

Climate Change and Increasing Environmental Risks in the Aral Sea Region

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Abstract

This article examines the processes of climate change in the Aral Sea region and evaluates their significant impact on the ecological system. In recent decades, the region has experienced a noticeable rise in average temperatures alongside a decline in annual precipitation, which has accelerated the desiccation of the Aral Sea. These climatic shifts have intensified environmental degradation and contributed to a range of interconnected ecological problems. The study highlights key issues such as soil degradation and increasing salinization, which reduce agricultural productivity and threaten food security. In addition, the loss of biodiversity has become a critical concern, as many plant and animal species struggle to survive under harsh and changing environmental conditions. The drying of the sea has also led to the exposure of large areas of seabed, resulting in frequent dust and salt storms that further damage ecosystems and human settlements. Furthermore, the article explores the negative implications for public health, including respiratory diseases and other health risks associated with environmental pollution. These challenges underscore the urgent need for integrated and sustainable solutions. To address these issues, the article proposes a set of recommendations focused on mitigating environmental risks, promoting the rational use of natural resources, and enhancing regional cooperation. Emphasis is placed on sustainable development strategies that balance ecological preservation with socio-economic needs. Overall, the study provides a comprehensive analysis and offers practical insights for policymakers and stakeholders working to restore environmental stability in the region.

Keywords: *Aral Sea Region, Biodiversity, Climate Change, Desertification, Environmental Hazard, Natural Resources, Public Health, Salinization, Sustainable Development*

Introduction

Climate change, observed on a global scale since the beginning of the 21st century, has emerged as one of the complex processes significantly impacting the balance between human development and nature. Changes in the climate system are characterized not only by rising temperatures but also by changes in precipitation patterns, an increase in

extreme weather events, and the disruption of natural ecosystems. These processes are particularly pronounced in ecologically sensitive areas with high anthropogenic pressure. The Aral Sea region deserves special attention as one of these regions. For many years, the Aral Sea region has been one of the important natural-geographical and socio-economic centres of Central Asia. However, since the second half of the 20th century, the Aral Sea has shrunk sharply because of improper management of the waters of the Amu Darya and Syr Darya rivers, inefficient irrigation systems, and excessive use of water resources. This led to one of the largest environmental disasters in history—the Aral Sea crisis. As a result of the decrease in sea level and water volume, hundreds of thousands of hectares of land dried up, forming new desert areas—the Aralkum. This ecological crisis has significantly impacted the climate of the Aral Sea region.



Figure 1: The state of the Aral Sea in the 1960s Figure 2. State of the Aral Sea in 2025 1960s

The previously relatively mild climate began to take on a sharply continental character: summers became extremely hot and dry, while winters became cold and prolonged. At the same time, increased wind speeds and an increase in dust storms have further complicated the environmental situation in the region. Salt and dust particles rising from the seabed are spreading over hundreds of kilometres, having a negative impact not only on a local but also on a regional scale.

Climate change processes in the Aral Sea region are occurring in close connection with global climate change. Increasing greenhouse gas emissions into the atmosphere, the expansion of industrial and transport sectors, and population growth are further accelerating these processes. As a result, problems arise in the region such as the annual increase in temperature, the depletion of water resources, and the reduction of biodiversity. This, in turn, creates new socio-economic and health-related risks for the region's population.



Aral Sea bed at point "0" April 2026 (N: 44o 07-34 M; E: 58o 50-48)



Figure 3. Fieldwork view of the dried

Review of Related Literature

Research on the Aral Sea basin and its surrounding regions has long emphasized the environmental and climatic challenges affecting both ecosystems and agriculture. Ivanov et al. (1996) provided one of the earliest comprehensive reviews, highlighting the scientific and ecological issues tied to the basin's degradation. More studies that are recent have shifted toward the assessment of hazardous hydro meteorological phenomena, particularly their impact on agricultural productivity. Qaldibaevich and colleagues (2022, 2023) examined dangerous events such as droughts and storms, employing modern programs to evaluate risks to crops in Uzbekistan and the Lower Amudarya region. Similarly, Imanmurzaev et al. (2023) focused on Karakalpakstan, underscoring the vulnerability of local agriculture to extreme weather conditions.

Parallel research has addressed broader environmental processes. Kim et al. (2024) investigated vegetation introduction versus natural recovery in the dried Aral Sea bed, demonstrating significant effects on topsoil properties and land restoration. Sultashova et al. (2024) analysed the formation of dust storms, a recurring hazard in Uzbekistan, while Imanmurzaev and Kalmurzaev (2024) explored socio-environmental changes in the region. Studies on climatic conditions of the southern Aral Sea (Imanmurzaev, 2022) further contextualize the interplay between climate variability and environmental degradation.

Collectively, this body of literature reveals a dual focus the persistent ecological crisis of the Aral Sea basin and the increasing frequency of hazardous hydro meteorological events affecting agriculture. These works underscore the need for integrated approaches that combine environmental restoration, agricultural resilience, and climate adaptation strategies to mitigate risks in one of Central Asia's most vulnerable regions.

Objectives

This study aims to examine the effects of climate change on the Aral Sea region, focusing on the transformation of its ecological and socio-economic systems. Rising temperatures, altered precipitation, and extreme weather events have reshaped the area's climate, turning it from relatively mild to sharply continental. The drying of the Aral Sea and the formation of the Aralkum desert have intensified dust storms and salt dispersion, creating widespread environmental challenges.

Another objective is to analyse the interaction between global climate drivers and local anthropogenic pressures, such as inefficient water management, irrigation practices, and greenhouse gas emissions. These factors accelerate processes like biodiversity loss, water scarcity, and ecosystem disruption, which in turn generate new socio-economic and health risks for communities in the region.

The study also seeks to establish a framework for adaptation strategies, emphasizing sustainable resource management, environmental restoration, and resilience planning. By identifying the climatic transformations and their cascading effects, the research intends to support policies that balance ecological recovery with human development in one of Central Asia's most vulnerable zones.

Methodology

The article examined the air temperature, annual precipitation, and humidity coefficients of meteorological stations operating in the Republic of Karakalpakstan for 2020-2024. These meteorological data were statistically evaluated and analysed using mathematical models.

Findings and Discussion

During the study, long-term observation data from meteorological stations in Nukus, Chimbay, Kungrad, Takhtakupir, Takhiatash, and nearby areas were studied, and changes in temperature, precipitation, and wind regime were clarified. According to the research results, certain changes in average annual temperatures were observed across meteorological stations in the region during 2020–2024. In particular, at all stations, temperature indicators show a trend of increase with slight annual fluctuations. At the Bostan station, the temperature rose from 14,2°C in 2020 to 15,5°C in 2023, and decreased slightly to 14,6°C in 2024. At the Nukus station, the temperature is relatively stable, with an increase from 13,35°C to 14,9°C. The highest variability was recorded at Shimbay station, reaching 15,8°C in 2021 and decreasing to 13,1°C in 2024. Temperature indicators at Takhtakupir and Takhiatash stations changed relatively moderately, maintaining an overall upward trend. At the Kungrad station, a sharp rise (14,8°C) was observed in 2022 and a further decline was recorded in subsequent years. Overall the analysis indicates a process of climate warming in the region. However the observation of sharp fluctuations in some years confirms that climate change is uneven and complex in nature.

Table 1. Average annual air temperature from meteorological stations located in the Republic of Karakalpakstan

Indicators	Meteorological station	2020	2021	2022	2023	2024
Average annual temperature (°C)	Bostan	14.2	14.7	14.5	15.5	14.6
	Nukus	13.35	14.3	13.95	14.9	14.8
	Shimbay	12.72	15.8	13.2	15.5	13.1
	Takhtakupyr	12.4	12.9	13.3	13.8	12.9
	Takhiatash	14.6	15.3	15.2	15.3	14.2
	Kungrad	12.3	13.1	14.8	12.4	13.05

*Prepared based on Uzhydromet data

Based on the research results, a significant variability in annual precipitation levels across meteorological stations in the region was identified between 2020 and 2024. The obtained data indicate the instability of the precipitation regime and the presence of sharp fluctuations under the influence of climate change. In particular, the amount of precipitation at the Bostan meteorological station was unevenly distributed over the years, with a minimum value of 55,5 mm observed in 2021 and reaching 67,3 mm and 67,6 mm in 2022 and 2024 respectively. At the Nukus station, variability was more pronounced with a sharp increase (135,8 mm) observed in 2022 and a sharp decrease (43,2 mm) was recorded in 2023. A sharp increase in precipitation at Shimbay station was observed in 2024 (180,7 mm), indicating the emergence of extreme humidity conditions in the region. At the Takhtakupyr and Takhiatash stations, fluctuations in precipitation were also observed over the years, with high values recorded in some years (2022 and 2024). At the Kungrad station, a significant increase in precipitation levels (119,9 mm and 146,7 mm) was recorded between 2023 and 2024. Overall, the analysis provides a scientific basis for the uneven distribution of precipitation in the region, the increase in extreme events and the intensification of climate system destabilization processes. These trends indicate the need to apply scientifically grounded approaches to water resource management and agricultural planning in the region. At the same time, it is important to strengthen comprehensive monitoring and adaptation measures to mitigate the negative impacts of climate change in the future.

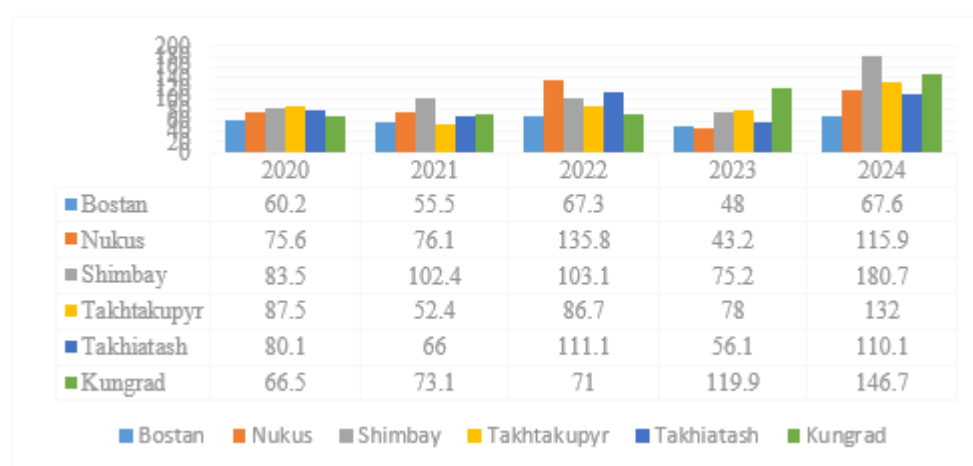


Figure 4. Annual precipitation amounts from meteorological stations located in the Republic of Karakalpakstan

Based on the provided table data the dynamics of changes in the average annual humidity coefficient at various meteorological stations during 2020–2024 were analysed. The results of the study show that at all observation points humidity indicators have a certain degree of fluctuation over the years and a relatively stable increase is observed as a general trend. In particular the humidity coefficient at the Bostan station increased from 47,5 in 2020 to 50,9 in 2024 indicating an increase in humidity in the area. A similar situation was observed at the Nukus station, although there were decreases in some years an increase in the total result from 44,4 to 48,4 was recorded. At Shimbay station the indicators are relatively high ranging from 53 to 55,3 indicating a good moisture supply to the territory. A sharp increase in the humidity coefficient from 40,7 to 51,5 was observed at the Takhtakupyr station, indicating a significant change in climatic conditions here. At Takhiatash station the values were relatively high with a slight downward trend from 61,6 to 53,5 but the overall level remained high. An increase of 50,8 to 54,2 is also observed at the Kungrad station. Overall, the analysis results show that while the humidity coefficient in the studied regions fluctuates over the years a positive upward trend is observed at most stations. This may be related to climate change precipitation and evaporation processes. These results are of great importance in assessing regional agro-climatic conditions and drawing scientifically grounded conclusions on the efficient use of water resources.

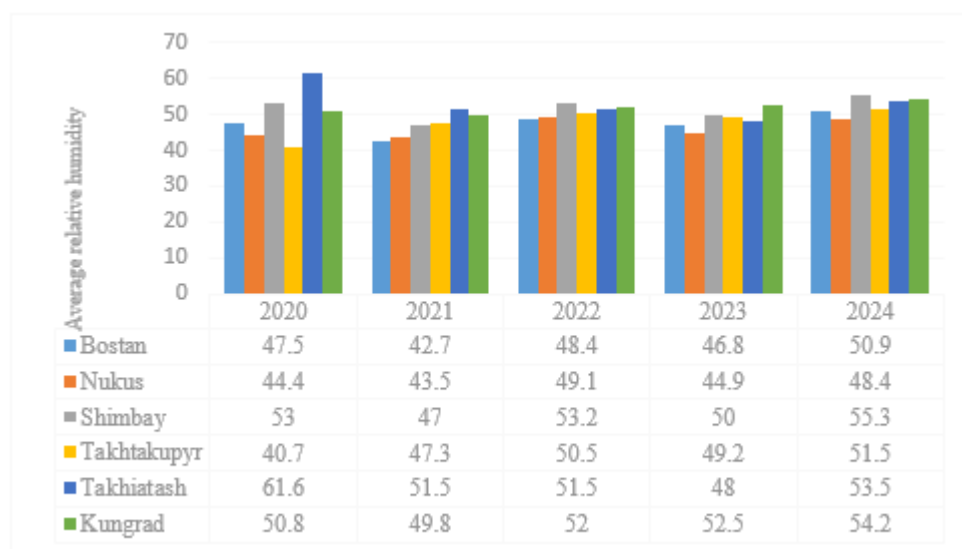


Figure 5. Average annual relative humidity from meteorological stations located in the Republic of Karakalpakstan

The research results are a systematic analysis and a generalized expression of the data obtained during the scientific research process. At this stage, the collected empirical data are processed using tables, diagrams, and statistical methods, revealing their scientific significance. The results are interpreted in accordance with the goals and objectives of the study and indicate how far the problem solution has been achieved. Correlations between the obtained indicators are also determined, and scientific conclusions are drawn based on them. The section on research results is the main part of the work, which substantiates the novelty and practical significance of the research.

The results of research conducted in the Aral Sea region show that in recent years, the environmental situation has been worsening under the influence of global climate change

and anthropogenic factors. In particular, because of the sharp drop in the level of the Aral Sea, the natural and geographical conditions of the region have radically changed, and desertification processes have intensified. This led to soil salinization, the rise of salt and dust particles into the atmosphere, and the disruption of the ecological balance in the region.

The research results confirm that climatic parameters particularly an increase in air temperature and a decrease in precipitation are being observed. These changes have negatively impacted agricultural production further exacerbating the problem of water scarcity. At the same time, the region is experiencing a decline in biodiversity and the degradation of natural ecosystems. Environmental problems also pose a serious threat to public health. The increase in dust and salt storms causes an increase in respiratory diseases and other chronic diseases. This situation also has a negative impact on socio-economic stability. An analysis of the aforementioned factors shows that the environmental crisis in the Aral Sea region is complex in nature, resulting from the interaction of natural and human factors. Therefore, it is necessary to develop scientifically grounded, comprehensive, and long-term measures to eliminate this problem.

Conclusion

According to the World Bank (2020) and the University Grants Commission (2023), only a small proportion of Sri Lankan students' progress to higher education, reflecting the highly competitive and limited nature of the system. Slow learners in 1C schools face added barriers such as poor academic support, socio-economic challenges, and lack of parental involvement (UNESCO, 2021; Iloanya, 2019). These schools often lack science streams and access to modern learning technologies, limiting inclusive teaching approaches (World Bank, 2020). Traditional, teacher centered methods dominate, leading to disengagement and high dropout rates.

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