoration efforts.

2.2. Data Sources

Land Use and Land Cover (LULC)

Land cover dynamics were assessed using the MODIS Land Cover Type Product (MCD12Q1), hereafter referred to as MODIS500 land dynamics. This dataset provides annual global land cover classifications at a spatial resolution of 500 meters from 2001 to 2020 (Friedl & Sulla-Menashe, 2019). The classifications are generated using supervised algorithms applied to MODIS Terra and Aqua surface reflectance data. These outputs undergo additional refinement through post-processing techniques that incorporate ancillary datasets and prior knowledge to improve class accuracy.

Economic Valuation of Ecosystem Services

Estimates of the economic value of ecosystem services were obtained through a review of existing literature containing information on the values of Central Asian ecosystems (Mirzabaev et al., 2016, Brander et al., 2024). Given the lack of spatially explicit valuation data at the pixel level, a benefit-transfer approach was employed to extrapolate representative economic values across land use categories and ecosystem types.

Costs of Land Restoration Interventions

Data on the costs of land restoration practices were compiled from multiple sources, including the World Overview of Conservation Approaches and Technologies (WOCAT, n.d.), the Economics of Land Degradation (ELD) Initiative (Mirzabaev et al., 2016), and national statistical publications and technical reports from the study countries. These sources provided cost estimates associated with restoring different land cover types, including cropland, rangeland, forest, and wetlands.

3. Results and Discussion

Table III provides a detailed view of how land use and land cover (LULC) classes have evolved between 2001 and 2020. The analysis reveals that, over the studied period, different ecosystem types have experienced significant transitions. Forest ecosystems, for example, demonstrate a complex pattern: while some areas have retained their forest cover, others have transitioned to shrubland, grassland, or even agricultural land due to partial clearance and degradation. The shifts among shrubland and grassland categories indicate nuanced changes in vegetation density that may reflect both degradation and recovery processes. Agricultural areas have expanded at the expense of natural ecosystems in certain locations, pointing to an increased conversion of grasslands or shrublands into cropland. Such changes not only modify the landscape but also have implications for soil quality, carbon sequestration, and biodiversity. At the same time, regions previously characterized by robust vegetation are now showing an increase in areas with little or no vegetation—a potential signal of environmental stress and desertification. Conversely, instances where barren areas begin to exhibit signs of vegetation suggest that natural regeneration or restoration efforts might be taking effect. Wetlands, which are highly sensitive to variations in water availability and land management practices, have also experienced noticeable changes. These variations are indicative of shifts in hydrological conditions or the impact of conservation measures (Table III).

Table III. Land use and land cover shifts in Kazakhstan (2001-2020) (Friedl and Sulla-Menashe, 2019)

Land use and land cover in 2001, hectares	Land use and land cover in 2020, hectares											
	Evergreen Needleleaf Forest	Deciduous Needleleaf Forests	Deciduous Broadleaf Forest	Mixed Forest	Closed shrubland	Open shrubland	Woodland	Grassland	Permanent wetlands	Cropland	Cropland/Natural Vegetation Mosaics	Barren
Evergreen Needleleaf Forest				1,851			3,288	5,646	3,081		41	
Deciduous Needleleaf Forests	186		21	3,443	41		2,585	1,044	610	52	52	
Deciduous Broadleaf Forest		41		68,378	2,802	41	151,016	14,786	155	83	858	
Mixed Forest	13,969	2,440	2,182		21		132,331	7,600	1,282	279	124	
Closed shrubland			1,230			31	28,208	2,802				
Open shrubland		21			21		724	33,719				35,311
Woody savannas	17,392	2,678	16,306	45,475	1,282	755	148,265	234,956	6,804	2,709	27,401	93
Grassland	32,995	1,034	6,338	6,525	13,752	409,950	705,901		333,444	1,615,770	23,420	2,081,173
Permanent wetlands	4,643	600	93	1,044		41	5,780	144,222		310		23,224
Cropland			21	83			3,412	4,235,977	2,306		9,937	600
Cropland/Natural Vegetation Mosaics			124	114			3,536	2,471		4,581		
Barren						74,055	269	1,708,044	38,527	165		

Note: the data shows only the extent of those areas which experienced land use and land cover change.

Figure 3 provides an overview of the economic losses attributed to land degradation through LULC during 2001-2020. Kazakhstan incurred overall economic losses totaling approximately 5.6 billion USD, with the majority stemming from grassland degradation (2.6 billion USD) and significant losses from forest and shrubland degradation (2 billion USD).

Overgrazing and unsustainable livestock management are prominent drivers, compounded by inadequate pasture rotation and the encroachment of agricultural activities onto fragile rangelands. The desiccation of the Aral Sea has exacerbated grassland degradation. The hotspots of land degradation in Kazakhstan are Mangistau (grassland loss), Eastern Kazakhstan (deforestation), Northern Kazakhstan (wetland, shrubland, and forest loss), Kostanay (wetland loss), and Kyzylorda provinces (grassland and cropland loss). Agricultural expansion into ecologically sensitive areas, particularly in Kostanay, has further contributed to land degradation (Figure 4).

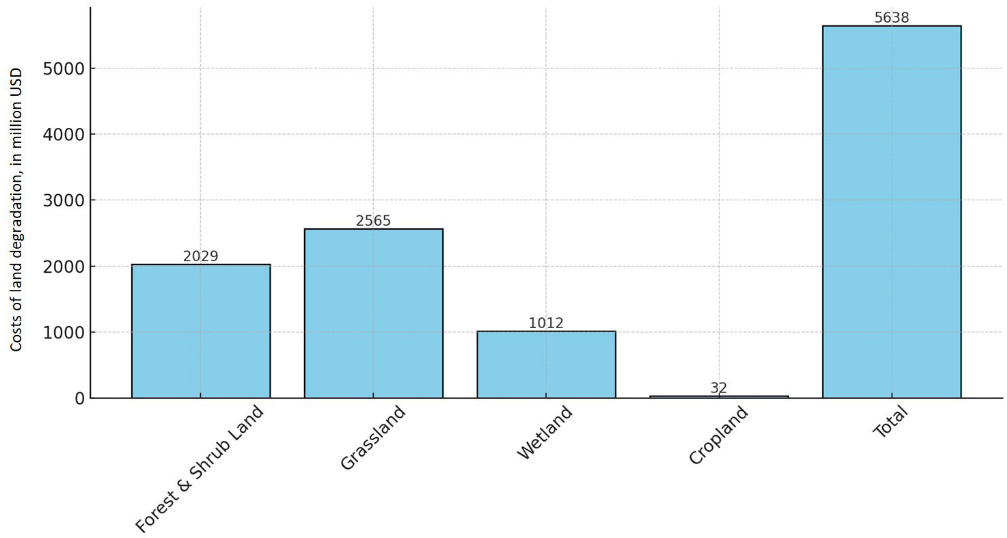

Figure 3. Economic losses from land use and cover change (millions of USD)

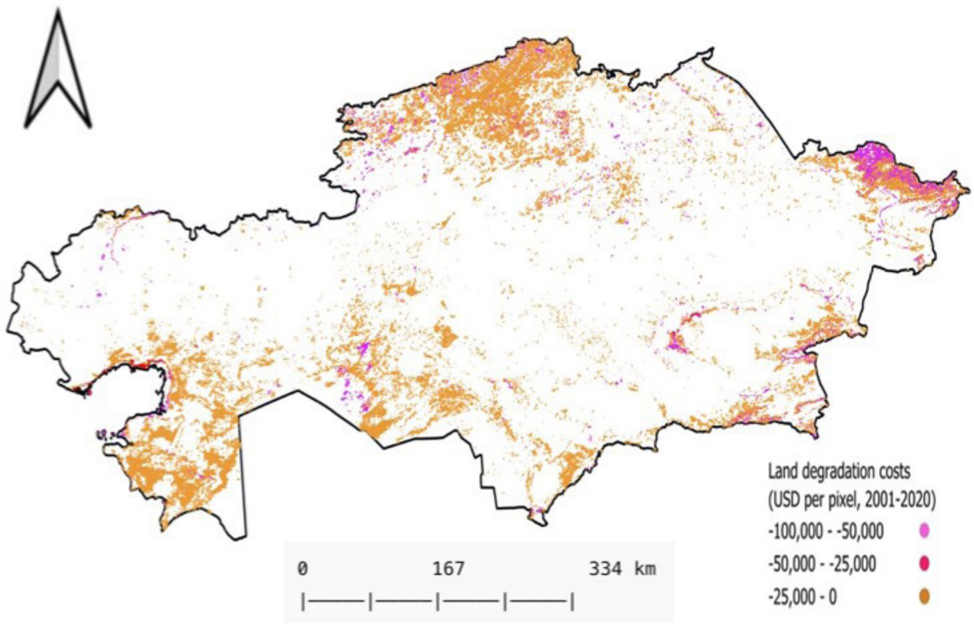

Figure 4. Hotspots of land degradation in Kazakhstan

The results of the investment needs analysis for land restoration in Kazakhstan reveal substantial economically viable and environmentally sustainable opportunities for land restoration in the region. The returns from land restoration activities will vary depending on future economic conditions and climate change impacts (Table IV, Figure V). In the Base scenario, the total investment required for land restoration in Kazakhstan is 11.6 billion dollars. The benefit-cost ratio in this scenario stands at

2.0 over the period of 2020-2050. In comparison, the Optimistic scenario shows a total investment need of 10.9 billion dollars, reflecting the opportunity of restoring a larger extent of degraded lands in an economically profitable and environmentally sustainable manner. This scenario also boasts an improved benefit-cost ratio of 4.3. Conversely, the Pessimistic scenario portrays a less favorable economic and climatic outlook, with total investment needs reduced to 6.7 billion US dollars due to fewer opportunities for environmentally viable and economically profitable investments for land restoration. The average benefit-cost ratio drops to 1.4, signaling reduced economic returns and potential challenges in justifying investment under less favorable climatic conditions. Projected climatic changes will reduce the environmental and economic viability of land restoration activities.

Table IV. Investment needs, economically viable restoration, returns on (2020-2050)

Indicator	Base Scenario	Optimistic Scenario	Pessimistic Scenario
Investment Needs (billions of USD)	11.6	10.9	6.7
Area for Restoration (million ha)	3.2	3.6	1.8
Returns per USD Invested	2.0	4.3	1.4

This is the reason why the investment levels are lower under the pessimistic scenario, compared to base and optimistic scenarios. Specifically, the extent of area that can be restored in an environmentally sustainable and economically profitable manner is only 1.8 million ha under the pessimistic scenario, while under the base and optimistic scenario these are 3.2 million ha and 3.6 million ha, respectively.

Figure 5 presents the relationship between the investment needs and the benefit-cost ratios (BCR) for restoring different land types across Kazakhstan. The restoration of wetlands has the highest BCR of 3.6, with investment needs of approximately 1.5 billion USD, while forest restoration also shows a high BCR of 2.6, with investment needs of around 2.1 billion USD.

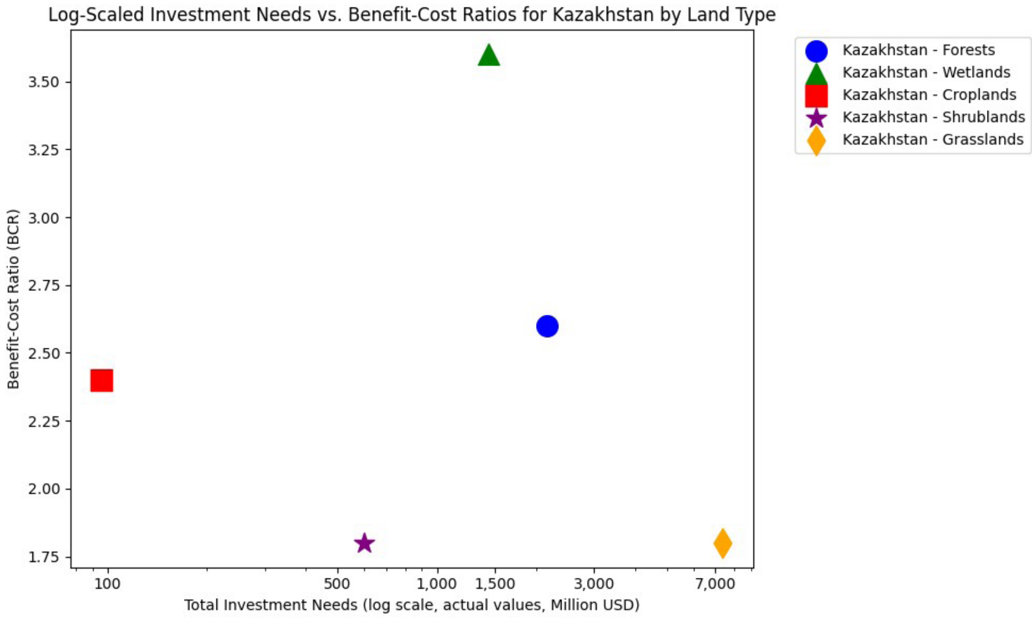

Figure 5. Investments needs and returns from investments by each ecosystem

Based on the analysis of the benefit-cost ratios and investment needs for restoring different land types across Central Asia, policy actions could focus on the following priorities:

- Prioritizing Wetlands Restoration: Wetlands restoration generally shows high BCRs. Policymakers could consider prioritizing wetlands for restoration projects, as they provide significant ecological benefits with relatively favorable returns on investment.

- Allocate Resources Based on Cost-Effectiveness: Given the differences in BCRs and investment needs across land types, resources could be allocated to restoration activities that maximize cost-effectiveness. Policymakers can develop regional or national restoration plans that target high-BCR land types first, especially those requiring moderate investment, such as croplands and wetlands.

- Integrated Planning for Co-Benefits: Restoration policies should integrate co-benefits such as biodiversity conservation, carbon sequestration, and social impacts (e.g., job creation). High-return land restoration activities requiring large-scale investments such as grassland and forest restoration can contribute significantly to meeting broader environmental and socio-economic goals in Kazakhstan.

These land restoration activities will also create important impacts in terms of gains and losses of above and below ground carbon in Kazakhstan. In most cases, land restoration activities will lead to additional carbon sequestration. Particularly high potential for carbon sequestration activities is related with reforestation in parts of

Eastern Kazakhstan, Almaty, and Akmola provinces in Kazakhstan. There would be also some losses due to these land restoration activities, specifically, in cases when croplands are being restored back from grasslands. Grasslands provide bigger carbon sequestration potential than croplands, but in highly productive cropland areas, the total economic value of croplands can be higher than the total economic value of grasslands.

4. Conclusion

The analysis reveals that Kazakhstan's landscapes have undergone profound transformations between 2001 and 2020, with significant shifts in land use and land cover that reflect both degradation and opportunities for restoration. Economic losses from land degradation, which totaled approximately 5.6 billion USD—with grasslands and forests bearing the brunt—underscore the urgent need for targeted restoration initiatives. The spatial patterns of degradation, particularly in hotspots such as Mangistau, Eastern, and Northern Kazakhstan, highlight the necessity for tailored interventions that address the specific challenges of each region.

Investment needs analysis for land restoration demonstrates that, under economically favorable conditions, restoring degraded lands can yield substantial returns. The Base scenario projects a benefit-cost ratio (BCR) of 2.0 with an investment of 11.6 billion USD, whereas the Optimistic scenario improves these figures significantly, achieving a BCR of 4.3 with a slightly lower investment. Conversely, the Pessimistic scenario, characterized by reduced opportunities due to adverse climatic conditions, shows a diminished BCR of 1.4.

These findings call for a strategic, integrated approach to land restoration in Kazakhstan—one that aligns economic viability with environmental sustainability. There is a need to prioritize high-return ecosystems, allocate resources based on cost-effectiveness, and incorporate integrated planning that considers broader socio-economic and ecological co-benefits. Such measures will be pivotal in reversing the trends of land degradation, safeguarding vital ecosystem services, and ensuring long-term sustainable development in the country.

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