The Past, Present, and Future of the Aral Sea (Postprint)

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Abstract

The Aral Sea was once the fourth largest lake in the world, and has now shrunk to approximately one-tenth of its original area. Questions regarding how the Aral Sea formed, the evolutionary processes it has undergone, and its formation mechanisms have long been subjects of scientific inquiry. The Aral Sea water system (the Amu Darya and Syr Darya basins), under the combined influence of regional and global factors such as the uplift of the Tibetan Plateau, the retreat of the Neo-Tethys Sea, and Cenozoic global climate cooling and sea-level decline, constitutes a major component of the complete Asian water tower system centered on the Tibetan Plateau. From its formation until approximately the mid-20th century, the Aral Sea water system maintained a relatively stable state in terms of lake area and hydrological pattern; however, since the second half of the 20th century, it has experienced large-scale exploitative development and utilization of water resources, resulting in the Aral Sea crisis.

Full Text

The Past, Present and Future of the Aral Sea

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Abstract

The Aral Sea was once the fourth largest lake in the world and has shrunk to about 10% of its former size today because of extensive exploitation and utilization of water resources, resulting in the shrinking surface water area, the increasing exposed dry lakebed and frequent salt dust storms in the context of climate change from the second half of the 20th century, which have caused the crisis in the Aral Sea basin. The Aral Sea basin (the Amu Darya and the Syr Darya), a main component of the complete Asian water tower system centered on the Qinghai-Tibet Plateau, which came into being after uplift of the Qinghai-Tibet Plateau, the retreat of the Neo-Tethys Sea, and under the impact of regional and global factors such as the global climate cooling and sea level decline. The Aral Sea system has maintained a relatively stable level in water surface area and hydrology pattern from the formation to the middle of the last century. It has only experienced extensive exploitation and utilization of water resources, resulting in the shrinking surface water area, the increasing exposed dry lakebed and frequent salt dust storms in the context of climate change from the second half of the 20th century, which have caused the crisis in the Aral Sea basin.

Keywords: Aral Sea; formation process; evolution mechanism; crises; Tibetan Plateau; arid Central Asia

1. Geographical Setting of the Aral Sea

The Aral Sea basin, comprising the Amu Darya and Syr Darya river systems, represents a main component of the complete Asian water tower system centered on the Qinghai-Tibet Plateau. This system came into being after the uplift of the Qinghai-Tibet Plateau and the retreat of the Neo-Tethys Sea, under the impact of regional and global factors such as global climate cooling and sea level decline [FIGURE 3]. The basin' s hydrological cycle is characterized by complex interactions between mountain water sources, oasis ecosystems, and terminal lake systems, forming a distinct pattern of "mountain-oasis-desert" ecological zones.

The Aral Sea itself maintained a relatively stable water surface area and hydrological pattern from its formation until the mid-20th century. However, from the 1960s onward, extensive exploitation of water resources for irrigation triggered a severe ecological crisis, marked by shrinking surface area, expanding exposed lakebed, and increasingly frequent salt dust storms [2-6].

2. Historical Evolution and Mapping

2.1 Early Cartographic Records

Jean B.B. d' Anville produced one of the earliest reliable maps of the Aral Sea region in 1734, marking a significant advancement in European geographical knowledge of Central Asia. Subsequent Russian expeditions in the 19th century, particularly between 1839 and 1889, conducted systematic surveys of the water systems. The 1847 expedition produced detailed measurements of the lake' s dimensions, while later surveys in the 1850s and 1860s established the foundation for modern hydrological monitoring [FIGURE 4].

Historical maps from the mid-19th century, including those published in the United Kingdom in 1856, depicted the Aral Sea with reasonable accuracy, showing its position at approximately 60°E, 42°30 N. These early cartographic efforts documented a stable lake system with surface areas varying seasonally but maintaining long-term equilibrium.

2.2 Water Resources Development in the Soviet Era

During the 1950s-1960s, large-scale water resource development transformed the Aral Sea basin. Irrigation projects expanded dramatically, with the total irrigated area reaching 7.00×10 km^2 by the 1960s. Water distribution between the Syr Darya and Amu Darya became a critical management challenge, with allocation quotas established for different administrative regions [TABLE 2].

The Soviet-era development prioritized agricultural expansion, particularly cotton production, leading to construction of extensive canal systems. By the 1980s, the total irrigated area had increased to 7.30×10 hm^2, with water consumption rising proportionally. This development pattern fundamentally altered the natural hydrological balance that had persisted for millennia [3, 26-27].

3. Hydrological Changes and Environmental Crisis

3.1 Water Balance Disruption

From 1911 to 1960, the Aral Sea maintained an average water level of approximately 53.3 m, with a surface area of 6.6×10 km^2 and volume of 1.00×10^{12} m^3. The annual inflow averaged 560×10 m^3, sustaining a stable equilibrium. However, post-1960 water diversion for irrigation reduced inflow dramatically, causing a precipitous decline in water level, area, and volume [FIGURE 6].

Between 1970 and 1989, irrigation water consumption increased by 150-130% compared to previous decades, while the lake' s surface area shrank to 3.70×10 km^2 by 1987. The water level dropped at rates of 20 cm annually during the 1960s, accelerating to 50-60 cm annually in the 1970s, and reaching 80-90 cm annually by the 1980s. Salinity increased correspondingly from 10 $g \cdot L^{1}$ to 45 $g \cdot L^{1}$, fundamentally altering the lake' s ecosystem [3, 28-29].

3.2 Formation of the New Great Desert

The exposed lakebed, covering approximately 1.76×10 km^2, has become a major source of salt dust storms. The dried seabed contains extensive salt deposits, with annual precipitation in the region averaging only 100-300 mm. This arid climate, combined with strong winds, mobilizes salt-laden sediments, affecting regional air quality and agricultural productivity across Central Asia [4-6].

The Kokaral Dam project represents one attempt to mitigate these impacts by regulating water flow and stabilizing the Northern Aral Sea. However, the broader ecological consequences continue, including loss of fisheries, degradation of delta ecosystems, and regional climate modification [FIGURE 7].

4. Mechanisms of Evolution

The Aral Sea' s evolution reflects the interplay of natural geological processes and anthropogenic interventions. The lake formed as a terminal basin in the tectonically active Central Asian region, where the collision of the Indian and Eurasian plates created the complex topography that governs water flow patterns [12-13]. Cenozoic tectonic evolution established the basic framework of the basin, while Quaternary climate fluctuations controlled water availability [14].

Human intervention, particularly the large-scale diversion of water for irrigation beginning in the mid-20th century, accelerated natural desiccation trends. The construction of reservoirs and canals on both the Amu Darya and Syr Darya reduced inflow to less than 10% of natural levels by the 1980s, triggering the rapid retreat observed in recent decades [FIGURE 8].

5. Current Status and Future Prospects

By 2001, the Aral Sea had separated into distinct water bodies, with the southern basin nearly completely dry. The Northern Aral Sea showed some recovery following dam construction, but the overall system remains severely degraded. Water management policies among the five Central Asian states continue to influence the lake' s trajectory, with competing demands for agricultural, industrial, and ecological water use [FIGURE 9].

The crisis has demonstrated the vulnerability of closed basin lakes to anthropogenic pressure, particularly when combined with climate variability. Future scenarios depend critically on regional cooperation in water management and the implementation of more efficient irrigation technologies to reduce water consumption while maintaining agricultural productivity [3, 33-34].

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Note: Figure translations are in progress. See original paper for figures.