Review Article

Shrinking of the Aral Sea - causes, effects, possibilities of revitalization

Abstract. The Aral Sea, which a few dozen years ago was the fourth largest lake in the world, currently exists only in a rudimentary form. The drastic reduction in the flow of water from the two great rivers feeding the Aral Sea, caused by the Soviet plan to irrigate cotton-growing areas, caused enormous economic, social and health problems and a decline in biodiversity.The main natural consequences of disturbing the water balance are: a significant decrease in biodiversity, local climate changes, an increase in the salinity of remaining waters and dry bottom soils. The social consequences discussed include: the decline of fishing and fish processing and the disappearance of tourism, which results in unemployment and increased poverty of the local population. A very important problem are dust storms that arise on a dry bottom and spray salty and toxic dust throughout the Aral Sea basin, which results in different negative health effects for the people living there. The article also discusses the possibilities of minimizing the price paid for shrinking a large body of water. A return to the pre-1960 state is very unlikely in the foreseeable future, but a relatively simple, although partial, solution to the problem, is to reduce soil erosion by introducing vegetation. The research proposed and conducted by a group from the National University of Uzbekistan is aimed at correlating soil parameters with the possibilities of effectively introducing plants into existing habitats. The importance of the selection of species was pointed out not only because of their adaptation possibilities, but also because of their economic importance and phytoremediation possibilities.

1. Introduction

The dynamically growing world population after the end of World War II brought about the development of a number of problems previously unknown to humanity.Technological, social and urban requirements and the need to secure food have led to an imbalance in many ecosystems. In some cases, the cause of the disruption of the environmental balance lies in ill-considered political decisions that do not take into account the possibilities of homeostasis of natural habitats. In some parts of the world, disruption of the environmental balance causes irreversible consequences, and the price to pay for ill-considered decisions is very high.An excellent example of such a situation are the changes in the Aral Sea basin, often called in the scientific literature the greatest ecological disaster caused by humans. In other words, the Aral Sea tragedy is well known throughout the world as an example of the destructive impact of humans on nature.

Scientists from all over the world are trying to understand the negative effects of the drying up of the Aral Sea. As a result of the implementation of many projects, more and more works are being created proposing more or less comprehensive methods of limiting the negative effects of the almost complete disappearance of this large body of water. Many ideas, are also emerging on how to, at least to a limited extent, reduce the effects of the ecological disaster related to the drastic change in water conditions in the region.

One of the elements of such research is a new project entitled "Creation of scientific bases for grouping of sites planting plants depending on salinity, physico-chemical and biological properties of soils spread on the dry bottom of the Aral Sea**",** which will be carried out by a team of scientists from the National University of Uzbekistan and the University of Warsaw (Poland).

The aim of this article is to present an outline of the causes of drastic hydrological changes in the Aral Sea basin, the broadly understood natural consequences of this event, and to analyze the possibilities of their minimization.

Fig. 1. Moynaq ship cemetery – the symbol of Aral Sea disaster (Photograph by Bogusław Wiłkomirski)

2. The origin of the problem

Although the geographical concept of Central Asia is understood in different ways, a common feature of this region is its climatic description.Central Asia has a distinctive continental arid and semi-arid climate with hot, dry and cloudless summers as well as moist, relatively warm winters in the south and cold winters with severe frosts in the north of this area.

In an area with a clearly continental climate and a deficit of rainwater, any disturbance of the hydrological balance is particularly strongly felt. It is safe to say that the existence of millions of people depends on water from rivers fed by rainfall and glaciers in the mountains and carrying these water resources to lower regions. Among the many global threats, the water deficit crisis is one of the most visible and urgent to solve (Editorial Nature, 2023).

In world public opinion, one of the most famous areas affected by the water crisis is the Aral Sea Basin (Toderich et al., 2024). The Aral Sea basin occupies a huge area of about 1,300,000 square kilometers and covers the entirety of Uzbekistan and Tajikistan, much of Turkmenistan and Kyrgyzstan, and southern Kazakhstan. In a narrower, but more frequently used sense, the Aral Sea basin is defined as the basins of two large rivers, the Amu Darya originating in Tajikistan and the Syr Darya originating in Kyrgyzstan, together with the surface of the Aral Sea itself. This area, far away from the ocean and separatedfrom the main moisture-bearingwinds, is characterized by an extremely continental climate (Ivanov et al. 1996).

On a geological time scale, the Aral Sea is a relatively young body of water.Its history has been described by many researchers, for example (Boomer et al., 2009; Burr et al., 2019; Krijgsman et al., 2019). However, although over the last several dozen thousand years the water level in the Aral Basin has changed many times, due to tectonic reasons, this is only of significance to researchers of the planet's past history.

However, from the point of view of modern man, his economic, health and social needs, as well as for current environmental research, what is significant is the catastrophically rapid decline in the water level in the Aral Sea over the last few decades(Yang et. al., 2024)Although the year 1960 is considered to be the starting date of the noticeable shrinkage of the Aral Sea, the beginnings of this situation should be sought in the early days of Soviet power. It was then decided that the territories of present-day Uzbekistan would become an area of intensive production of "white gold", as cotton was called.Cotton was and still is a strategic raw material not only because of its great importance in the clothing industry, but also as a substrate for the production of nitrocellulose, which is an important component in the explosives industry.

Cotton is a plant that requires a warm climate and a lot of sun, and these conditions are met in the Aral Sea basin. Unfortunately, cotton also requires a lot of water during growth, which could not be easily obtained in the steppe and desert areas. The natural source of much water seemed to be the two great Central Asian rivers, the Amu Darya and the Syr Darya. The first irrigation canals were built in the 1930s. They were built without following the principles of hydrological engineering, but their scale was small enough not to significantly disturb the water level in the Aral Sea.

The situation worsened after the end of World War II. In accordance with Stalin's "Great Plan for the Transformation of Nature," irrigation was scaled up to impose a cotton monoculture in the Aral Sea basin. A huge portion of the Amu Darya's water was diverted through extensive canal networks. Despite Stalin's death in 1953, this irrigation network continued to grow at an even faster pace (Brain, 2010; Peterson, 2019).

In 1954, the USSR began its largest project on the Amu Darya - the Karakum Canal.Without regular water replenishment, the very large lake began to evaporate, water levels began to drop rapidly, and the receding lake left behind increasingly salty soil in which most plants could not grow. The year 1960 is considered to be the beginning of drastic changes in the water level in the Aral Sea.

Until the 1960s, river discharge provided on average 56 km^3/year of fresh water to the Aral Sea. Such volume represented about half of their total runoff capacity flow and was sufficient to keep the balance between income and evaporation and maintain the lake level at +53 m above ocean level (Bortnik, 1999).

From 1960 until the collapse of the Soviet Union, thousands of kilometers of canals were built along the Amu Darya and, on a smaller scale, along the Syr Darya. These canals were built without regard to the disastrous consequences for the Aral Sea, although Soviet engineers and biologists were well aware of the ecological consequences of such water exploitation.

3. Characteristics of the Aral Sea and the shrinking of the water body.

The Aral Sea, formally a lake, is located in the northern part of the Central Asian deserts, on the territory of two countries, Uzbekistan and Kazakhstan. Its surface area of 68 thousand square kilometers placed it fourth among the world's lakes. Only the Asian Caspian Sea, the American Lake Superior and the African Lake Victoria were larger (Micklin, 2016).

The water surface of the Aral Sea was located at a height of about 50 meters above the level of the World Ocean, the volume of water was about 1,060 cubic kilometers, with a maximum depth of 69 meters. The water salinity of 10-12 g/dm^3 placed the reservoir in the group of brackish seas and was comparable to the current salinity of the Baltic Sea. Before 1960, water salinity was maintained at a constant level due to the balance between evaporation and the inflow of freshwater from the Amu Darya and Syr Darya rivers.The surface water temperature in summer ranged from 26-30°C, while in winter it dropped below 0°C due to salinity. Water transparency was very high, reaching up to 25 m, which favored the development of fishing and tourism.

There were several islands in the Aral Sea, the most important of which, due to the consequences associated with the drying up of the water body, was Vozrozhdeniya Island. A secret biological weapons research centre began operating on this island in 1948. The falling water level connected the island to the mainland, creating a threat of the expansion of pathogenic microorganisms.

The two main ports on the Aral Sea were Aralsk in the north and Moynaq in the south. As the water area shrank, both ports moved further and further away from the coastline. At the turn of the 20th and 21st centuries, as a result of the water level dropping by several meters, the port of Aralsk moved about 100 km away from the water surface.

Fig.2. Moynaq Museum. Boards illustrating the shrinking of the Aral Sea (Photograph by Bogusław Wiłkomirski)

As already mentioned, the conventional beginning of the rapid shrinking of the Aral Sea was 1960. The direct cause of this state of affairs was the enormous acceleration during the decade of 1950-1960 of irrigation of the surrounding desert areas using the constantly expanded network of canals receiving the waters of two great Central Asian rivers.

It seems that the political leaders of the Soviet Union were aware of the potential risk of disrupting the flow of river waters into the Aral Sea, but they agreed to it in the name of illusory economic gains. The local population borne the multiple costs of this reasoning (Micklin, 1988, White, 2014).

Political decisions meant that over the next 30 years (until thecollapse of the Soviet Union), the water level in the lake dropped to around 13 m.In 1989, when the lake level decreased to about +40 m, the northernmost part of the lake, known as the Small Aral Sea, separated from the principal water body (Aladin et al., 1995; Izhitskiy el al., 2016).

The moment of division, as a result of the drying of the Berg Strait, of a large body of water into two smaller parts caused them to evolve in two ways. The Small Aral located at the north on the territory of Kazakhstan continues to be slightly fed by the Syr Darya and its level decreased more slowly in the 1990s than the level of the Big Aral located on the south, mostly in Uzbekistan, where the discharge of the Amu Darya to the Aral Sea has nearly ceased(Aladin et al., 2005).

The process of the disappearance of the Big Aral was much more interesting.The progressive decline in the level in the 1990s resulted in the expansion of the Vozrozhdeniya Island, which in 2001 turned into a peninsula.This meant the division of the reservoir into a shallower eastern part and a deeper western part.

After 2001, the shallower eastern part retreated rapidly over the next several years. Especially large retreats in the eastern lobe of the Big Aral appear to have occurred between 2005 and 2009, when drought limited and then completely cut off the flow of the Amu Darya. Water levels then fluctuated annually between 2009 and 2018 in alternately dry and wet years. In 2014, the eastern lobe of the Big Aral completely disappeared. Only a small, deeper western lobe remains (Singh et al., 2018).Fig. 3 shows a particularly drastic shrinking of the waters of the remnant Aral Sea in the last ten years.

The dry bottom formed in the place of a former water body, especially the eastern part of the South Aral, began to be referred to in scientific literature as Aralkum (the "Aral Desert") (Breckle, Wucherer, 2012; Löw et al., (2021). This desert covers an area of approximately 60,000 square kilometers (Banks et al., 2024).

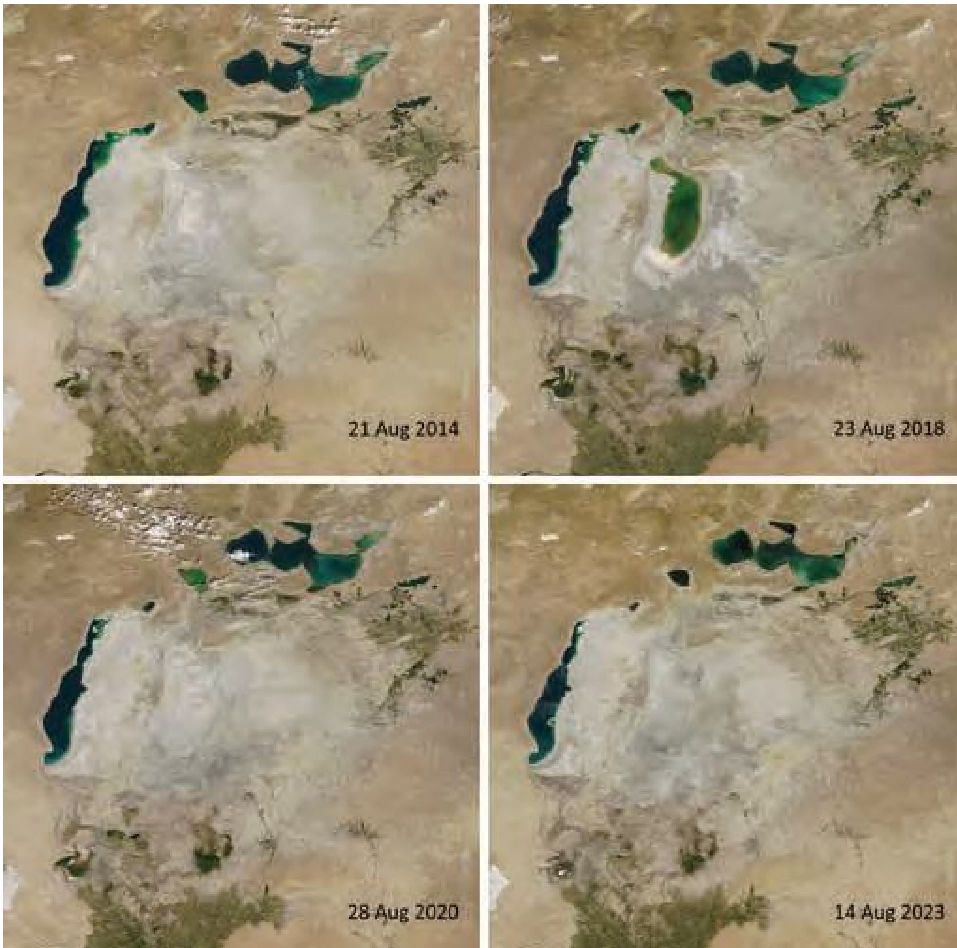

Fig3. The Aralkum Desert, which forms in the area of the former Aral Sea: Source NASA, Terra MODIS (True Color)

4. Various consequences of the disappearance of water in the Aral Sea and the formation of Aralkum.

4. 1Increasing salinity of water and soil

The first six decades of the 20th century, during which the water level and volume in the Aral Sea were stable at an altitude of approximately 53 m above the level of the world ocean, with a volume slightly exceeding 1000 km^3, were characterized by relatively low water salinity, at the level of 10 g/dm^3.

In 1989, when the reservoir was divided, the salinity of water in the Small Aral Sea and the Large Aral Sea increased three times, up to 30 g/dm^3. In 2007, after several years of operation of the Kokaral dam, thanks to which the waters of the Syr Darya fed only the Small Aral Sea, the salinity in this water body decreased to approximately 14 g/dm^3.However, the water salinity increased significantly in the Large Aral Sea, reaching 100 g/dm^3 in its deeper western part and even 120 – 160 g/dm^3 in its shallower eastern part (Aladin et al., 2009).

Presently, salinity levels have reached around 140 g/dm^{3}in the western part and exceeded 210 g/dm^{3}in the remaining water residues of eastern part. In contrast, the Small Aral Sea has transitioned into a brackish lake with salinity levels no higher than 12 g/kg, with the restoration of its water body (Ma et al., 2024).

The increasing salinity of water and the shrinking of the reservoir are related to the salinity of soils appearing on the dry bottom of the Aral Sea. As a result of the lake drying up, salts contained in the water appeared in the soil, resulting in high salinity of the exposed seabed. The main salts found in Aralkum soils are sodium chloride, magnesium sulphate and calcium sulphate. The strongly and extremely saline areas were mainly located in the northeastern part of the eastern basin of Large Aral Sea and western part of former Vozrozhdeniya Island (Duan et al., 2022).

4. 2 Erosion and dust aerosols

The new dry land emerging from the shrinking Aral Sea was easily susceptible to wind erosion (Song et al., 2023). Harsh climatic and weather conditions in the Aral Sea area favour wind erosion of the dry bottom. The severe wind erosion areas within the dry lakebed are most probably where salt dust storms occur (Song et al., 2024).

Salty dust spread by the wind, containing not only salt particles but also organic and inorganic pollutants, is not only an important factor in atmospheric chemical changes and biogeochemical cycles, but also a threat to human health. The Aral Sea basin has become an important "hot spot" on the global map of dust storms, with all their health and economic consequences (Indoitu et al., 2015).

Between 1984 and 2015, dust emissions from the growing desert almost doubled from 14 to 27 million tons. The Aralkum Desert is now considered one of the most significant man-made sources of dust on earth (Banks et al., 2024a, 2024b). Although the Aralkum is much smaller than the neighboring natural deserts of Karakum to the south in Turkmenistan and Kyzylkum to the southeast in Uzbekistan and Kazakhstan, the dust from the Aralkum is considered much more dangerous because it contains residues of fertilizers and pesticides from former agriculture.

The cotton monoculture is connected with strong toxic pollution. The Aral Sea basin was sprayed high amount pesticides such as lindane and DDT regularly. Due to the large area of cotton cultivation, spraying was carried out using airplanes, which also resulted in contamination of inhabited rural areas, including fruit and vegetable crops at home.

The scale of the dust storm phenomenon is enormous. The main source of dust was found to be in the eastern part of Large Aral Sea. The total source area in the Aral Sea region exceeds 27,000 km^2, with annual average dust emission of up to 87.6 million metric tons from 2010 to 2020 (Chen et al., 2022). PM_{10} dust emitted from the dry bottom of the Aral Sea area can be transported over 4,000 km, and the area of land surface affected was more than 6.21×10^6 km^2.The zone most severely impacted by polluted aerosols from the Aralkum region was mainly distributed in the vicinity of the Aral Sea region, including western Kazakhstan, and most of Uzbekistan and Turkmenistan. The size of dust storms around the Aral Sea is among the largest in the world, and the pollution content they carry significantly exceeds WHO standards (O'Hara et al., 2000; Törnqvist et al., 2011).

4. 3 Loss of biodiversity and creation of new ecosystems

Fig.4. The dry bottom of the Aral Sea at the research surfaces of a new scientific project from the National University of Uzbekistan.(Photograph by Bogusław Wiłkomirski)

Medieval scholars from the Khorezm Academy of Mamun in Khorezm, located near the Aral Sea, claimed that the presence of water meant the existence of life. The increasingly disappearing water surface confirmed this old wisdom. Both invertebrates and ichthyofauna began to visibly disappear. This situation has become noticeable since the 1960s, when changing water salinity became the main factor affecting the fauna and flora of the Aral Sea, especially its fish communities.

The crisis among invertebrate fauna began about a decade later, when in the 1970s the salinity level began to exceed the limit of 13 g/dm^3, considered the limit for the development of freshwater species. The second water salinity limit (approximately 30 g/dm^3) was reached in 1987 and since then only marine species, euryhaline species of marine origin, and representatives of euryhaline halophilic fauna of inland saline waters were present. The transformation of the Large Aral into a hyperhaline water body led to a further significant reduction of biodiversity. Even the majority of surviving representatives of marine fauna became extinct. Only some invertebrate species which are the most resistant to high salinity, have survived(Aladin et al., 2019).

In the Aral Sea before 1960, the physical and chemical parameters of the water allowed developmentof a variety of plant communities in all parts of the reservoir, i.e.in deeper waters, along the shores as well as in the river delta regions.The main factor of changes in the reservoir's flora (as in the case of fauna) was the increasing salinity of the water.

The causes and resulting changes in the biodiversity of the reservoir itself seem quite obvious. The former water areas turned into a desert called Aralkum. Therefore, it is worth focusing on changes in habitats around the lake's shoreline before the shrinking process begins, i.e. in the Aral Sea basin.

The plant form characteristic for Uzbekistan river valleys is tugai forest, In a narrow sense it refers to reverie forests composed mainly of the two poplar species *Populuseuphratica*, *Populuspruinosa* and *Eleagnus* spp. associated with schrubs (*Tamarix* spp.) and herbacerous species, distributed along rivers in Asian deserts (Khaydarov et al., 2014). Some of the most valuable tugai ecosystems are located in the lower reaches of the Amu Darya. This area of tugai vegetation was degraded during the shrinking of the Aral Sea and this process is still ongoing. It seems that valley poplar forests are one of themost threatened vegetation type (Korolyuk etal., 2024).

Most authors describing changes in ecosystems in the Aral Sea basin focus on the degradation and disappearance of specific habitats. However, there are fewer works on diametrically different situations, when a completely new ecosystem is created and developed, with diametrically different characteristics.

This situation arose on a large natural depression in the Syr Darya basin, which is bordered by the Kyzyl-Kum desert, the foothills of the North-Nuratau mountains and extensive irrigated areas of the Golodnaya steppe.A system of lakes called the Aydarkul-Arnasay Lake System was created in this area. The beginning of a new human-made ecosystem was the emergency release of excess water from the Shardara reservoir with a volume of over 20 km^3 in 1969.

In the following years, water from the Shardara retention reservoir supplemented the water resources of the lake system and eventually a new lake ecosystem was formed, approximately 300 km long and approximately 50 km wide.

Over the course of half a century, a very large reservoir with rich biological diversity has developed. Water, according to the old maxim, brought life, and the symbol of this was the inclusion of AALS in the Ramsar Convention in 2008. Now it is one of wetlands of international importance, which, according to environmental experts, will attract the attention of the world community to the problem of preserving and improving the ecological state of this unique biological system (Wiłkomirski et al., 2014; Erkabaev et al., 2024).

4. 4 Economic, social and medical implications

The Aral Sea region, in the times of the Soviet Unionwell known for its thriving fisheries, has a rich and deeply rooted fishery culture that has evolved over centuries (Ermakhanov et al., 2012). The fishery culture served as the economic backbone of many communities in the region and provided income and employment for fishermen and their families.Low salinity of water meant that both fresh and saltwater fish lived there.

In the two most important ports in the Aral Sea, Muynaq and Aralsk, fish was landed and transported further or processed in local processing plants. More than 40 species of fish (19 was native) lived in the lake and the rivers flowing into it, some were endemic, such as the Amu Darya pseudo-shovelnose (sturgeon fish nicknamed “mousetail”, which the Muslims did not eat because of its long and thin tail) and the Aral barbel, and some, for example, silver carp, flounder and grass carp were artificially added (Plotnikov et al., 2023).

Fishing has been a vital source of sustenance and economic activity for generations of people living along the sea’s shores. The region’s fishery culture was characterized by traditional fishing techniques, such as using nets and small boats, which were passed down through families and communities. Fishery culture in the Aral Sea region extended beyond economic importance (Glantz, Figueroa, 1997; Alieva et al., 2023).

Initially, fishermen tried to enter the waters of the rapidly shrinking lake by digging canals connecting the port areas with the water surface, but this strategy soon turned out to be insufficient.The desiccation and subsequent salinization of the Aral Sea have led to the collapse of its once-thriving fishing industry. Most of the fish species that once lived in the Aral Sea have perished as the salinity of the lake has significantly increased over the past decades. The Aral Sea has practically lost all of its commercial and most of its ecological importance as a fishery.Of course, the situation has become different in the Small and Large Aral Sea areas.

In Kazakhstan territory after the completion in 2005 of a dam that attempted to revive a part of the Aral Sea, a small fishing industry was revived.The reservoir (Small Aral Sea) filled up, salinity decreased, and fish stocks rebounded(Smurov 2022). The full revival of the Small Aral is still being discussed, but with less optimism than before due to the diminishing waters of the Syr Darya River.

In the dried-up Large Aral Sea in Uzbekistan, the situation is much worse. Muynaq district, has suffered the most from the Aral disaster. Some time ago local residents used to fish for a living, but now the majority of the region are plains, deserts, salt marshes and the dried-up sea.

As the Aral Sea has dried up, fisheries and the communities that depended on them collapsed. The increasingly salty water became polluted with fertilizer and pesticides. The blowing dust from the exposed lakebed, contaminated with agricultural chemicals, became a public health hazard. The associated socio-economic processes involved decline in the standard of living, deterioration of health, growth of unemployment and outmigration from the affected region. Unfavourable economic trends have brought with them social problems. In the Aral Sea basin, the region most affected by social problems is Karakalpakstan, an autonomous region located in the former Amu Darya delta.

A separate group of problems generated by the drying up of the Aral Sea are disturbances in the health of the population living near the former borders of the water body.Drinking water that meets sanitary standards has become a scarce commodity, and storing its limited resources poses an additional risk of contamination.

A natural consequence of this state of affairs is the increased transmission of foodborne infections, such as hepatitis A and various diarrheal diseases (Small et al. 2003). It is worth remembering that diarrheal diseases are one of the main causes of mortality in young children (Wolf et al., 2014; Jabborova et al. 2024).

Although various types of inorganic salts, including those containing sodium ion, play a significant role in the human body, their excess may lead to serious health consequences. In the Aral Sea basin, an increased incidence of hypertension, cardiovascular diseases, skeletal disorders and kidney diseases is observed (Anchita et al., 2021; Jabbarov et al. 2019).

Another type of threat, although partially removed, are the potential remains of secret research centre on Vozrozhdeniya Island, where biological weapons were tested in the laboratory named Aralsk-7 in the secret town Kantubek. The island was suitable for a secret laboratory, it was located in a very secluded place; practically only accessible by air.

During the Cold War, the possibility of infecting people with diseases such as plague, anthrax, smallpox, tularemia and brucellosis were tested there. As the Aral Sea began to shrink, the island grew larger, and when it became a peninsula, there was a great danger of animals spreading dangerous materials.

In the years 1995 - 2002, several expeditions were carried out with the participation of American scientists, which disposed of pathogenic microorganisms. In 2021, the authorities decided to completely destroy the remains of the city of Kantubek. Despite all the safety measures taken, it cannot be guaranteed that some virus or bacteria won't escape from the burial sites on Vozrozhdeniya Island.

5. What's next? - i.e. possible scenarios for minimizing the costs incurred for disturbing the balance.

5. 1 General comments

According to the general consensus of scientists dealing with the ecological catastrophe in Central Asia, the direct cause of the drying up of the Aral Sea was the excessive and uncontrolled use of the waters of two large rivers, the Amu Darya and the Syr Darya, to irrigate the surrounding desert areas.

Ill-considered decisions dictated by short-sighted political interests led to the virtual disappearance of water over a huge area. It must be remembered that this area was so large that its disappearance was associated with comprehensive, dangerous consequences, described in the current article.

Since the drying up of the Aral Sea is called the greatest ecological disaster caused by humans, the restoration of the water body would seem to be a natural reversal of this situation.Reversal, that is, filling the dried-up basin with water with a volume of about 1,000 km^3, leading to the recovery of a water surface exceeding 60,000 km^2. The question remains: where to get such a huge amount of water?

Theoretically, there would be two possibilities. The first one involves pumping water from the Mediterranean Sea, which connects to the world ocean, through the Black Sea and the Caspian Sea. A variant of this idea is to obtain water from the great Siberian rivers Ob and Irtysh through a system of canals and pumps. While technically possible, both variants of the project of refilling the Aral Sea involve considerable engineering challenges, ecological risks, and they are unimaginably expensive, hence should be considered unrealistic in the foreseeable future.

The second option is to restore the water supply from local rivers, especially the Amu Darya.This could be done by eliminating, or at least drastically reducing, irrigation of the surrounding agricultural areas. This is technically much simpler than long-distance pumping of water, but it has further serious economic and social consequences (Micklin 2016).Lack of irrigation of cotton fields will cause serious economic consequences for local residents.

Since it seems impossible to restore the water level of the Aral Sea before 1960, what can be done to improve the natural and social situation in the areas of the dry bottom of the dry lake and in the areas surrounding the former reservoir?

5. 2 The use of plants to reduce the consequences of the drying up of the Aral Sea.

The comprehensive and sustainable use of plants to minimize the negativeeffects of Aralkum is natural, relatively effective and simple to implement.It seems natural, if only because of the presence of vegetation effective mitigationof the occurrence of wind erosion within these areas is possible.

In addition, some plant species can be effectively used in the phytoremediation process. Certain plants are also of economic importance. Of course, it is crucial to determine which plant species and under what conditions will be able to adapt to the unfavourable habitat parameters in Aralkum. It is not enough to pay attention to halophytes, because even representatives of this group of plants have different habitat requirements and economic usefulness.

One of the leading research centres dealing with the possibilities of introducing appropriate plant species is the National University of Uzbekistan. The university has just started leading a new research project entitled: “Creation of scientific bases for grouping of sites planting plants depending of salinity, physico-chemical and biological properties of soils spread on the dry bottom of the Aral Sea”.

The research group conducted pilot experiments at the university research site in Moynaq.

Fig5. The entrance to the university research site in Muynaq, on the dry bottom of the Aral Sea.(Photograph by Bogusław Wiłkomirski)

Fig.6. *Haloxylon* seedlings growing during pipe experiments at the university research site in Muynaq(Photograph byZafarjonJabbarov)

During pilot experiments, for the first time it was possible to obtain satisfactory seedlings of the *Haloxylon* genus (Jabbarov et al. 2024; Jabbarov, Abdrakhmanov, et al. 2024;). The success of plant growth in the conditions of the experimental training ground is not synonymous with the possibility of growing plants on large areas. In addition to the appropriate amount of water, soil parameters are of key importance for large-scale plant cultivation. Therefore, the primary goal of the new project is to group areas for planting plants based on the study of salinity, chemical, physical, biological, and microbiological properties of sand dunes scattered in the dry bottom of the Aral Sea (Jabborova et al. 2023; Eshova et al. 2024).

According to one of the definitions given by Flowers and Colmer (2008), halophytes are plants that, thanks to certain biochemical mechanisms, are able to regulate high salt concentrations in their tissues and therefore adapt to life in a highly saline environment. In other words, halophytes are remarkable plants that tolerate salt concentrations that kill 99% of other species.

Since salinity, apart from the lack of adequate substrate moisture, is the most important factor limiting the growth of plants on the dry bottom of the Aral Sea, attention of researchers from the research group obviously focuses on halophytes. Of course, variable salinity is related not only to the concentration, but also to the type of salt, in other words, to the variability of cations and anions. In addition to salinity, other factors must be taken into account, which is why the innovative nature of this project consists in grouping dry bottom regions in terms of salinity, physical, chemical and biological properties of sand dunes.

If we take into account the factor of pollution, especially with heavy metals, it is worth looking for plants that can survive in salty and polluted areas and are able to reduce the level of heavy metals in the substrate. Heavy metals are among inorganic pollutants of soils that have been the most intensively investigated and frequently found (Wiłkomirski et al., 2012; Jabbarov et al. 2024).

Phytoextraction (a type of phytoremediation), uses metal-accumulating plants to remove toxic elements from contaminated soil. The effect of phytoextraction depends mostly upon the selection of a proper plant species, able to accumulate the selected elements in specific environmental conditions. Plants that could reduce nickel and copper concentration in saline soils are sunflower (*Helianthus annus*) and corn (*Zea mays*). Both species prefer a warm climate, so they could be suitable for growing in Aralkum. Laboratory tests have shown that both corn and sunflower can be used for phytoremediation of soils polluted with nickel and copper and with a high NaCl content. Soil salinity facilitates high accumulation of heavy metals. Both species are also of agricultural importance, which would further increase their reclamation value (Rogacheva et al., 2018).

Conclusion

Sandra Postel, founding director of the Global Water Policy Project, organization whose purpose isto promote the preservation of Earth's freshwater through research, writing, outreach and public speaking, said:“The Aral Sea tragedy provides the most strikingexample of the interconnections between the health of an ecosystem and that of theeconomy, community, and people dependent on that ecosystem”(Postel 2000).

The review of the literature carried out in this article shows that the fateful decision to reverse the course of the rivers feeding the Aral Sea in order to turn the desert into a large oasis of farmland resulted in a disastrous disturbance of the water balance in the entire region, with all its consequences.

The consequences of this decision have been far-reaching and profound. A region with a once thriving fishing industry and well developed tourism has fallen into disrepair, causing economic hardship, unemployment and physical and mental health problems for the local population (Wæhler, Dietrichs, 2017). Moreover, environmental pollution with pesticides and other toxic organic and inorganic derivatives spread during dust storms causes many diseases that ruin the health of people living around the shores of the former reservoir.

Since a complete or even significant restoration of balance seems unrealistic, the efforts of politicians and scientists should be directed towards rapid development of Aralkum that will eliminate the worst problems, such as erosion, dust storms and ground pollution.It seems that the easiest way to do this is through plant reintroduction. First of all, those that are able to grow in the conditions existing on Aralkum, and then a selection of those that not only belong to halophytes, but also have economic and phytoremediation importance. Therefore, the research of scientific team from the National University of Uzbekistan seems to be promising.

What is important for solving Aralkum's problems is that President Mirziyoyev and the government of the Republic of Uzbekistan have directed far more attention towards the Aral Sea Crisis than any previous one. Proposal of transformation the Aralkum into a zone of new ecological solutions was enacted by the UN General Assembly in 2021.

***Funding Statement*:** This article is based on the following project funded by the Agency for Innovative Development of the Republic of Uzbekistan: FL-8323102111-R1 on topic "Creating a scientific basis for grouping areas for planting plants according to the salinity, physical, chemical and biological properties of the soils distributed in the dry bottom of the Aral Sea".

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

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