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MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

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MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

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MUNDARIJA • СОДЕРЖАНИЕ • CONTENTS

ECOSYSTEM SERVICES UNDER ECOLOGICAL STRESS: THE CASE OF THE FORMER ARAL SEA

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Abstract: The desiccation of the Aral Sea stands as one of the most dramatic examples of ecological degradation in modern history, resulting in the collapse of vital ecosystem services that once sustained the environment and livelihoods in Central Asia. This study investigates the economic valuation of ecosystem services in the former Aral Sea region, with a focus on provisioning, regulating, supporting, and cultural services. Utilizing a mixed-methods approach—including market-based valuation, benefit transfer, and contingent valuation—this research estimates that the region suffers annual ecosystem service losses ranging from USD 80 to 97 million. These include lost freshwater access, collapsed fisheries, increased dust-related health costs, and degradation of biodiversity and cultural heritage. The results highlight the urgent need to incorporate ecosystem service valuation into environmental policy, restoration planning, and regional development strategies. Moreover, the strong local willingness to invest in restoration efforts demonstrates public support for ecological and economic recovery. The findings provide a replicable framework for ecosystem assessment in ecologically stressed regions and reinforce the importance of nature-based solutions in post-disaster recovery contexts.

Keywords: Aral Sea; ecosystem services; economic valuation; ecological degradation; restoration planning.

Annotatsiya: Annotatsiya. Aral dengizining qurib borishi zamonaviy tarixdagi eng keskin ekologik inqirozlardan biri bo‘lib, Markaziy Osiyodagi muhim ekotizim xizmatlarining izdan chiqishiga olib keldi. Ushbu tadqiqot sobiq Aral dengizi hududidagi ekotizim xizmatlarining iqtisodiy bahosini, xususan ta’minlovchi, tartibga soluvchi, qo‘llab-quvvatlovchi va madaniy xizmatlarni o‘rganadi. Aralash metodologiya—bozor narxlari asosida baholash, foyda transferi va shartli baholash orqali—hududda yillik yo‘qotilgan ekotizim xizmatlari qiymati 80 dan 97 million AQSH dollarigacha baholandi. Yo‘qotishlar ichiga toza ichimlik suvi imkoniyatining yo‘qolishi, baliqchilik sohasining qulash, chang tufayli sog‘liq bilan bog‘liq xarajatlarning oshishi, biologik xilma-xillik va madaniy merosning yemirilishi kiradi. Tadqiqot natijalari ekologik siyosat, tiklash rejalashtiruvi va mintaqaviy rivojlanish strategiyalarida ekotizim xizmatlarini hisobga olish zarurligini ta’kidlaydi. Bundan tashqari, mahalliy aholining tiklash tashabbuslariga sodiqligi ekologik va iqtisodiy tiklanish uchun ijobiy ijtimoiy qo‘llab-quvvatlovni ko‘rsatadi. Ushbu yondashuv ekologik inqirozga uchragan hududlarda ekotizimni baholash bo‘yicha takrorlanadigan modelni taqdim etadi va ofatdan keyingi holatlarda tabiatga asoslangan yechimlarning ahamiyatini kuchaytiradi.

Kalit so‘zlar: oral dengizi; ekotizim xizmatlari; iqtisodiy baholash; ekologik yemirilish; tiklash rejalashtiruvi.

Аннотация: Иссушение Аральского моря является одним из самых драматичных примеров экологической деградации в современной истории, что привело к разрушению жизненно важных экосистемных услуг, поддерживавших окружающую среду и средства к существованию в Центральной Азии. В данном исследовании рассматривается экономическая оценка экосистемных услуг бывшего региона Аральского моря, включая обеспечивающие, регулирующие, поддерживающие и культурные функции. Используя смешанный методологический подход — рыночную оценку, метод переноса выгод и условную оценку — исследование показывает, что ежегодные потери экосистемных услуг составляют от 80 до 97 миллионов долларов США. К потерям относятся: утрата доступа к пресной воде, разрушение рыболовства, рост затрат на здравоохранение из-за пылевых бурь, деградация биоразнообразия и культурного наследия. Результаты подчеркивают необходимость включения оценки экосистемных услуг в экологическую политику, планы восстановления и стратегии регионального развития. Кроме того, высокая готовность местного населения к участию в восстановлении демонстрирует общественную поддержку экологического и экономического возрождения. Полученные выводы могут быть использованы в других экологически уязвимых регионах и подчеркивают значимость природоориентированных решений в посткризисных ситуациях.

Ключевые слова: Аральское море; экосистемные услуги; экономическая оценка; экологическая деградация; планирование восстановления.

INTRODUCTION

The collapse of the Aral Sea ecosystem is one of the most striking examples of environmental degradation caused by unsustainable resource use and mismanagement of water systems. Once the fourth-largest inland lake in the world, the Aral Sea has undergone drastic shrinkage since the 1960s, resulting in the disruption of regional hydrological cycles, biodiversity loss, soil salinization, and the collapse of local economies. This ecological crisis has had far-reaching consequences not only for the natural environment but also for the well-being of communities in Uzbekistan, Kazakhstan, and neighboring regions.

The concept of ecosystem services—the direct and indirect contributions of ecosystems to human well-being—provides a valuable framework for understanding the full magnitude of losses resulting from the degradation of the Aral Sea. These services include provisioning services, such as freshwater and fish; regulating services, like climate moderation and air purification; supporting services, such as nutrient cycling; and cultural services that encompass recreation, spiritual value, and heritage.

In the context of the former Aral Sea, many of these ecosystem services have been severely disrupted or lost altogether. The drying of the sea has led to the disappearance of commercial fisheries, increased the frequency of dust storms due to exposed seabeds, and transformed once-productive landscapes into saline deserts. At the same time, efforts toward ecosystem restoration and sustainable development in the region—such as afforestation, wetland restoration, and regional cooperation—underscore the importance of assigning economic value to these services to inform policy and resource allocation.

The present study explores methodological approaches to the economic valuation of ecosystem services in the former Aral Sea area, aiming to provide insights into their role in environmental recovery, livelihood support, and regional planning. By identifying the types of services lost, quantifying their value, and analyzing the cost–benefit implications of ecosystem restoration, this research seeks to support integrated decision-making and contribute to the global discourse on managing ecological stress in vulnerable environments.

LITERATURE REVIEW

The concept of ecosystem services emerged as a central theme in environmental economics and policy discourse in the late 20th century—notably popularized by the Millennium Ecosystem Assessment (2005)—which classified ecosystem services into four categories: provisioning, regulating, supporting, and cultural. These services are increasingly recognized for their critical role in sustaining human well-being, particularly in ecologically vulnerable regions (Costanza et al., 1997; Daily, 1997).

Numerous studies have explored economic valuation methods for ecosystem services, including market pricing, contingent valuation, choice modeling, and benefit transfer methods (Turner et al., 2003; de Groot et al., 2012). These tools help quantify environmental benefits in monetary terms to support cost–benefit analysis and policy-making. However, applying these tools in arid and post-crisis landscapes—such as the former Aral Sea region—poses unique challenges due to ecological degradation, lack of market signals, and institutional weaknesses.

The Aral Sea disaster has attracted global attention since the 1980s as one of the most dramatic examples of anthropogenic environmental degradation. Scholars such as Micklin (2007) and Glantz (1999) have extensively documented the historical drivers of the crisis, including Soviet irrigation policies that diverted the Amu Darya and Syr Darya rivers. More recent research has shifted focus toward rehabilitation efforts and the implications for regional development and human health (Martius et al., 2004; UNEP, 2012).

While there is substantial research on the ecological and social impacts of the Aral Sea's desiccation, fewer studies explicitly focus on ecosystem service valuation in the region. A limited number of works—such as those by Ismailov et al. (2018) and the World Bank (2014)—attempt to estimate the economic costs of lost services, including fisheries, agriculture, and dust suppression. These studies stress the need for a systematic and spatially explicit valuation of services to guide environmental restoration and sustainable development planning.

In the broader Central Asian context, researchers have highlighted the potential of integrating ecosystem services into regional water governance and land-use policies (Dukhovny & de Schutter, 2011). Recent developments in remote sensing, GIS-based modeling, and natural capital accounting offer new opportunities for assessing ecosystem changes and their implications for human welfare (Bagstad et al., 2013).

In summary, the literature underlines the importance of ecosystem service valuation in post-disaster landscapes such as the Aral Sea, while identifying significant methodological gaps—especially in valuation under data scarcity, community-based assessment, and long-term policy integration. This study builds upon existing works by developing a tailored valuation framework for the Aral Sea region, addressing both ecological and socio-economic dimensions.

RESEARCH METHODOLOGY

The methodological framework for this study is designed to assess and economically value selected ecosystem services affected by the desiccation of the Aral Sea. It integrates both qualitative and quantitative approaches, combining literature-based estimation, geospatial analysis, and survey-based valuation methods.

1. Study Area Delimitation.

The research focuses on the southern part of the former Aral Sea basin, primarily located in Karakalpakstan (Uzbekistan), where ecosystem degradation is most evident. The area includes the exposed seabed (Aralkum Desert), adjacent wetlands, and partially restored zones such as the Amu Darya delta.

2. Selection of Ecosystem Services.

Based on field relevance and prior studies, the following ecosystem services were selected for valuation:
Provisioning services: freshwater availability, fishery potential;
Regulating services: dust suppression, climate moderation;
Supporting services: biodiversity preservation, soil formation;
Cultural services: landscape aesthetics, historical/spiritual value.
These services were prioritized using a stakeholder relevance matrix and environmental change analysis.

3. Valuation Methods.

Table 1: The following economic valuation methods were applied depending on the service type and data availability.

Ecosystem Service Type	Valuation Method Used	Data Source
Freshwater resources	Replacement cost method	Local water supply agencies
Fisheries (lost)	Market price method (using historical benchmarks)	FAO and national statistics
Dust regulation	Avoided cost method (healthcare and soil protection expenditure)	WHO, Ministry of Health
Biodiversity services	Benefit transfer from comparable wetland ecosystems	TEEB, de Groot et al. (2012)
Cultural heritage	Contingent valuation (willingness to pay, survey-based)	Local surveys and interviews

4. Data Collection and Tools. Primary data: Structured interviews with local residents, environmental experts, and public officials (N = 120); Secondary data: Statistical data from UzStat, FAO, World Bank, UNEP, and scientific databases; Remote sensing: Satellite images (e.g., Landsat, Sentinel) used to map land cover changes and estimate vegetation loss; GIS tools: ArcGIS and QGIS were used for mapping ecosystem degradation and spatial analysis.

5. Valuation Aggregation and Analysis. Monetary values obtained for each ecosystem service were: Converted to USD equivalents; Aggregated per hectare or per capita; Compared with restoration costs to assess net ecosystem benefit (NEB); Sensitivity analysis was conducted to account for uncertainties in data and discount rates (3–7%).

6. Limitations: incomplete historical data on fisheries and biodiversity; lack of formal markets for cultural services; possible biases in survey-based willingness-to-pay estimates; assumptions in benefit transfer estimates from other regions.

This methodology enables a multi-dimensional valuation of the Aral Sea ecosystem services, contributing to informed decision-making on regional rehabilitation, climate resilience, and socio-economic development planning.

ANALYSIS AND RESULTS

Ecosystem Services under Ecological Stress: The Case of the Former Aral Sea

The results of the study reflect the multidimensional impact of ecosystem degradation in the former Aral Sea region and the estimated economic values of selected services. The analysis was conducted based on both biophysical changes (via remote sensing and field reports) and economic losses (using valuation methods). The findings are categorized according to the types of ecosystem services.

1. Provisioning Services

Freshwater Availability. Due to a significant reduction in water flow from the Amu Darya River, the amount of accessible freshwater for agricultural and domestic use has decreased by approximately 60% compared to pre-1960s levels. The estimated annual replacement cost is USD 22–26 million, which includes artificial irrigation and water transportation expenses in the Republic of Karakalpakstan. Fisheries Collapse. Historical data indicate that the Aral Sea once supported an annual fish harvest of over 40,000 tons. Currently, the fishery output is nearly zero. The estimated market value loss is approximately USD 25 million per year. This collapse has also led to additional socio-economic losses such as employment reduction, decline in food security, and diminished trade potential.

2. Regulating Services

Dust Storm Regulation. More than 60,000 km² of exposed salt plains have become a source of windborne dust, posing serious threats to human health and agriculture. The estimated health-related avoided costs,

including hospitalization and respiratory illness, amount to USD 8–12 million per year. Agricultural losses due to dust and salinity result in an additional USD 10–15 million annually. Climate Moderation. The decline in microclimate regulation—formerly maintained by the sea—has led to more extreme temperature fluctuations and reduced humidity levels. Although quantitative valuation of this service is limited, the loss is acknowledged as a significant non-market impact with wide-ranging socio-economic consequences for the region.

3. Supporting Services

Biodiversity Loss. Wetland degradation and increasing soil salinization have caused the disappearance of over 50% of native plant and bird species. Using a benefit-transfer approach from comparable wetland ecosystems, the estimated annual value of biodiversity loss ranges from USD 5.5 to 7.8 million.

4. Cultural and Aesthetic Services

Surveys conducted among 120 local residents and regional authorities revealed that 81% of respondents consider the Aral Sea a vital source of cultural identity and regional pride. Based on contingent valuation methods—specifically the willingness-to-pay (WTP) approach—the average WTP per person per year is estimated at USD 7.5–10.3. When extrapolated to the regional population of approximately 1.2 million, the total non-use cultural value is estimated at USD 9–12 million per year.

Table 2 : Annual Economic Valuation of Key Ecosystem Services

Ecosystem Service Type	Estimated Annual Value (USD)
Freshwater provisioning	22–26 million
Fisheries (lost potential)	25 million
Dust regulation	18–27 million
Biodiversity (supporting)	5.5–7.8 million
Cultural/spiritual services	9–12 million
Total Estimated Value	~80–97 million/year

Key Observations

The total estimated loss of ecosystem services significantly exceeds the current level of investment in ecological restoration projects. This highlights a strong economic rationale for prioritizing large-scale rehabilitation of the Aral Sea ecosystem.

Cultural and regulating services—despite their substantial non-market value—remain systematically undervalued in formal development and land-use planning frameworks.

Notable spatial disparities are evident across the region. Communities located closer to the former Aral Sea shoreline experience disproportionately higher losses in ecosystem services. However, these same communities also demonstrate a higher willingness to participate in and support restoration activities.

DISCUSSION

Ecosystem Services under Ecological Stress: The Case of the Former Aral Sea

The analysis results underscore the multifaceted nature of ecosystem degradation in the former Aral Sea region, revealing not only profound environmental transformations but also significant economic losses. The discussion focuses on three central themes: the implications of valuation results, methodological reflections, and policy relevance.

1. Significance of Ecosystem Service Losses

The estimated annual loss of USD 80–97 million in ecosystem services highlights the magnitude of the ecological collapse and reinforces previous assessments that the Aral Sea crisis is not only an environmental issue but also a severe economic and social disaster. Provisioning and regulating services—such as freshwater, fisheries, and dust suppression—demonstrate direct financial impacts on health, agriculture, and livelihoods. Cultural and supporting services, though harder to quantify, reveal a strong societal connection to the landscape and a significant loss of heritage value. The community's willingness to pay for restoration (USD 9–12 million per year) indicates deep emotional and intergenerational stakes. This valuation validates the importance of non-market ecosystem services, which are frequently ignored in infrastructure or irrigation planning—especially under centralized systems like the one responsible for the Aral Sea crisis.

2. Methodological Considerations and Limitations

While the applied methods (market-based valuation, benefit transfer, and contingent valuation) offer a practical approach under data-constrained conditions, several challenges and limitations must be acknowledged. Data scarcity in the post-crisis context limits long-term trend analysis, particularly for biodiversity and historical fisheries. The contingent valuation method, although useful, is sensitive to hypothetical bias and may over- or underestimate real willingness to pay. Benefit transfer from other wetland systems introduces geographic and ecological mismatches, requiring caution in interpretation. Nonetheless, the integration of geospatial analysis, stakeholder surveys, and economic techniques presents a replicable framework for post-disaster

ecological valuation in arid regions.

3. Policy and Management Implications

The findings have direct implications for regional planning, climate adaptation, and environmental restoration. The valuation evidence can strengthen the economic justification for large-scale restoration projects, such as afforestation of the Aralkum Desert, construction of artificial wetlands, or controlled water release into delta zones. Cross-sectoral integration is essential: health, agriculture, and environment ministries must jointly assess the co-benefits of ecosystem services. Transboundary cooperation between Uzbekistan, Kazakhstan, and other Central Asian states is critical, as the ecosystem spans political boundaries. Introducing ecosystem service accounting into national and local budget planning could guide sustainable development priorities and enhance donor engagement.

4. Toward a Post-Aral Ecological Economy

This research contributes to the emerging discourse on building a "post-Aral ecological economy," where environmental restoration is aligned with economic regeneration. Valuing nature not just for its market benefits but also for its supportive and cultural contributions is essential in reshaping policy thinking in ecologically stressed zones. The former Aral Sea, once seen as an irreversible ecological catastrophe, may yet become a global model for restoration-driven economic resilience—provided that ecosystem services are placed at the core of governance and investment strategies.

CONCLUSION

The former Aral Sea region presents a stark example of how unsustainable natural resource management can lead to large-scale environmental, economic, and social degradation. This study has demonstrated that the collapse of the Aral Sea ecosystem has resulted in the significant loss of a wide range of ecosystem services, including provisioning (freshwater, fisheries), regulating (dust suppression, climate moderation), supporting (biodiversity), and cultural services. By applying a combination of economic valuation methods—market-based estimates, benefit transfer, and contingent valuation—this research has estimated that the annual loss of ecosystem services in the region ranges from USD 80 to 97 million. These losses, while partial and conservative, highlight the hidden costs of ecological degradation and the opportunity value of restoration.

The results underscore the critical importance of integrating ecosystem service valuation into regional development planning, particularly in post-crisis landscapes such as the Aral Sea. Recognizing and accounting for these services in policy decisions can strengthen the case for ecosystem restoration, guide more sustainable land and water use practices, and promote socio-economic recovery. Furthermore, the study revealed strong local support for ecological rehabilitation, as evidenced by residents' willingness to contribute financially to restoration efforts. This indicates a valuable foundation for community-based conservation models and participatory governance frameworks. However, several challenges persist—particularly data limitations, methodological constraints, and the undervaluation of non-market benefits. Future research should prioritize longitudinal studies, spatial modeling of ecosystem services, and the development of region-specific valuation frameworks that better reflect cultural, climatic, and economic realities.

In conclusion, the valuation of ecosystem services in the former Aral Sea area is not merely a technical exercise; it is a necessary step toward building a resilient, ecologically informed, and economically viable future for the communities of Central Asia. The lessons drawn from this case can inform broader global efforts to value and restore ecosystems under ecological stress.

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