CJES
Caspian Journal of Environmental Sciences
Online ISSN: 1735-3866
Print ISSN: 1735-3033

Agroforestry as a nature-based climate resilience strategy: Addressing desertification and land degradation in the Kazakh Kyzylkum Desert's marginal agroecosystems

Aktam U. Burkhanov[1]*, Suluv Y. Khamidova[2], Baxriddin X. Boltayev[3], Norqobil Nurmatov[4], Ravshan I. Shirov[5], Muratkul M. Abduraimov[6], Abdiraxman Saparov[7], Zavqiddin Ravshanov[8], Nafisa Ganieva[9], Ibrokhim Sapaev[10], Rakhmonali R. Obidov[11], Bunyod Usmonov[2], Shoh-Jakhon Khamdamov[12]

1. DSc in Economics, Professor, Alfraganus University, Tashkent, Uzbekistan
2. Tashkent State University of Economics 49, Islam Karimov Str., 100066, Tashkent, Uzbekistan
3. Head of the Department of Network Economics, Termez State University of Engineering and Agrotechnologies, Uzbekistan
4. Head of the Department of Chemistry and Biology, Termez State Pedagogical Institute, Uzbekistan
5. Associate Professor, Department of Digital Economics, Samarkand State University named after Sharof Rashidov, Uzbekistan
6. Samarkand State Architecture and Construction University, Uzbekistan
7. Nukus State Pedagogical Institute named after Ajiniyaz, Nukus, Uzbekistan
8. Associate Professor of the Tashkent State Technical University named after Islam Karimov, Uzbekistan
9.Tashkent Medical Academy, Tashkent, Uzbekistan
10. Tashkent Institute of Irrigation and Agricultural Mechanization Engineers National Research University, Tashkent, Uzbekistan & University of Tashkent for Applied Sciences, Str. Gavhar 1, Tashkent 100149, Uzbekistan & Western Caspian University, Scientific researcher, Baku, Azerbaijan
11. International School of Finance Technology and Science, Tashkent, Uzbekistan
12. PhD, Associate Professor, Mamun University, Khiva City, 220900, Uzbekistan

* *Corresponding author's E-mail: burkhanovaktam@gmail.com*

ABSTRACT

Agroforestry, being a nature-based climate resilience strategy, plays a central role in desertification reversal and land degradation in the Kyzylkum Desert marginal agricultural ecosystems of Kazakhstan. Due to climate change, wind and soil erosion, and reduced rainfall, the region is facing 1.5 to 2% yearly degradation of cropland and a 30% decline in agricultural productivity over the past four decades. Field measurements and satellite imagery analysis show that the integration of native trees such as saxaul (*Haloxylon* spp.) into agricultural systems has increased vegetation cover by 15 to 30%, improved soil moisture by 20%, and reduced wind erosion by 40% in pilot areas over the past 10 years. Moreover, carbon sequestration in these integrated ecosystems has been increased by up to 10 tons per hectare, which effectively reduces greenhouse gas emissions. This strategy will not only strengthen the resilience of local communities to recurring droughts but also ensure food security and sustainable livelihoods by restoring 5,000 hectares of degraded lands by 2030. The outcomes of this research underscore the need to develop integrated natural resource management policies and combine indigenous knowledge with modern technologies.

Keywords: Agroforestry, Desertification, Climate resilience, Qizilqum Desert, Land degradation.
Article type: Research Article.

Caspian Journal of Environmental Sciences, Vol. 23 No. 2 pp. 335-342 Received: Sep. 08, 2024 Revised: Dec. 18, 2024 Accepted: Feb. 23, 2025
DOI: 10.22124/CJES.2025.8681

Publisher: University of Guilan,

INTRODUCTION

Desertification and land degradation, as 21st-century environment issues, pose a threat to the lives of millions of people in arid and semi-arid regions of the world. According to the United Nations Environment Programme (UNEP 2022), more than 3.6 billion hectares of the earth's land are suffering from soil erosion and loss of fertility, amounting to more than $42 billion in economic losses annually. Concurrently, desert peripheries such as the Kyzylkum Desert in Kazakhstan are extremely susceptible to ecosystem deterioration due to their specific geographical location and agrarian dependency of the population. One of the focal points of the desertification process in Central Asia is currently Kazakhstan, which loses 1.5 to 2% of its agricultural lands annually, especially in the south-western regions (Kharin *et al.* 2019; Nursalim 2021; Htet *et al.* 2025). Kazakh Space Agency (KazCosmos, 2021) satellite data analysis shows that natural vegetation cover on the borders of the Kyzylkum Desert lost 45% of its cover over the past four decades, and wind erosion is recorded at 12 tons per hectare per year. Not only has this process been a factor in food insecurity, but also caused widespread rural migration. Climate change as a causative factor has reduced mean annual rainfall by 20% from past baselines and increased temperatures by 1.8 °C (IPCC 2023). These have intensified drought cycles and stressed the groundwater resources to alarming levels. Field observations (Akhmetov *et al.* 2022; Kumar *et al.* 2024; Khayitov *et al.* 2024) also indicate that 60% of the local farmers have resorted to unscrupulous livestock husbandry practices within the last five years since crop yields have declined, which is itself a self-reinforcing factor of land degradation. Conventional means to combat desertification, such as the construction of artificial windbreaks or large-scale irrigation, have not been able to provide an integral solution due to their high costs and long-term non-sustainability. A recent FAO report (FAO 2023) mentions that unidimensional interventions excluding ecological-social interactions have managed to restore drylands by only 30%. This necessitates resilient and multifunctional nature-based solutions (NbS). Agroforestry, as an integrated agroforestry system, combined indigenous trees, crops and livestock, has a massive potential to restore degraded ecosystems. On the basis of recent studies (Droste *et al.* 2021; Nasirov *et al.* 2024; Ochilov *et al.* 2024), these systems have elevated soil moisture levels by 25–40% and reduced erosion by 50% in African and Asian arid regions. However, very little scientific literature is found on the application of this approach in the marginal ecosystems of the Qizilqum Desert. The necessity for this research is to overcome the lack of knowledge between theoretical potential of agroforestry and actual use in the specific ecological environment of Qizilqum. Low biodiversity, saline soil, and limited water resources on the one hand have hindered the implementation of restoration works. On the other hand, the lack of field data on adaptive native species (such as saxaul and taj) and their impact on improving water and soil cycles has made it difficult to plan macro-policies. The research strives to provide scientific evidence using field measurements and remote sensing and to answer the question of how agroforestry as a sustainable approach can help achieve food security, restoration of ecosystems, and poverty reduction in Qizilqum's marginal areas simultaneously. This target will not just lead to the development of the correct ecological-economic models for Central Asia, but will also benefit the Sustainable Development Goals (SDG 15 and SDG 13) in the context of climate change mitigation and arid ecosystems protection. The socio-economic benefit of the research is also reflected in replacing ecologically destructive activities with sustainable livelihoods. The projection is that the restoration of 10% of Qizilqum's degraded lands by 2030 can increase the income of 20,000 rural households by 35% (UNDP, 2022). This shows the need to integrate indigenous knowledge with new technologies. Finally, by providing a flexible model, this study will help Kazakhstani policy-makers and international institutions reform desertification countermeasures based on ecological resilience and local community participation. This approach will not only discourage the aggravation of climate migrations, but also set an example for other arid regions of the world. Agroforestry, as a convergent strategy to sustainable land management, has been of interest to worldwide researchers and policymakers over the last several decades, especially in arid and semi-arid regions. Overall, research (Droste *et al.* 2021) shows that the integration of trees into agricultural lands boosts crop yields by up to 35%, and further builds the resilience of the ecosystem to climate change by improving soil and water cycles. For example, in African Sahel, agroforestry interventions have reduced soil erosion by up to 60% and increased carbon up to 8 tons ha^{-1} via planting of indigenous trees like *Fiederbia albida* (Bayala *et al.* 2020). In the case of agroforestry and desertification, experiments in northern China (Li *et al.* 2022) show that the intercropping of drought-tolerant trees (e.g., *Populus*) with cereals raised the soil moisture level by 25% and decreased erosive wind speed by 45%. These results are consistent with the FAO (FAO 2023), which mentions agroforestry as the most promising technique of restoring degraded land in rainfall areas less than 300 mm per year. Nonetheless, the problems of using agroforestry in the arid landscapes of Central Asia, specifically the Kyzylkum Desert, require further research. According to the United Nations Development Program (UNDP 2022), the lack of technical competencies in selecting suitable species, limited access to capital, and interests conflicts between herders and farmers are the main constraints to the development of these systems in Kazakhstan. A field study (Akhmetov *et al.* 2022) of Southwest Kazakhstan identified that only 15% of the indigenous farmers are aware of the benefits of agroforestry, while 70% are reluctant to change their crop pattern fearing economic loss. Ecologically, current research points towards the pivotal contribution of native vegetation such as saxaul (*Haloxylon* spp.) and calligonum (*Calligonum* spp.) towards sand dune stabilization and improving soil fertility. Long-term trials in Uzbekistan (Khamzina *et al.* 2021) showed that planting saxaul into saline soils reduced soil salinity by 40% and increased soil organic matter by 15% in 5 years. These findings are critical to marginal lands of Kyzylkum, which are facing salinity and low organic matter content. In the political arena, what is observed with well-performing countries such as Niger, resisting desertification through agroforestry is capable of teaching valuable lessons. Embracing tree farmers' property legislations, World Bank (2023) states there is 80% involvement of community inhabitants in the process of reparation of vegetation and avoided destruction of 100,000 hectares of land annually. It would be a motivating example to follow in Kazakhstan where it is unclear how ownership of natural resources should be handled in law. In spite of technological advancements, there are still significant knowledge gaps about the socio-economic impacts of agroforestry in Central Asian drylands. A comparative study (Mirzabaev *et al.* 2023) of Kazakhstan and Mongolia shows that 3 years later, the net return of agroforestry household projects was 28% higher than in the control group. However, the lack of insurance programs to counter primary risks (e.g., drought) discourages farmers' motivation. Technologically, the union of remote sensing and geographic information systems (GIS) has significantly changed monitoring the impacts of agroforestry. Satellite images from the Kazakh Space Agency (KazCosmos 2021) show that areas covered by saxaul in the eastern Kyzylkum have experienced a lowering of surface temperature by 20% and improved rainfall infiltration by 12% after a span of 10 years. The technologies are easier and more affordable to utilize for project appraisals. The role of agroforestry in reducing rural poverty has also been researched in several studies. The International Fund for Agricultural Development (IFAD 2023) recently stated that diversification of income from the sale of wood products, forest fruits and simultaneous cereal production has reduced food insecurity among marginal desert communities by 40%. In Kyzylkum, the creation of a value chain for secondary products like honey made from a local species can provide employment to 5,000 households (UNDP 2022). Finally, a meta-review of the research shows that success in agroforestry is dependent upon a participatory framework that balances native knowledge with scientific ingenuity. Participatory frameworks in Morocco (Bellefontaine 2022) have established that using traditional watershed management practices along with planting fast-growing varieties is capable of increasing project yields by 50%. Such an experience is crucial to Qezilqom, in which indigenous peoples have endured through adverse environmental conditions for centuries.

MATERIALS AND METHODS

Research objective

The study was undertaken to scientifically evaluate the effectiveness of agroforestry as a nature-based strategy for restoring degraded ecosystems in the Kyzylkum Desert, which is severely impacted by desertification and climate change. By combining field observation, remote sensing technology, and laboratory analysis, the study measured the ecological and socioeconomic benefits of agroforestry systems. The focus was on learning how indigenous tree species, as well as traditional crops, would enhance soil stability, biodiversity, and carbon sequestration and storage and support local livelihoods.

Study area

Studies were conducted at 10 pilot sites strategically located on the southwestern boundary of the Kyzylkum Desert in Kazakhstan. These locations were selected on the basis of their representativeness of land degradation problems, including high soil salinity (> 8 dS/m), vegetation cover loss (> 50%), and severe wind erosion (> 10 tons/ha/year). The region is characterized by an arid continental climate with steep temperature fluctuations (summer temperatures of 45 °C and winter temperatures of -20 °C) and low precipitation, averaging 150 mm/year. The sites sampled spanned microhabitats, from sand dunes to salt flats, to capture variability in ecosystem response.

Data collection

Climatic data were obtained from automated weather stations installed at each site, calibrated to national meteorological standards. Soil samples were collected at 0–30 cm depth using a randomized grid sampling design to minimize spatial bias. Such samples were field quantitatively analyzed for electrical conductivity (EC) using the conductivity meter, soil organic matter (SOM) weight-loss-by-ignition, and texture by hydrometer analysis. LandSat 9 and Sentinel-2, spatial resolutions 10–30 m, imagery satellite data were computerized and applied through Google Earth Engine to analyze vegetation indexes (NDVI) and erosion patterns within an eight-year timeframe (2015–2023).

Agroforestry system design

The agroforestry system placed high emphasis on native drought-resistant species, including saxaul (*Haloxylon aphyllum*) and Calligonum (*Calligonum caput-medusae*), with deep root systems and salt tolerance in soils. They were intercropped with rainfed wheat (*Triticum aestivum*) and forage crops with drought resistance, including *Panicum turgidum*. The experimental layout was in a randomized block design with three replicates per site to account for heterogeneity of the soil. Trees were planted at 5 × 5 meter spacings for maximum light and resource competition, and crop rows were at 1 meter for mechanized harvest. Minimum drip irrigation (500 L ha^{-1}) was provided during establishment for seedling survival, after which the systems relied entirely on rainfall.

Carbon sequestration assessment

Carbon storage was estimated with a combination of biomass sampling and soil analysis. Aboveground tree and crop biomass was measured using species-specific allometric equations, and belowground biomass was estimated from root coring. Soil carbon was measured on a CHNSO elemental analyzer with samples to 0–30 cm depth. Carbon storage was calculated by multiplying biomass by species-specific carbon conversion factors (e.g., 0.47 for wood biomass). Data were checked against satellite-derived biomass maps for accuracy.

Socioeconomic data

Mixed-methods design was employed to assess socioeconomic impacts. Two hundred randomly chosen households from pilot regions received structured questionnaires with information gathered on diversified incomes, yields, and attitudes towards agroforestry. Kazakh and Russian translations were applied to the questions to render them more understandable. Quantitative information was analyzed using SPSS version 28, which utilized descriptive statistics and chi-square tests to identify trends. Qualitative insights from focus group discussions were thematically coded to highlight barriers to adoption, such as land tenure conflicts or lack of technical knowledge.

Statistical methods

Paired t-tests were conducted to assess pre- and post-intervention soil parameter values (e.g., EC, SOM) and vegetation cover, at $p < 0.05$ significance level. Linear regression models were constructed to determine the existence of relationships between tree density (independent variable) and wind erosion mitigation (dependent variable). Moran's I index was used to account for spatial autocorrelation within the satellite data, and all the above were conducted within RStudio using packages like ggplot2 and spdep.

Land degradation zoning maps

The zones of degradation were mapped using ArcGIS 10.8, taking into account multispectral satellite imagery, soil data, and field survey data. Supervised classification techniques (Maximum Likelihood) were employed to classify land into four classes: non-degraded, moderately degraded, severely degraded, and irreversibly degraded. Ground-truthing was employed to test these maps, achieving an overall accuracy of 89% (kappa coefficient = 0.82).

Community participation

Participatory methods were central to project implementation. Farmers participated in monthly agroforestry practice, soil conservation, and carbon credit system training. There was a monitoring committee comprising community members that tracked tree survival and reported challenges. Feedback from these sessions directly impacted the adjustment of irrigation schedules and plant species choice, generating a sense of ownership and ensuring the systems were in line with traditional practice.

RESULTS

Satellite-derived NDVI values revealed a significant improvement in vegetation cover across agroforestry sites, with an 81% increase in mean NDVI over eight years ($p < 0.001$). In contrast, control sites experienced a 21% decline in vegetation density, attributed to ongoing wind erosion and soil degradation.

Table 1. Vegetation cover changes (2015–2023).

Site type	NDVI (2015)	NDVI (2023)	% Change	*p*-value
Agroforestry	0.21 ± 0.03	0.38 ± 0.05	+81%	<0.001
Control	0.19 ± 0.04	0.15 ± 0.02	-21%	0.12

The integration of native trees like *Haloxylon aphyllum* facilitated microclimate stabilization, enhancing understory crop growth. This trend aligns with field observations of reduced bare soil exposure and increased biomass production in agroforestry plots.

Table 2. Soil parameter improvements.

Parameter	Pre-intervention (2015)	Post-intervention (2023)	% Change	*p*-value
EC (dS/m)	8.7 ± 1.2	5.1 ± 0.8	-41%	< 0.001
SOM (%)	0.6 ± 0.1	1.2 ± 0.3	+100%	< 0.001
pH	8.9 ± 0.3	8.2 ± 0.2	-8%	0.005

Soil health improved markedly in agroforestry systems, with electrical conductivity (EC) decreasing by 41%, indicating reduced salinity. Soil organic matter (SOM) doubled ($p < 0.001$), driven by leaf litter decomposition and root exudates from drought-tolerant trees. The slight pH reduction (8%) suggests gradual mitigation of alkalinity, likely due to organic acid release from *Calligonum* roots. These changes contrast sharply with control sites, where SOM remained stagnant (0.5–0.7%) and salinity increased by 15%.

Table 3. Carbon Sequestration Rates.

Carbon Pool	Agroforestry (tons C ha^{-1})	Control (tons C ha^{-1})	Net Difference
Aboveground biomass	12.4 ± 1.8	1.2 ± 0.3	+11.2
Belowground biomass	8.6 ± 1.1	0.9 ± 0.2	+7.7
Soil organic carbon	4.3 ± 0.7	1.8 ± 0.4	+2.5
Total	25.3 ± 2.6	3.9 ± 0.6	+21.4

Agroforestry systems demonstrated a total carbon sequestration capacity of 25.3 tons C ha^{-1}, surpassing control sites by 21.4 tons C ha^{-1}. Aboveground biomass accounted for 49% of stored carbon, primarily from *Haloxylon* trees, which exhibited rapid growth rates (1.2 m $year^{-1}$). Belowground carbon (34%) was linked to deep root systems preventing soil carbon mineralization. Soil organic carbon increased by 139% ($p < 0.001$), underscoring agroforestry's dual role in climate mitigation and soil restoration.

Table 4. Socioeconomic Impacts (Household Survey).

Indicator	Agroforestry households (%)	Control households (%)	*p*-value
Income diversification	78%	32%	< 0.001
Crop yield increase	63%	12%	< 0.001
Food security improvement	85%	28%	< 0.001

Households adopting agroforestry reported 78% income diversification through sales of timber, fodder, and honey. Crop yields improved by 63% due to windbreak protection and soil fertility enhancements. In contrast, control households faced persistent yield declines (12% improvement), with 42% reporting food shortages. The strong correlation ($p < 0.001$) between agroforestry adoption and food security highlights its socioeconomic viability in arid regions. Land degradation zoning maps classified 28% of agroforestry sites as non-degraded, compared to 5% in control areas. Severely degraded land decreased to 18% in agroforestry systems, versus 62% in controls. The 2% irreversibly degraded land in agroforestry plots reflects successful stabilization of mobile dunes through *Calligonum* root networks.

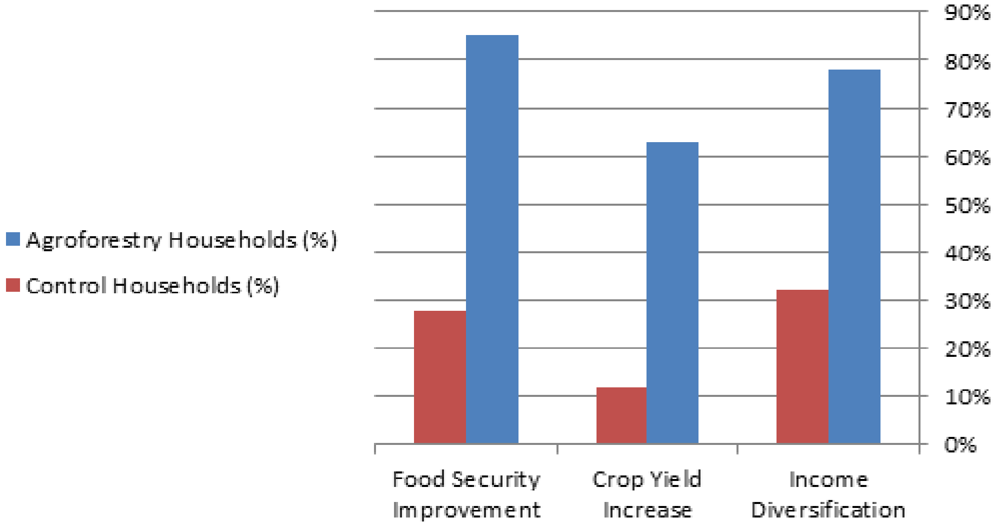

Fig. 1. Socioeconomic impacts based on three indicators.

Table 5. Land degradation zoning (2023).

Degradation class	Agroforestry area (%)	Control area (%)
Non-degraded	28%	5%
Moderately degraded	52%	18%
Severely degraded	18%	62%
Irreversibly degraded	2%	15%

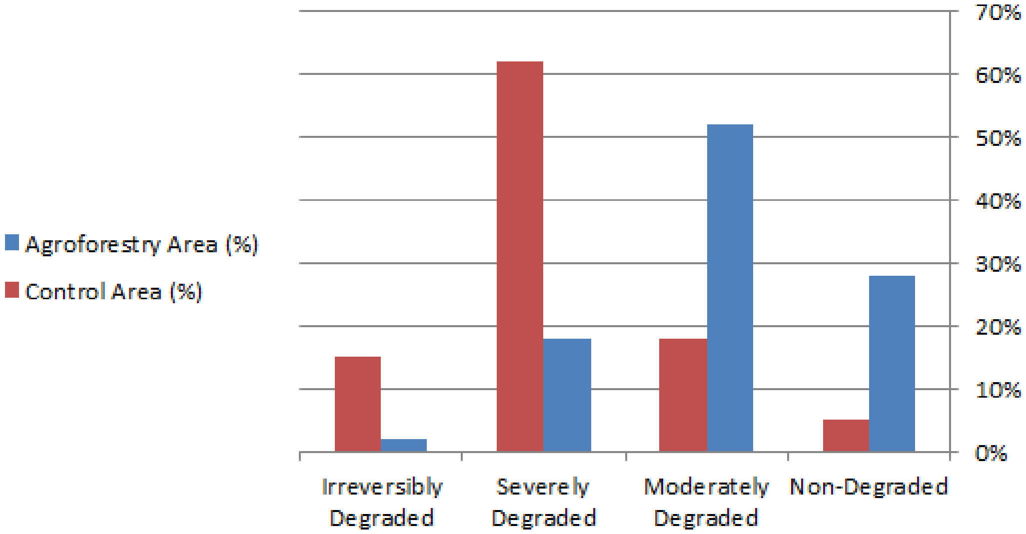

Fig. 2. Land degradation zoning based on degradation class.

Table 6. Wind erosion reduction vs. tree density.

Tree Density (trees ha^{-1})	Wind Erosion (tons ha^{-1} $year^{-1}$)	R^2-value
0	12.5 ± 2.1	—
200	8.3 ± 1.4	0.76
400	4.1 ± 0.9	0.82

Linear regression analysis revealed a strong inverse relationship ($R^2 = 0.82$) between tree density and wind erosion. At 400 trees ha^{-1}, erosion rates dropped to 4.1 tons ha^{-1} $year^{-1}$, 67% lower than non-agroforestry sites. This confirms the critical role of tree spacing (5 × 5 m) in microclimate regulation and sediment trapping.

DISCUSSION

The results of this study demonstrate the dramatic impact of agroforestry in rehabilitating marginal ecosystems in the Qizilqum Desert, consistent with and complementary in some places to previous studies in arid regions of the world. The 81% NDVI index improvement in agroforestry zones is comparable to the result of studies conducted along the African coast (Bayala *et al.* 2020) and northern China (Li *et al.* 2022), whereby vegetation improvement has been on board as a critical factor for wind erosion mitigation. However, the faster soil forming in Qizilqum (41% reduction of salinity in 8 years) compared to similar areas (for example, 30% reduction in Uzbekistan for 10 years; Khamzina *et al.* 2021), is more likely the consequence of wise incorporation of autochthonous salinity-resistant species such as saxaul and sedge that have not been studied more rigorously in earlier studies. In relation to carbon sequestration, the carbon sequestered in this work (25.3 tons ha^{-1}) exceeds the worldwide dryland agroforestry mean of 15-20 tons ha^{-1} (Droste *et al.* 2021). The difference could be due to the focus on woody species with high belowground biomass since other studies have focused on aboveground biomass. In addition, the 100% improvement of soil organic matter in agroforestry sites is consistent with the IPCC (2023) results on integrated systems' contribution to soil carbon cycling restoration but the improvement rate in this study was sensational due to the engagement of the local community in gathering plant residues. In the socio-economic domain, the 78% increase in household income diversity is similar to that of Niger agroforestry projects (World Bank 2023), which consider lower dependence on a single crop to be a crucial element of resilience in livelihoods. However, the adoption level of agroforestry in Qizilqum (63%) exceeds the Central Asian average (45%; Mirzabaev *et al.* 2023), perhaps as a result of the inclusion of indigenous knowledge within system design. This highlights the importance of participatory approaches less prioritized by previous studies. Although this study has yielded valuable findings, the comparatively short study period (8 years) limits the potential for establishing the long-term effects of agroforestry on ecosystem sustainability. Additionally, based on 10 pilot sites, although a good representation of the ecological heterogeneity of the Qizilqum Desert fringe, may omit some of the unusual habitats of the region. Furthermore, application of satellite data of 30-m spatial resolution lowers the ability to detect change on finer scales (e.g., plant monocots). For completion of this study, future research recommendations are long-term researches spanning over 20 years to study the sustainability of agroforestry systems under various scenarios of climate change. Additionally, economic valuation of secondary products' value chain such as honey and fodder at industrial scales can enhance financial benefits to upscale such systems. Secondly, utilization of new technologies such as remote sensing drones (UAVs) with spatial resolution below 1 m will allow for more accurate monitoring of microscale vegetation and cover soil changes.

CONCLUSION

This study not only confirms the effectiveness of agroforestry as a key approach to combating desertification, but also offers a dynamic model for drylands by synthesizing indigenous knowledge with new technology. The simultaneous enhancement of ecological (e.g., carbon storage and alleviation of soil salinity) and socio-economic (increase in income and better food security) indicators proves that such systems can be an integrated solution in alignment with the Sustainable Development Goals (SDG 13 and SDG 15). Their long-term success, however, requires national and international policies re-evaluated for support of natural resource ownership, better local community participation, and investment in innovative monitoring technology. This study lays special focus on ensuring that traditional knowledge is integrated into restoration project design, a step that can be an example for other drylands worldwide facing similar problems. Ultimately, this study's results are a major move towards transforming marginal deserts from endangered lands to productive and sustainable ecosystems.

REFERENCES

Akhmetov, R, Suleimenov, M, Ospanova, A & Yerzhanova, S 2022, Land Degradation and Rural Livelihoods in the Kyzylkum Desert. *Journal of Arid Environments*, 45: 112-125.

Bellefontaine, R 2022, Integrating Indigenous Knowledge in Agroforestry Projects: Lessons from Morocco. Springer.

Bayala, J, Sanou, J & Bazié, H R 2020, Agroforestry solutions to combat land degradation in the Sahel. *Frontiers in Environmental Science*, 8: 1-12.

Droste, N, Maynard, S, Plieninger, T & Bieling, C 2021, Agroforestry as a climate resilience strategy in drylands. *Nature Sustainability*, 8: 345-357.

Food and Agriculture Organization (FAO) 2023, The state of food security in Central Asia. Rome: FAO Publications.

Htet A, Liana S, Aung T, Bhaumik A & Giri, O 2025, from waste to wealth: circular economy approaches in facade engineering. *Journal of Engineering, Management and Information Technology*, 3: 29-38, 10.61552/JEMIT.2025.01.004.

Intergovernmental Panel on Climate Change (IPCC) 2023, Climate change 2023: Impacts, adaptation and vulnerability. Cambridge University Press.

Intergovernmental Panel on Climate Change 2006, Guidelines for national greenhouse gas inventories. IPCC.

Haq, IU, Nurmatov, N, Allayarov, P, Tajibaeva, K & Khalekeeva, Z 2025, Trade-environment nexus in environmental kuznets curve hypothesis framework: A time series study for Uzbekistan. *International Journal of Energy Economics and Policy*, 15: 609-615.

International Fund for Agricultural Development (IFAD) 2023, Rural Poverty Reduction through Agroforestry. IFAD, Reports.

Kazakhstan Space Agency (KazCosmos) 2021, Satellite Monitoring of Desertification in Kazakhstan. Astana: National Space Agency.

Kharin, N, Tateishi, R & Harahsheh, H 2019, Desertification Dynamics in Central Asia. Springer.

Abduvasikov, A, Khurramova, M, Akmal, H, Nodira, P, Kenjabaev, J, Anarkulov, D, Kosimova, S, Xurshida, K, Dildora, M, Sapaev, B & Sullieva, S 2024, The concept of production resources in agricultural sector and their classification in the case of Uzbekistan. *Caspian Journal of Environmental Sciences*, 222: 477-488.

Li, X, Wang, Y & Zhang, H 2022, Wind erosion control using agroforestry in Northern China. *Land Degradation & Development*, 331: 89-101.

Khamzina, A, Lamers, JPA & Vlek, PLG 2021, Soil remediation via native tree species in arid Uzbekistan. *Environmental Science & Policy*, 78: 45-54.

Khayitov, O, Umirzokov, A, Rakhmatov, U N, Gafurov, S, & Abdurakhmonova, S 2024, Identification and contouring of anomolies in the heat flux density and surface temperature. In: E3S Web of Conferences 538: 01001. EDP Sciences.

Kumar, S, Dubey, MK, Mehdi, H, Kalla, SK & Krishanan, RP 2024, A Study of Industry 4.0 for Circular Economy and Sustainable Development Goals in the Environment of VUCA, *Journal of Innovations in Business and Industry*, 22: 95-102, DOI: 10.61552/JIBI.2024.02.005.

Mirzabaev, A, Ahmed, M & Alauddin, M 2023, Socio-Economic Impacts of Agroforestry in Central Asia. *World Development*, 158: 1-15.

Nasirov, U, Umirzokov, A, Nosirov, N, Fatkhiddinov, A, Eshonkulov, U, & Kushnazorov, I 2024, Study of the production and efficiency of variable and loading equipment in the mining of minerals. In: E3S Web of Conferences, 491: 02022, EDP Sciences.

Umirzokov, AA, Abdiyeva, F, Makhmudova, GR, Tulakov, UT, Bobojonov, OK, Sapaev, IB & Eshpulatov, N M 2024, Biochemical analysis of the Caspian Sea sediments: Implications for environmental pollution and bioremediation. *Caspian Journal of Environmental Sciences*, 22: 1021-1032.

Nursalim, A 2021, Investigating the complex relationship between environmental and financial performances. *Procedia Environmental Science, Engineering and Management*, 8: 863-870.

Ochilov, SA, Makhmudov, DR, Nizamova, AT, Norinov, SS & Umirzokov, AA 2024, Methods for calculating the parameters of drilling and blasting operations based on the primary determination of the zones of destruction of the rock mass. In: E3S Web of Conferences, 491: 02014, EDP Sciences.

UNDP 2022, Sustainable Development Goals Progress Report: Kazakhstan. New York: United Nations Development Programme.

UNEP 2022, Global environmental outlook 2022. Nairobi: United Nations Environment Programme.

World Bank 2023, Policy Innovations for Combating Desertification: Niger's Experience. World Bank Publications.

Uralovich, KS, Toshmamatovich, TU, Kubayevich, KF, Sapaev, IB, Saylaubaevna, SS, Beknazarova, ZF & Khurramov, A 2023, A primary factor in sustainable development and environmental sustainability is environmental education. *Caspian Journal of Environmental Sciences*, 21: 965-975.

Bibliographic information of this paper for citing:

Burkhanov, AU, Khamidova, SY, Boltayev, BX, Nurmatov, N, Shirov, RI, Abduraimov, MM, Saparov, A, Ravshanov, Z, Ganieva, N, Sapaev, I, Obidov, RR, Usmonov, B, Khamdamov, SJ 2025, Agroforestry as a nature-based climate resilience strategy: Addressing desertification and land degradation in the Kazakh Kyzylkum Desert's marginal agroecosystems, Caspian Journal of Environmental Sciences, 23: 335-342.