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# Forecasting changes of hydrological and hydrochemical conditions in the Aral Sea

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**Abstract**: The increase of irretrievable river water withdrawals and regulation of river flow has a negative effect on the natural regime of the Aral Sea. The Amu Darya River and the Syr Darya River Basins are the largest irrigated farming areas. Their favorable soil and climatic conditions ensure guaranteed yields of various crops on irrigated lands. Since 1961, for the drastic increase of irretrievable river water withdrawal, mainly for irrigation, the inflow of river water into the Aral Sea has started to decrease significantly, accordingly the sea's hydrological and hydrochemical regimes disrupted dramatically. The sea level has continued to drop as evaporation exceeds inflow. This negatively transforms the natural environment and worsens socio-economic conditions in Priaralie as a whole, especially in the lower reaches of Amu Darya and Syr Darya, where natural conditions are largely determined by the sea's impact. At present, this causes desertification of the nonirrigated zone in the deltas, spreading to new areas as the Aral Sea dries out.
**Key words**: Aral Sea; hydrological condition; hydrochemical condition; river water withdrawal; natural environment

## 1 Introduction

Research on the Aral Sea and Priaralie problem has great scientific and practical importance for maximal mitigation of the negative consequences of sea level lowering, prevention of desertification processes, and preservation of the Aral Sea water area at a certain level by achieving efficient water use in the basin as a whole. The drying sea coast is a unique exposed Aral area, where origination, formation, and development of primary continental natural systems are observed and there is a process of formation of environmental components. In addition, the former seabed becomes the stage of aeolian processes, which typically occur in a desert zone. Deflation leads to transfer of materials, with the dust of salts accumulating in the soil because of intensive evaporation of near-surface water. The threat of further potential worsening of the geosystems in the region calls for the development of appropriate scientifically substantiated measures.

## 2 Research purpose and objectives

The purpose of this work is to forecast changes of the geosystems in the degrading part of the Amu Darya Delta, the drying bed of the Aral Sea and its hydrological and hydrochemical conditions by 2020, considering the progressive shrinkage of this water body and anthropogenic desertification, and finally to develop practical measures for cardinal environmental improvement of the Amu Darya Delta and of the dried bed of the Aral Sea.

To reach this goal, the following interlinked objectives need to be achieved:

1) Determine the scientific and applied relevance of forecasting changes in Priaralie geosystems and Aral Sea hydrology.

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2) Justify the scientific basis and establish the main forecasting factors.

3) Develop a forecast of changes in the geosystems of the portion of the Amu Darya Delta subjected to desertification.

4) Develop a forecast of changes in the geosystems of the dried bed of the Aral Sea within the boundaries of Uzbekistan.

5) Forecast changes in the hydrological and hydrochemical conditions of the Aral Sea by 2020.

6) Develop practical measures for cardinal environmental improvement of the Amu Darya Delta and of the dried bed of the Aral Sea.

## 3 Discussion and results

The major natural and anthropogenic factors of forecasting have been identified and the main natural system trends have been established. The Aral Sea and Priaralie have been scientifically substantiated as genetically single and paragenetic dynamic macro-geosystems, respectively. By taking into account the properties and features of the structural-dynamic state of the superaqual, subaqual, eluvial geosystems in Priaralie and the Aral Sea, a forecast of their transformations by 2020 was made. Practical measures for cardinal environmental improvement of the Amu Darya Delta and of the dried bed of the Aral Sea have been developed[1].

Moreover, the environmental disaster of the Aral Sea and Priaralie is now passing within the context of new geopolitical and socio-economic conditions[2]. All elaborated pre-project and scientific proposals of the past years remain mainly in place. Therefore, a revised understanding of what has transpired and its explanation are needed so that a strategy can be developed for overcoming the disaster or minimizing its consequences.

Since 1961, because of the drastic increase of irretrievable river water withdrawal, mainly for irrigation, the inflow of river water into the Aral Sea has started to decrease significantly. As a result, the sea's hydrological and hydrochemical regimes have been disrupted dramatically. The sea level has continued to drop as evaporation exceeds inflow[3]. This negatively transforms the environment and worsens socio-economic conditions in Priaralie as a whole, especially in the lower reaches of Amu Darya and Syr Darya, where natural conditions depend on the sea as well. This causes desertification of nonirrigated zone in the deltas that spreads to new areas as the Aral Sea dries out[3].

The morphometric characteristics of the sea up until 1960 were follows: water surface level = 53.4 m (above Baltic Sea level), volume = 1108 $km^3$, water surface area = 67700 $km^2$, mean depth = 16.4 m, and maximum depth = 69.4 m[3]. Such an approximate quasi-stationary state of the water body was maintained during 1900–1960[4] by the inflow of fresh river water into the sea. Since 1961, however, there has been a regular reduction in river water inflow into the sea. At present, there is virtually no inflow from the Amu Darya River, while inflow from the Syr Darya River to the Small Sea is about 3 $km^3$/year. According to estimations[5], approximately 80% of the reduction in inflow is caused by anthropogenic factors, while the rest of the inflow reduction depends on flow probability in rivers that have been shallow in the recent decade. Data[6] show that anthropogenic losses of flow account for 92%–95% of the total in the current period.

In general, from 1911 to 2010, the long-term average annual precipitation over the Aral Sea was 133 mm, whereas the average annual evaporation from the sea surface was 998 mm. Observations showed that the destabilization of the sea is caused by significant excess of evaporation over the sum of inflow elements[7]. As a result of the sea level lowering, the sea area decreased to 14000 $km^2$ by 2010 and the volume shrunk to 74 $km^3$. Moreover, the configuration of the sea has been significantly modified, with large shallow bays in the eastern, southeastern, and southern areas of Aral disappearing. The earlier existing islands such as Vozrozhdeniye, Barsakelmes, and Lazarev and the Muynak peninsula now form a single geographical feature together with the dried seabed.

The chemical composition of river waters flowing into the Aral Sea transformed from hydrocarbonate-calcium to sulfate-sodium. This indicates direct metamorphization of these waters. The inflow of salts with atmospheric precipitation accounts for fractions of 1% in the sea's salt balance and their contribution to formation of water salinity is estimated as minor. Currently, groundwater inflow to the Aral Sea is < 0.1–0.3 $km^3$/year and the corresponding ion flux is also insignificant[3]. Aeolian salt income and wind transfer of salts from the sea are caused by desertification. According to estimations, the income of salts is out of balance with atmospheric dust and wind transfer of salts. The wind transfer of salts is above 0. 1 Mt – 0. 2 Mt a year. Observations[9] over 1990–2000 show that the average amount of salts deposited on 1 $km^2$ of the dried seabed is 5 400 ton. The average annual amounts of salts deposited on the dried seabed over 1986–1990, 1991–2000, and 2001–2010 are estimated at 5. 3, 4. 8, and 6. 09 Mt, respectively.

The results of estimations of minimum and maximum growth of irretrievable water withdrawals in Amu Darya and Syr Darya Basins, without taking into account the long-term flow regulation by reservoirs, are shown in table 1. The table gives estimations for 50% flow probability. These estimations indicate that in the next decade sea level will continue to drop and its intensity will depend mainly on anthropogenic factors – irretrievable water withdrawals determined by various water-management scenarios in the sea basin[1].

Present and future changes in the Aral Sea salinity mainly will be determined by the concentration of sea water as the sea shrinks. At the same time, the impact of ion flux and other elements of the salt balance will be very minor owing to the drastic reduction of river water inflow and shrinkage of the sea area. Moreover, most salts carried by river water (carbonates and a portion of the sulfates) will precipitate when the river water mixes with the sea water because of oversaturation of the latter with these salts[1].

As salinization of the sea water increases, the salt composition of this water will be subjected to metamorphization as a result of precipitation of some sparingly soluble salts[1]. According to estimations[1], coprecipitation of only these salts will take place during a prolonged period, along with seasonal (in the coldest period of the year) deposition of mirabilite. From 2015, the Aral Sea will have shrunken dramatically in volume and area and will become close, in hydrochemical terms, to the Kara-Bogaz-Gol, whose brine is not saturated with NaCl. Precipitation of salts in the formed brine of the Aral Sea will follow the process that took place in the Kara-Bogaz-Gol: In winter, with cooling of the brine, mirabilite ($Na_2SO_4 \cdot 10H_2O$) and Ca will precipitate; in summer, along with continuing precipitation of the latter salts, mirabilite will transform into solution but, since the depth of the water body will be comparatively large and the water mass will warm very slowly, it can be assumed that not all the precipitated mirabilite will dissolve. A portion of mirabilite precipitated in winter may be washed ashore with storm wind similar to that what was happened in Kara-Bogaz-Gol[1]. Similarly, the mirabilite that is washed ashore may account for only a minor portion of its total quantity precipitated from the Aral brine[1].

As concentration of the Aral brine increases, it will become saturated with NaCl as well. Precipitation of the latter, in contrast to mirabilite, is not seasonal since solubility of NaCl depends little on water temperature. At the initial stage of saturation of the Aral brine with NaCl, precipitation of the latter in winter may be suspended because of mirabilite deposition and the total salinity of the brine will decrease. However, with complete cessation of river water inflow into the Aral Sea, this stage may last only a few years. As concentration of the brine increases, NaCl gradually will overlay sulfate salts deposited on the bed. At first, this will hinder and then totally exclude the possibility of their dissolution in the warm half-year[1].

The transformation into a chloride salt lake will be probably quick since precipitation of sulfates will start at a significant depth in the Aral Sea and an increase in temperature of the near-bottom water during the warm season, as already mentioned, will be insufficient to fully dissolve these salts. Such a phenomenon was ob-

**Table 1 Forecast of changes in morphometric and hydrochemical characteristics of the Aral Sea[1]**

| Year | Minimum water withdrawal | | | | Maximum water withdrawal | | | |
|---|---|---|---|---|---|---|---|---|
| | Actual water edge (m) | Water surface area ($km^2$) | Water volume ($km^3$) | Water salinity (g/L) | Actual water edge (m) | Water surface area ($km^2$) | Water volume ($km^3$) | Water salinity (g/L) |
| 2015 | 18.5 | 8.2 | 27.0 | 137 | 17.0 | 7.8 | 22.2 | 140 |
| 2020 | 12.8 | 6.7 | 17.5 | 155 | 11.3 | 6.35 | 12.7 | 160 |

served repeatedly in the shallower Kara-Bogaz-Gol; this exact phenomenon mainly caused a relative decrease of sulfate ions in Karabogaz brine compared to Caspian water. With the transformation of the Aral Sea into a chloride salt lake, only NaCl will be deposited. NaCl will account for more than 99% of precipitated salts; Ca salts will be minor. Finally, a brine lake will form. The upper part of its bottom will consist of a layer of almost pure common salt, whereas the lower part will be represented by various sulfates: mirabilite ($Na_2SO_4 \cdot 10H_2O$), glauberite ($CaSO_4 \cdot Na_2SO_4$), bloedite ($Na_2SO_4 \cdot MgSO_4 \cdot 4H_2O$), and others[1].

The mean thickness of the salt layer will be ≥2.5–3 m even if we deliberately consider an overestimated area of the Aral Sea by the beginning of NaCl deposition (1500 $km^2$). Approximately half of this layer will be common salt[1]. As numerous observations show[4], in the Russian Federation's lakes, such as Kulundinskoye (Altay territory), Baskunchak (Astrakhan province), Al'ton (Volgograd province), and other salt lakes, the layer of halite is a very solid mass, which is virtually not subjected to wind erosion. No blowing off of material from this layer and, hence, transfer of salts can take place[4].

In contrast to halite, dewatered sodium sulfate ($Na_2SO_4$) is a powder, which is easily blown by wind. However, under the described conditions, all sulfate salts will be protected from being blown away by the solid layer of halite[9].

Thus, as is shown, the hydrological and hydrochemical characteristics of the Aral Sea will worsen under the conditions of destruction. The sea itself will transform into a brine lake, making it useful only as a spa or for production of salt[9].

# 4 Conclusions

The forecast by 2020 of changes in arid geosystems under conditions of continued environmental destabilization in South Priaralie allow us to make the following conclusions:

1) The landscape and natural-soil features of the given area will gradually transform from hydrohalomorphic (water boundary) to eluvial complexes (original coast as of the 1960s) inclusive. Therefore, the sea drying is characterized by different polyspectra of arid geosystems and processes.

2) According to our forecasts, by 2020, under average climatic conditions and depending on water use scenario, the sea level may drop by 0.5–0.25 m BSL. By 2020, salinity of the sea may increase up to 237%–250‰.

3) According to our forecasts, coprecipitation of salts will take place during a prolonged period, along with seasonal (in coldest time of the year) deposition of mirabilite. At the final stage of drying of the Aral Sea, a salt lake will be formed. Its solid and liquid phases will be represented by a total salt mass of about 9 billion tons, i.e., virtually all dissolved in the present Aral Sea salts of Na and Mg.

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