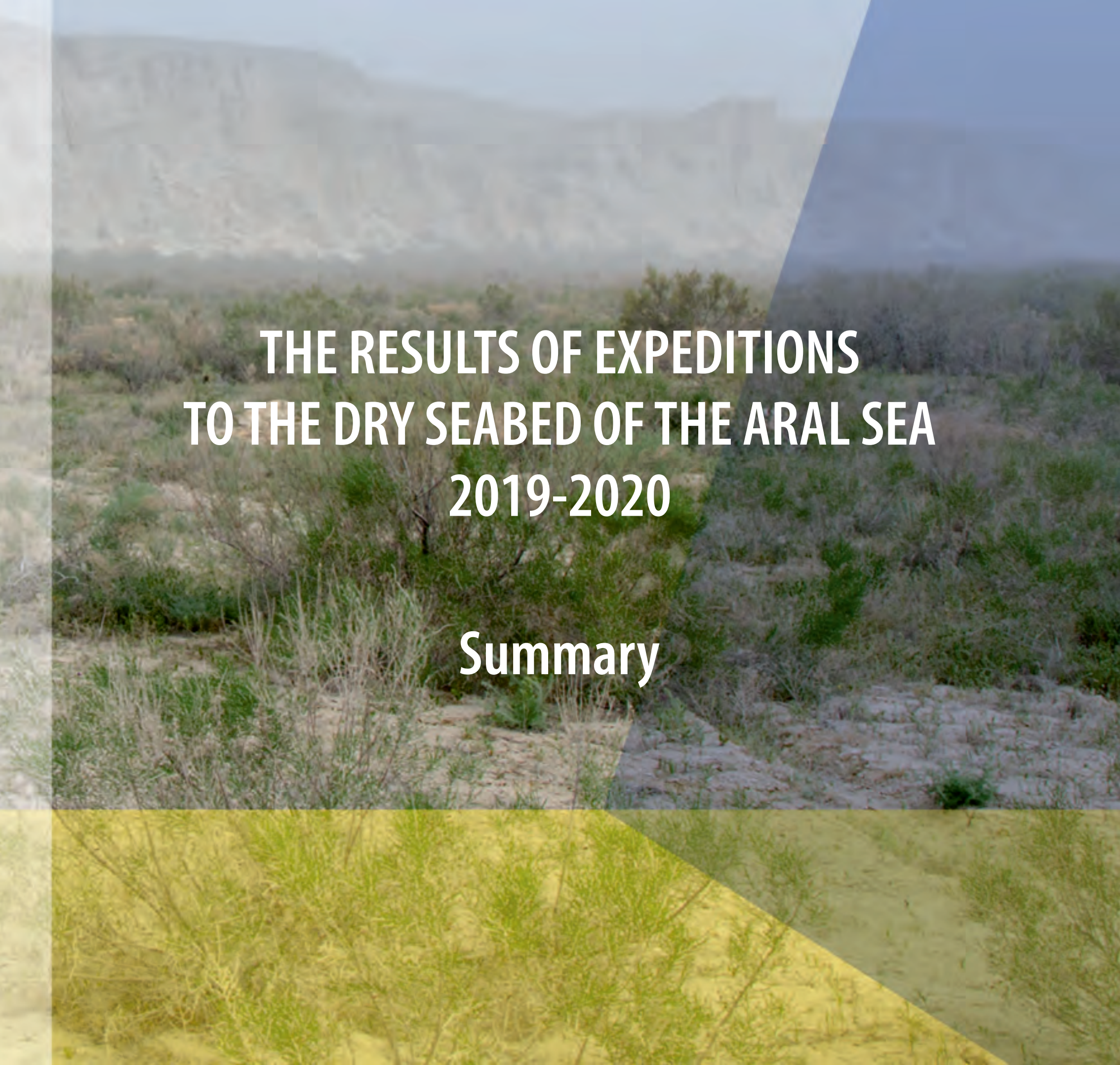
Ministry of Economic Development
and Poverty Reduction of the Republic of Uzbekistan

THE RESULTS OF EXPEDITIONS TO THE DRY SEABED OF THE ARAL SEA 2019-2020

Summary



United Nations Development Programme

Scientific-Information Center of the Interstate Coordination
Water Commission of Central Asia

The UNDP-UNESCO Joint Programme on

“Addressing the urgent human insecurities in the Aral Sea region through promoting sustainable rural development”

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THE RESULTS OF EXPEDITIONS TO THE DRY SEABED OF THE ARAL SEA 2019-2020

Summary of the book “Monitoring the Dried Seabed of the Aral Sea”

Tashkent 2020

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Introduction

The United Nations Development Programme (UNDP) held an online round table on “Results and conclusions of two expeditions to the drained bottom of the Aral Sea in 2019-2020” on 16 December 2020. These two expeditions were conducted within the framework of the joint UNDP and UNESCO project on “Addressing the urgent human insecurities in the Aral Sea region through promoting sustainable rural development”, as funded by the UN Multi-Partner Human Security Trust Fund for the Aral Sea region (MPHSTF) in Uzbekistan. The meeting was opened by UNDP Deputy Resident Representative in the Republic of Uzbekistan, Ms. Doina Munteanu, and the First Deputy Chairman of the Council of Ministers of the Republic of Karakalpakstan, Mr. Jusipbek Kazbekov.

Reports were presented by Professor Dukhovny V.A., Director of the Scientific-Information Center of the Interstate Commission for Water Coordination in Central Asia (SIC ICWC), Dr. Stulina G.V., Head of the expeditions, Dr. Sh.M. Kenjabaev, Deputy Director of SIC ICWC and head of remote sensing work, and by the expedition participants.

All activities which have been conducted on the dried seabed of the Aral Sea began on 11 January 1994, through the decision made by the heads of Central Asian countries to approve the "Programme on specific actions to improve the environmental situation in the Aral Sea basin over the next 3-5 years, taking into account the socioeconomic development of the region". Paragraph 4 of this programme stated:

"Carry out appropriate research and studies to select appropriate engineering solutions, and then ensure the drafting and implementation of works to create artificially watered landscape ecosystems on the territory of the Amudarya and Syrdarya deltas and adjacent areas of the dried Aral Sea bottom, conduct the necessary reclamation measures to restore the natural and historical environmental regime and rehabilitate these territories."

Accordingly, work was begun to ensure the sustainability of the Sudochie Lake. Following this a project on returning water to the whole Amudarya River delta was developed, which was estimated to cost US$90 million. To justify these costs, SIC ICWC with partners, and with the support of the European Union, carried out studies to assess the damage caused in Uzbekistan due to the decrease in the Aral Sea's sea level, and the related environmental and socio-economic losses. Direct losses in the Southern Aral Sea region, in financial terms, have amounted to US$144.83 million per year, including $58.68 million in agriculture losses and $40.6 million in industry losses. Indirect and social losses have amounted to $16.74 million and $28.81 million per year, respectively.

The government's decision to build a complex of water bodies in the Amudarya River delta at its own expense, prolonged the project's implementation for 15 years, and this work concluded only in 2020 after the intervention of the President Sh. M. Mirziyoyev, who initiated a programme to turn the dried seabed into a zone of ecological innovation.

BAll this time, since 2004, SIC ICWC has carried out satellite monitoring of the state of the delta's water, and has systematically published these results on its website. Considering the insufficiency of such assessment of the dried seabed's condition, joint expeditions to the sea bottom were initiated in 2005 with the financial support of the German Agency for Technical Cooperation (GTZ), lasting until 2011. In total 9 expeditions were carried out, covering more than 10,000 kilometres with 800 sites examined and 300 soil profiles studied. This work allowed for obtaining data on the delta's dynamic trends over seven years, on a number of matters. This research has included estimating vegetation on the area of 240,000 hectares with a 70 percent survival rate, detecting the self-overgrowing state of the seabed to an area of 200,000 hectares, creating a classification of landscapes by environmental risks, establishing patterns of development of soil-forming process on the dried seabed, and developing soil, hydrogeological and dendro-maps of the dried seabed on the territory of Uzbekistan.

Despite two Resolutions of the Cabinet of Ministers of Uzbekistan, these works recommenced only in 2019 after the establishment of the MPHSTF under the initiative of UNDP, which has included these two expeditions into its funding plan.

1. RESULTS OF STUDIES

SIC ICWC, with the participation of the International Innovation Center for the Aral Sea Region under the President of the Republic of Uzbekistan, as well as specialists from the Academy of Sciences of Uzbekistan and the Aral Sea expedition, organized two expeditions in the fall of 2019 and in late spring of 2020, and surveyed a total of 1.2 million hectares of the southern part of the delta twice over. This itinerary made it possible to cover the territory from the Ustyurt cliff to the former Akpetka archipelago, and to the historical edge of the sea.

These expeditions were integrated. The expedition team included an ecologist, soil scientist, hydrogeologist, dendrologist and botanist, and Geographic Information System (GIS) specialists.

The results of the two expeditions:

a) Unstable environmental zones on the dried seabed of the Aral Sea were identified, and risk zone maps were developed according to 17 risk classes.

b) Dynamics of soil-formation processes were investigated, assessment and classification of soils on the dried seabed were carried out, and a soil map was developed.

c) The hydrogeological situation and the state of the observation network were studied, and recommendations on this network's development were elaborated.

d) A geobotanical description of the vegetation was developed, an herbarium of plants was collected, and recommendations to preserve vegetation cover were prepared.

e) Scientific and field studies of forest plantations' conditions have been conducted based on the data collected. The previously discovered self-overgrowing has increased, covering an area of 160,000 hectares since 2010.

f) Thematic territorial GIS maps were developed through the use of GPS based on the method of retrospective analysis conducted using satellite images, while a methodology for remote directing of saxaul and tamarix growth was elaborated.

g) A comparison of changes in landscape classes and risk zones over the past 10 years was conducted.

The scientific value of monitoring can hardly be overestimated. Through such monitoring scientists have a unique opportunity to study processes that normally last for centuries, but now take place within a single generation in an accelerated manner.

> *The environmental assessment of dynamic trends taking place in water bodies of the Aral Sea, together with the soil-landscape changes in the drained part of the sea bottom, provides a scientific and practical basis for developing proposals for their use in new natural-anthropogenic conditions.*

1.1. Soil formation processes on the dried seabed

The process of the drying up of the Aral Sea has led to the formation of soil cover based on the exposed continental ground. This soil cover should be considered soil which differs from zonal types due to specific features, characterizing the dynamism of the development of soil formation processes over space and time. This allows the newly formed soil cover of the dried part of the Aral Sea bottom to undergo a century-long development cycle over a short period.

The evolution of saline soils (solonchaks) goes through several stages. At the final stages of soil development, alkaline processes caused by hydromorphic conditions slow down, and then the impact of the arid-zonal factor escalates many times, under the influence of which the further development of soils typically follows a desert pattern. The study of the dried seabed showed that the chain of the transformation of solonchaks results in the formation of desert-sandy soils. The parent rock of the modern soil formation on the dried bottom of the Aral Sea has marine, lacustrine, alluvial, and aeolian genesis.

During the expedition, 56 soil profiles were studied at typical selected sites. The expedition team developed descriptions of soils by genetic horizons with photos of soil profiles and collected soil samples. These samples were analysed to determine the chemical and physical properties of the soils, particularly their content of organic matter (humus), and the qualitative and quantitative composition of water-soluble salts, as well as gypsum and carbonates. Laboratory analyses were performed by the laboratory of the Analytical Center for Soil Quality, Composition and Repository, under the Committee on Land Resources, Geodesy, Cartography and State Cadaster.

Fifty soil contours were identified, and a GIS soil map of the territory of the drained bottom of the Aral Sea was developed in 2020, as a result of the performed field and laboratory works, as well as on the basis of the analysis of obtained results and satellite images (Fig. 1). The following types of coastal soils are distinguished, including hydromorphic solonchaks, semi-hydromorphic solonchaks, semi-automorphic solonchaks, automorphic solonchaks, desert sandy soils, deserted alluvial-meadow deltaic soils, and sands fixed to different degrees.

The soil cover on the dried bottom of the sea is an indicator of environmental stability (Fig. 2).

The colonization of solonchaks through artificial plantings or self-overgrowth reduces the ecological hazard, most significantly during the transition of solonchaks to desert-sandy soils.

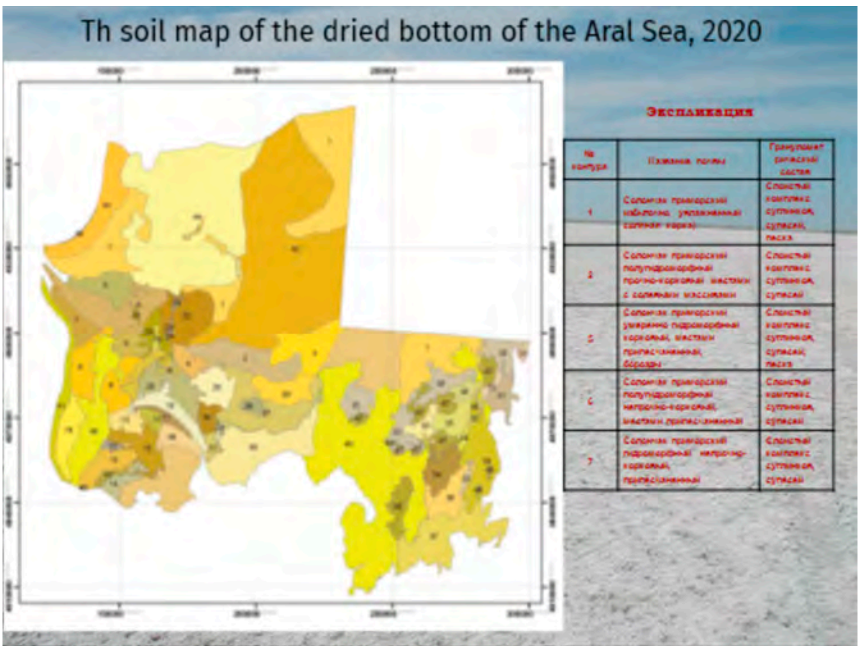

Fig. 1. Soil map, 2020

During the period of 1990 to 2020, there was a significant decrease in hydromorphic solonchaks by 15.1 percent due to the development of the process of aridization. This has correspondingly increased the automorphism of solonchaks, decreased the groundwater table, and contributed to the transition of hydromorphic soils to automorphic analogues, soil sanding-off and climatophytic soil formation. There is a formation of desert-sandy soils, and an increase in their area by 5.7 percent, which is a positive sign. An increase in the sand cover indicates an intensification of erosion processes on the dried-up seabed.

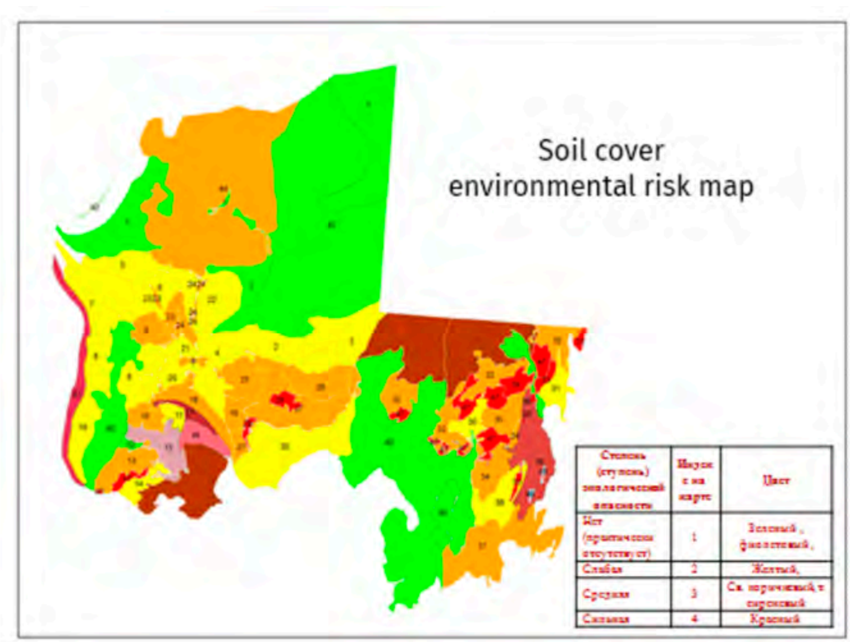

Fig. 2. Soil cover environmental risk map, 2020

1.2. Hydrogeological conditions of the dried seabed

An important task of the research was to study the current state of hydrogeological conditions of groundwater, forecasting these changes, and studying hydrogeological processes under the influence of natural and anthropogenic factors.

The objects of study are located in the basins of the left and right banks of the Lower Amudarya, specifically deposits of phreatic water, and confined groundwater of the Ustyurt and South Aral artesian basins. The zones and sites of the anthropogenic impact of groundwater on the dried part of the Aral Sea water area were also considered.

Hydrogeological conditions are characterised by the distribution of aquifers, namely the marine New Aral and the underlying alluvial-lacustrine Amudarya and marine Holocene deposits. These have a widespread distribution within the dried seabed.

The characterisation of the level and hydrochemical regimes of the groundwater of the Muynak part, located near the surface of aquifer complexes, has been carried out on two hydro-geological sites, specifically the Sudochie-Adjibay and Muynak, and in the second expedition on the Djiltyrbas part and the Akkala section line. Due to the draining of the sea and a drop in the groundwater level, these Muynak and Akkala section lines have been closed since 2010, and no observations are currently conducted there.

The groundwater regime in the Muynak part within the dried bottom of the Aral Sea is influenced both by a decrease of water levels in the sea, which is the regional hub for all water discharges, and by periodic discharges from the Sudochie Lake and Ribatskiy water body. In the northern direction, as it nears the modern sea level, the influence of discharges from the delta's reservoirs decreases and the regime of changes in the groundwater level (GWL) of northern wells is determined by the natural decline in the sea level.

The closest to the water's edge for 2017 is the Hydrochemical cluster (HCC) -801, at which the groundwater table is more dependent on the sea level. In 2009-2017, the groundwater level almost settled at the level of 7 metres with a salinity of 30 g/l, having decreased by 1 metre, that is, by 0.1 metre per year.

For further observations in 2019, the target section line was extended in a northerly direction. Fig. 3 shows the distribution of the ground water level in the new observation wells.

The problem of the interaction of the sea and ground water and its impact on ground water has been studied for many years. The search for an answer is complicated by the fact that this influence was very weak and could not be detected by existing research techniques and methods. Some groundwater backwater from the sea existed, but the flow was so negligible that it was impossible to measure.

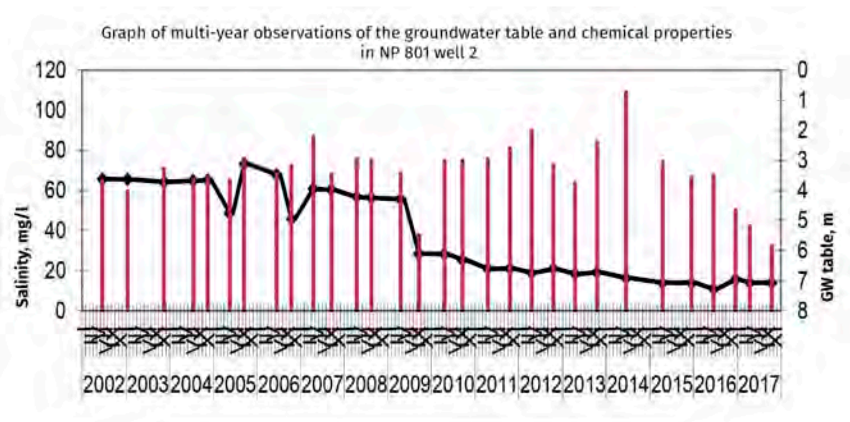

Fig. 3. Dynamics of the level and salinity of groundwater, at the Sudochie-Adjibay section along HCC-801 (2)

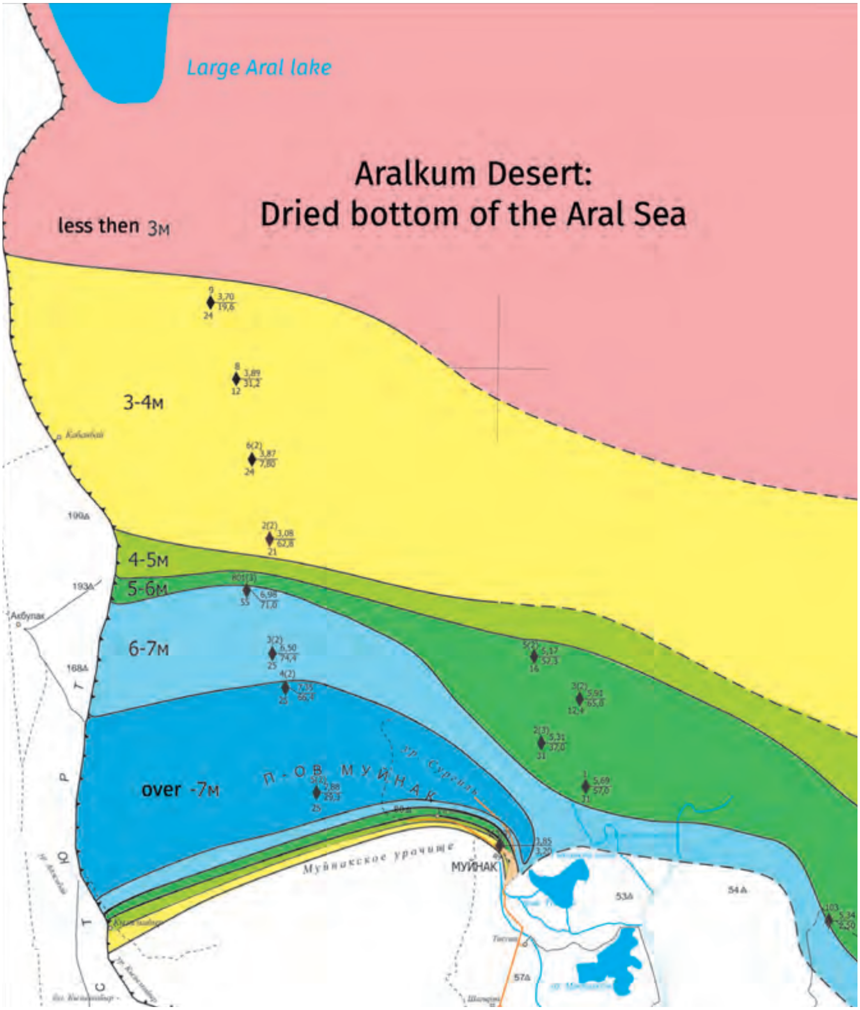

Fig. 4. Observation hydrogeological wells, of the Sudochie-Adjibay and Muynak sections - groundwater level in the Muynak part of the dried seabed, 2019

Long-term regime observations within the Muynak site, covering the dried seabed itself, as well as the dynamics of the GW regimes for wells located in the northern part of the site, partially indicate dependence on the ground flow coming from the Rybatsky Polder and the Amudarya riverbed, but mostly directly determined by the receding coastlines of the Aral Sea.

The Akkala section is located between the Aral-Kyzylkum swell and the Djiltyrbas Lake. At present, only four clusters were found out of the five observation sites during the expedition. The fourth, last cluster of the Akkala section is located on the former coastline of the sea, with an absolute elevation of 46 metres. The groundwater levels in them were within 5.79 metres, but it was dry in the last in a row well at a depth of 11.7 metres. The groundwater salinity is 33.6 g/l. Discharges from the Djiltyrbas Lake, collector-drainage networks (CN-1 and CN-3), and from the Kazakhdarya channel, affected the groundwater level regime, which showed a GWL growth and a decrease of salinity. In the

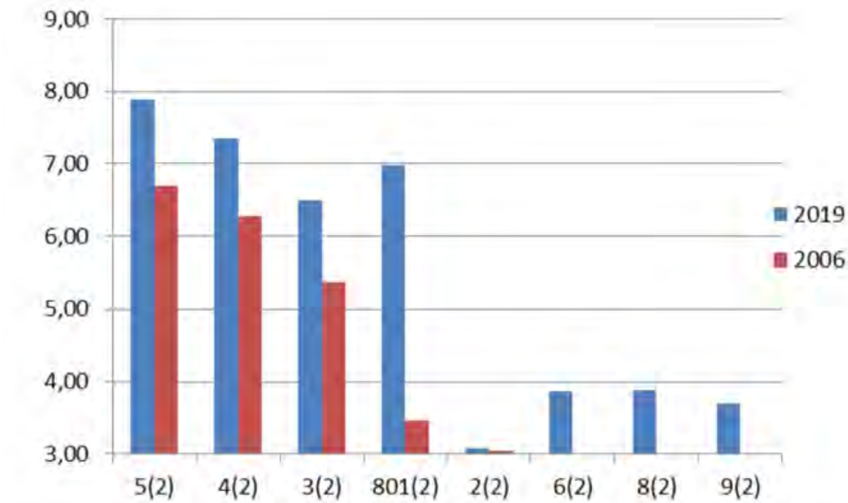

Fig. 5. Groundwater levels in the sections of the HCC, located adjacent to the water's edge

northern direction, as we move closer to the present-day sea level, the influence of discharges decreases and the regime of changes in the groundwater table is determined by a natural decrease in the sea level. In this regard, to study the level and hydrochemical regimes of groundwater, it would be desirable to lay the Akkala section, equipped with paired observation wells every 7-10 kilometres for both aquifers up to the Aral Sea.

The data obtained earlier (within the 'Aral Kum' project) proved that ground waters move towards the sea, but are discharged in the backwater zone adjacent to the sea level, and are represented by a strip with an average width of 250 metres. The observed runoff along the dried seabed almost completely evaporates into the atmosphere. The total value of the ground and pressure groundwater runoff was 4.67 m^3/s or 0.14 km^3/year, from the area under consideration. This represents a twofold in-

Fig. 6. Self-discharging well on the way to the Vozrojdenie Island

crease compared to that of 1960. According to the latest data, the discharge value is 0.12 km^3 per year.

The area between the Djiltyrbas Lake and the Kokdarya channel on the eastern border, and to the south the collector-drainage networks of CN-3 and Karauzyak, is very poorly studied in terms of its hydrogeological characteristics.

Covering the length of this area involved more than 70 km of off-road driving, through very difficult driving conditions, and requiring bypasses around loose sands, swamps, barchans and wet solonchaks.

There are no groundwater monitoring stations at the site. We surveyed four deep (up to 500 metres) self-discharging wells here. The wells are fed from the chalk aquifer, and are used for water supplies for livestock, forestry and shallow irrigation. Well flow rates are 0.2-4 l/s, while the water temperature is 40-45 ^oC, and the water salinity is within 1.7-2.5 g/l (quantity of salts in a litre of solution) with a hardness of 3.4-7.0 mg-eq/l.

In total 11 self-discharging wells were surveyed throughout the entire territory, over the course of the two expeditions.

Recommendations:

It is necessary to undertake an inventory tracking of all self-discharging wells, to determine their potential target use for free-range animal husbandry, forestry, medicine production, and other purposes.

1.3. Geobotanical research

At this time, one of the problematic issues related to Aralkum biodiversity is the natural formation of vegetation cover, which is of great scientific and practical interest to botanists, ecologists, and foresters. The need for a thorough study of the seabed is the result of the development of new natural complexes of plant communities, the structure, evolution and vital activity of plants, succession, and landscape changes. The formed land and processes occurring on it have indicated the need for a detailed study of the dynamics (migrations) of plants.

Halophilic species and communities are an indispensable component of the flora and vegetation of the desert zone, where increased salt content is typical for almost all types of soils. In the southern part of the dried seabed of the Aral Sea, almost all groups of halophytic communities are present. The purpose of these expeditions has been to determine the spring and summer species composition of higher plants of the south-eastern Aralkum, and to study the current state of the vegetation cover.

During the first expedition (2019), the vegetation cover on a number of large arrays of the south-western part of the dried bottom of the Aral Sea were investigated. These included “Tigroviy Hvost” (Tiger’s Tail), Akhantay, Uchsay, the Muynak cove, the vicinity of the Sarybas Lake, Lazarev Island along the perimeter of the Eastern Chink of Ustyurt, around “zero” area, and other areas. During the second expedition in 2020, the studied massifs of the dried south-eastern bottom of the Aral Sea included the vicinity of the Kazakhdarya settlements, from Djiltyrbas to Kokdarya, covering the Karateren and Kokdarya lands.

Seventy-four species of higher plants belonging to 51 genera, 21 families were identified on more than 2,060 spots of the dried bottom of the Aral Sea, as well as plant communities determined in almost all vegetation covers, as a result of the collection of herbarium samples, during the research work of the second expedition.

Analysis of the distribution of genera and species by family shows that six large families of *Chenopodiaceae, Tamaricaceae, Fabaceae, Polygonaceae, Poaceae* and *Brassicaceae* comprise 58 species. The remaining families comprise 16 species. The largest family of *Chenopodiaceae* includes 16 genera and 24 species. The results of laboratory studies of herbarium samples make it possible to conclude that the dominant species are mainly halophilous and some psammophilous plants from *Chenopodiaceae, Tamaricaceae, Fabaceae, Polygonaceae* and other related families, as they shape formations, associations and occupy a certain part of the dried area.

Dominant and subdominant vegetation species undoubtedly play a major role as fixers of blown barchan sands and solonchaks. These include *Haloxylon aphyllum* (Minkw.) *Iljin, Tamarix hispida* Willd., *Salsola richteri* Kar., *Ammodendron conollyi* Bunge ex Boiss., *Halostachys belangeriana* (Moq.) *Botsch., Phragmites australis* (Cav.) Trin. ex Steud., *Stipagrostis pennata* Trin., *Climacoptera lanata* (Pall.) Botsch., *Artemisia terrae-albae* Krasch., *Artemisia diffusa* Krasch, and others. As a result, one plant with decreasing range was identified to be protected, specifically *Atriplex pratovii* Sukhor (Fig. 7). The area of distribution of this plant has been expanded, after research has been conducted.

Fig. 7. Atriplex pratovii Sukhor

In the early years in waterless areas, plants were found to be solitary, or not at all. This is due to the fact that the soil layer in the first year of water release is very high. As a result of the research, it was confirmed that the vegetation on areas with saline soils occurs due to natural patterns that cause the replacement of halophilic plants by psammophilic plants (Table 1).

Table 1.

Migration groups	Brief description	Types of vegetation	Dominant and subdominant plants	Soil ratio
Migrating	This group is formed by a band of the first years of drying, arising after the retreat of the sea. The group continues to form in a progressive dynamic.	Halophilic annuals	*Salicornia europaea, Climacoptera lanata, C. aralensis, Suaeda crassifolia, Bassia hyssopifolia, Atriplex pratovii*	Solonchak (wet)
Expanding	This group is formed in the later stages of overgrowth of the dried seabed. Their distribution covers the direction from the native shore to the water's edge. The group continues to form in a progressive dynamic.	Halophilic and sammophilic shrubs and semi-shrubs	*Tamarix ramosissima, T. hispida, Halosta-chys belanger-iana, Salsola richteri, Haloxylon aphyl-lum, Calligonum eriopodum, C. ca-put-medusa, etc.*	Solonchak (crusty and puffy), saline sand

Migration groups	Brief description	Types of vegetation	Dominant and subdominant plants	Soil ratio
Stabilizing	This group forms off the coast of the native shores of the former sea, requiring a less saline soil. The group is forming in a progressive dynamic, but relatively slower than the previous ones.	Psammo-philous perennials and semi-shrubs	*Artemisia terrae-albae, Stipagrostis penna-ta, Carex physodes, Halimo-dendron haloden-dron, Astragalus am-moden-dron, Ammoden-dron conollyi, etc.*	Saline sand
Shrinking	A group of declining species that are common among hygro- and hydrophilic plants, growing next to shallow water and presentatives of meadow - Tugai flora. This is a group in regression.	Herbaceous marsh species, hygro- and hydrophilic annuals and perennials	Ceratop-hyllum de-mersum, Najas marina, Zostera minor, Phragm-ites austra-lis, Typha angus-tifolia	Wetland

In terms of economic value, forage plants predominate. There are 24 species, 10 species of sand and solonchak fixers, 9 species of essential oil and alkaloid plants, and 7 species of medicinal plants. Observations have identified the formation of phytogenic mounds and barchans, reaching an average height of 1.5 to 2-3 metres, and an average diameter of 1.5-3.7 metres. Each such phytogenic barchan contains an average of 15-20 tons of salt-mixed sand (topsoil).

Identified species can be used for fixing blown sands and solonchaks in phytoreclamation works, while there are also those that have fodder value, which can be used as pasture vegetation for livestock.

The practical significance of the results of this work, is that the approach for phytoreclamation work to cover the dried seabed of the Aral Sea with promising plant species (*Tamarix hispida, T. ramosissima, Halostachys belangeriana, Haloxylon aphyllum, Salsola dendroides, S. orientalis, Climacoptera aralensis, Nitraria schoberi, Lycium ruthenicum* and *Limonium otolepis*), in order to strengthen the blown sands and solonchaks, has been developed. The promising use of plants of this region as a resource base for developing the pharmaceutical industry of the republic has been revealed.

The consideration of the duration of the formation of flora of the Southern Aralkum has shown that the number of plants and the composition of taxonomic units is undoubtedly increasing. Based on observations made during the expeditions, it can be assumed that in a few hundred years the flora of the Southern Aralkum will come to a stable state, as in the neighbouring natural-geographical areas.

Recommendations:

- To use a number of plant species in phytoreclamation works on the dried bottom of the Aral Sea.
- To use the Aral Sea region plants as a natural source for extracting protein-peptide components with high biological activity, and, in the future, to create a new generation of medicines based on these components.

1.4. Phytomelioration work

Under the conditions of intensive desertification and a large freshwater deficit, phytoreclamation is an accessible and reliable, economically feasible and environmentally friendly measure to reduce albedo, the intensity of deflation and the aeolian transfer of saline dust, and to increase phytoproductivity of the dried part of the Aral Sea bottom and the deserted cone delta of the Amudarya.

Work on the establishment of forest plantations to fix blown sands on the dried bottom of the Aral Sea within the territory of Uzbekistan have been carried out since 1980.

> *To date, the planting area is 952,618 hectares, while an additional 50,903 hectares have been planted at the expense of donor funds.*

The main areas of the territory surveyed during two expeditions belong to the State Forest Fund of the Muynak Forestry Management, and the Kazakhdarya Forest-Hunting Ground. The artificial planting and sowing of forest crops has been carried out in the surveyed areas.

The condition of forest reclamation works on the south-eastern and south-western part of the dried Aral Sea bottom has been monitored.

The determining factors of forest site conditions is the moisture regime of the upper sand horizons, the ground water depth level, and the degree of water salinity.

A generalization of the results of the quantitative monitoring of the state of various tree crops, made based on daily expedition routes, has made it possible to determine the distribution of different species in the target area of each expedition. As can be seen from Table 2, the total vegetation coverage of the territory in the target area of the first expedition is 32 percent, while in the second it is more than 60 percent. This difference is determined by better watering in the second expedition area. At the same time, saxaul is prevalent in both zones.

Table 2.

№ Expedition	Vegetation coverage, expert assessment, %				
	Saxaul		Moisture-loving plants: rushes, reeds	Tamarix, karabarak	Furrows
	Totally	In good condition			
I	18,8	12,7	6,2	12,9	23,9
II	36,2	30,0	18,5	15,5	12,0

One of the reasons for the poor condition of plants, including saxaul, is the impact of plant diseases (powdery mildew) and pests (locusts).

Fig. 8. Locusts on the Akhantay array

Fig. 9. The powdery mildew disease

In 2019 about 1 million hectares were prepared for planting on the dried seabed, with intensive aerial seeding on 700 hectares.

To date, the seeds sown by An-2 aircraft over an area of 250,000 hectares have resulted in an uneven spread of shoots, with their average number being from 300 to 2,000 seedlings per hectare. According to the rules of forest plantation development in the desert zone, the forest area is considered to be successfully covered if there is a rate of 300 to 500 germinated seedlings per hectare.

Seeds were sown by hang-glider over an area of 3,000 hectares, in 'Akhantay', over gypsiferous and highly saline soils. At present no germinated seedlings have been detected, but there are seeds on the soil surface. According to scientists, saxaul seeds can keep their germinating capacity for 2 years.

The seedlings of tamarix and Halostachys belangeriana (karabarak) were planted on highly saline soils (solonchaks). The survival rate of the 10 indicated plants was 3-4 seedlings (30-35 percent), while for some seedlings the upper part was dry and the lower part was wet, which allows us to expect their further growth.

Saxaul seedlings were planted on the territory of 15,400 hectares, in sandy and moderately saline soils. At the same time, in some areas, on average, 5-8 seedlings (50-80 percent) out of every 10 seedlings have taken root, compared to 1-2 seedlings (10-20 percent) on highly saline soils.

Crop planting with the help of agricultural machinery on an area of 119,400 hectares resulted in 55-60 sprouts on 10 m^2 of sandy soils, and 15-25 sprouts on medium and weakly saline soils. There were no sprouts found on gypsiferous soils.

According to the results of the preliminary monitoring, the condition of seeds and seedlings of plants was assessed to be positive. In order to provide the disaster area with water suitable for livestock growth, as well as to establish conditions for reproduction of flora and fauna in the region, certain work has been done. To date water has been obtained from 41 wells, including 16 wells in the Aral Sea area, 17 wells in the Kazakdarya settlement of the Muynak region, and 8 wells in the Takhta-Kupyr region. The process of the drilling and reconstruction of 9 wells is coming to an end. Prepared wells are equipped with a crane control mechanism and are used for watering livestock.

In order to prevent the movement of sands, protective belts of reeds with a total area of 1,244 m^2 have been planted along 93.5 kilometres.

Conclusions and recommendations

- Methods of phytomelioration and forest-cultivation works in the target area were studied.
- Phytopathological and entomological conditions of the plantations were surveyed.
- Recommendations on improvement of seed production and the application of advanced technologies in sowing were prepared.
- It is proposed that an expedition be conducted to monitor the state of Tugai forests along the Amudarya River.

1.5. Environmental survey and risk classification

To gain a perspective on progress and the development of environment protection measures, it is very important to assess the landscape of the dried and drying seabed from the position of possible changes, the development of deflation processes, and dust and salt transport. Such assessments should be based on the classification of landscapes in relation to soil cover, the state of vegetation, and other factors.

A landscape by its nature is a highly non-equilibrium, changeable system, characterized by daily, annual and multi-year rhythms. The modern transformation of the natural environment in the Aral Sea region, which has a regional scale, is assessed as an anthropogenically-determined process of aridization. As noted above, environmental hazards are considered from the perspective of the hostility of the landscape to life, and the possibility of human economic activity. Ecological hazards appear not only in the momentary state of landscapes, but may also occur with any economic interference into the dynamics of their formation, as the landscapes of the dried seabed of the Aral Sea are currently in a very unstable (unbalanced) state. Therefore the assessment of environmental hazards is carried out, taking into account the dynamics of the processes occurring in the area, in accordance with the scheme given earlier[1].

Environmental hazards have been assessed based on the results of the two expeditions, taking into account the dynamics of ongoing processes in accordance with the distribution of classes, and according to the degree of instability of the dried seabed area of the Aral Sea. There are four levels of environmental hazards, including there being almost no environmental hazards, weak hazards, medium hazards, and strong hazards.

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1 Complex remote sensing and ground surveys of the dried bed of the Aral Sea. Edited by Prof. V.A. Dukhovny. - Tashkent: SIC ICWC, 2008. - – 190 p.

Both desertification and natural soil formation processes are emerging on the drained and drying seabed. The direction of these processes is determined by a complex combination of changes in groundwater levels, the formation of a new landscape, aeolian transfer, and the formation of new soils and vegetation cover. All these processes are interconnected.

It was determined that the vegetation cover of the dried seabed of the Aral Sea depends on the stable moistening of the dried seabed area. At the same time it also directly depends on the sustainability of water bodies moistening in the Southern Aral Sea region.

The results of environmental survey show a need to create a system of environmental control.

Table 3.

Environmental hazard classification scale

Degree (level) of environmental hazard	Index on the map	Distribution of classes according to the degree of territory instability
None (practically absent)	1	1.3 1.4 2.1 2.2 2.5 4.1 4.3 4.5
Low	2	1.1 1.2 3.5 4.2
Medium	3	2.3 3.4 4.4
High	4	2.4 3.1 3.2 3.3

The scale of ecological hazard is adopted according to the assessment of the development of destructive exogenous processes:

1. Practically no environmental hazard

1.1. The water surface.

2.1. Marsh solonchaks without vegetation or with saltwort communities, excessively hydromorphic.

2.2. Wet seaside solonchaks with barnacles, sometimes with isolated specimens of salsazan and sarsazan, hydromorphic.

2.5. Sulfide solonchaks of closed depressions without vegetation, sometimes framed by sarsazanites, hydromorphic and semi-hydromorphic.

4.1. Meadows on alluvial plains (reedy, mixed grass-cereals) on alluvial-meadow, swamp-meadow and meadow-swamp soils.

4.3. Brushwood (halophytic: tamarix, karabarak) on alluvial-meadow soils.

4.5. Shrubby saxaul (desert forests/artificial plantations) on desert-sandy soils.

Solonchaks are not dangerous, since most of the year they are in a hydromorphic regime.

There is no danger in the landscapes of lake plains periodically or constantly watered by river and collector-drainage waters, as they belong to the hydromorphic regime. In addition, vegetation is one of the main factors in determining the dynamic state of the landscape. Meadows on alluvial plains have a sufficiently high projective cover, and shrub thickets contribute to the fixation of shifting sands.

2. Low environmental hazard

1.2. Shallow water, sometimes with reeds.

3.5. Hilly, fixed hilly-ridgy sands with ephemeral-wormwood-shrub communities.

4.2. Alluvial-meadow soils under desertification, hydromorphic, with cereal-halophyte-grass communities with shrubs.

These classes are categorized as having a low ecological hazard, because their existence depends on the water inflow into the delta, specifically water availability during the year. For example, in low-water years the area of water surface decreases significantly, which in turn leads to the suppression of reed vegetation.

3. Medium environmental hazard

2.3. Crust-puffed and crust solonchaks without vegetation, sometimes with single specimens of shrubs (karabarak and tamarix).

3.4 Hilly and hilly-ridgy sands without vegetation and weakly fixed.

4.4 Desertifying meadow-alluvial soils covered with shrubby plants.

Surfaces without vegetation, sometimes with single specimens of shrubs (karabarak and tamarix) are one of the main suppliers of salt and dust to the atmosphere. Desertifying shrublands pose a danger in terms of vegetation degradation, which, in turn may lead to intensive development of aeolian processes. Hilly and hilly-ridgy sands, not fixed by vegetation, occupy significant areas of the dried bottom of the Aral Sea. The degree of projective coverage varies from 20 to 40 percent, which contributes to the development of aeolian processes. Therefore, the inter-barchan depressions are the main suppliers of salt and dust into the atmosphere.

4. High environmental hazards

2.4. Solonchaks with overblown sandy cover, with thinned communities of quinoa and selinum.

3.1. Plains (with shell rocks) without vegetation or with thinned shrubs cover (saxaul and tamarix).

3.2. Dunes without vegetation.

3.3. Shallow-hilly (weakly fixed) with thinned communities of wormwood, shrubs and selinum plantations.

These classes represent areas with intensive development of exogenous processes, and represent the highest degree of ecological hazard, specifically the formation of salt-dust-transfer hubs. A significant part of the territory is under an automorphic mode of development.

Conclusions and recommendations

- For different classes of landscapes related to medium and strong environmental hazards it is necessary to improve planting technology, considering different initial hydrogeological and soil conditions and accumulated experience, as well as to establish selective tracking of the dynamics of growth processes.
- Develop an action plan for organizing the planting of seedlings, and sowing seeds in accordance with risk maps.
- Organize regular monitoring for crop protection with the use of modern chemical and microbiological products, as well as biological methods of protection.
- Take measures to organize the control of the crops' state and prevent their damage, as well as the establishment of a fire safety system.
- Develop an action plan for pasture use, for the development of pasture livestock on the basis of a network of self-discharging wells and prepare a feasibility study.
- Develop a plan to monitor the performance of seedling planting, seeding and aerial seeding carried out in 2019-2020, and assess the state of new plantings on the dried seabed of the Aral Sea.

1.6. Satellite observation results

The expeditions were accompanied by a satellite study conducted by SIC ICWC, with the participation of the German company 'Map Tailor' (Dr. Low F.).

The main goals of remote sensing:

- Determination of the expedition route for setting GPS coordinates of ground measurements and field observations;

- Interpretation of Landsat 5 and 8 images to analyse changes in the landscapes of the dried Aral Sea bottom, from 2006 to 2019-2020.

The main objectives of the study:

- Development of two land cover maps, for 2006 and 2019-2020;

- Development of two environmental risk maps based on two maps of land cover;

- Based on these maps, quantifying the change in land cover and area at risk of erosion during 2006 and 2019-2020.

The method of retrospective analysis of satellite images and the development of thematic maps for the research territory consists of several consecutive steps:

(1) Preparation of the ground control data matrix;

(2) Pre-processing of satellite images from the Landsat-5 TM and Landsat-8 OLI series;

(3) Calibration of the classifier algorithm (Random forest) based on (1) and (2);

(4) Development of a map of land cover and an environmental risk zone for 2006 and 2019.

The presented maps of land cover show an intense water reduction in the eastern part of the Aral Sea. While shallow water covered the eastern part of the basin in 2006, this water almost completely receded in 2019, leaving behind a salt/solonchak desert consisting mostly of marsh and coastal solonchaks and other solonchak soils. The western part has fewer changes, but here a narrow strip of marsh and coastal solonchaks appeared in close proximity to the eastern shore of the West Sea.

Each category on the land cover maps can be translated into environmental hazard classes, in terms of wind erosion risk. This information is essential for understanding the spatial and temporal dynamics of areas at risk of erosion. Finally, this information is useful for identifying new sites for forest plantations, for instance places with the greatest risk of erosion.

Below are the environmental risk maps for 2006 and 2019, respectively. As can be seen from the maps, the forest plantations existing in 2006 were established in areas mostly characterized as being high ecological hazard zones, for instance "IV (High)" (Fig. 11, right). In 2019, their hazard status decreased significantly, mostly to the "II (Low)" category (Fig. 11, left).

The assessment of maps for the two different years allowed for quantifying the changes in the area of environmental danger. Table 4 summarizes changes in environmental hazard zones in 2006 and 2019. With the recession of the Aral Sea in the period from 2006 to 2019, a wide strip of land appeared on the outer border of the new coastline in 2019. In particular, saline soils have appeared, which greatly increase the environmental hazards in these areas. Therefore, the area of environmental hazard that characterizes Class I (none) decreased by 15,000 hectares during 2006-2019. In contrast, there was a partial improvement in the ecological situation (in terms of the risk of erosion) in the area to the south of the drained seabed, which has not been covered by water since 2006. This can be partly explained by the continued succession of plant growth and the emergence of shrubby plant communities. Consequently, the area of environmental hazard that characterizes class IV (high) has significantly decreased from 505,000 hectares in 2006 to 414,000 hectares in 2019.

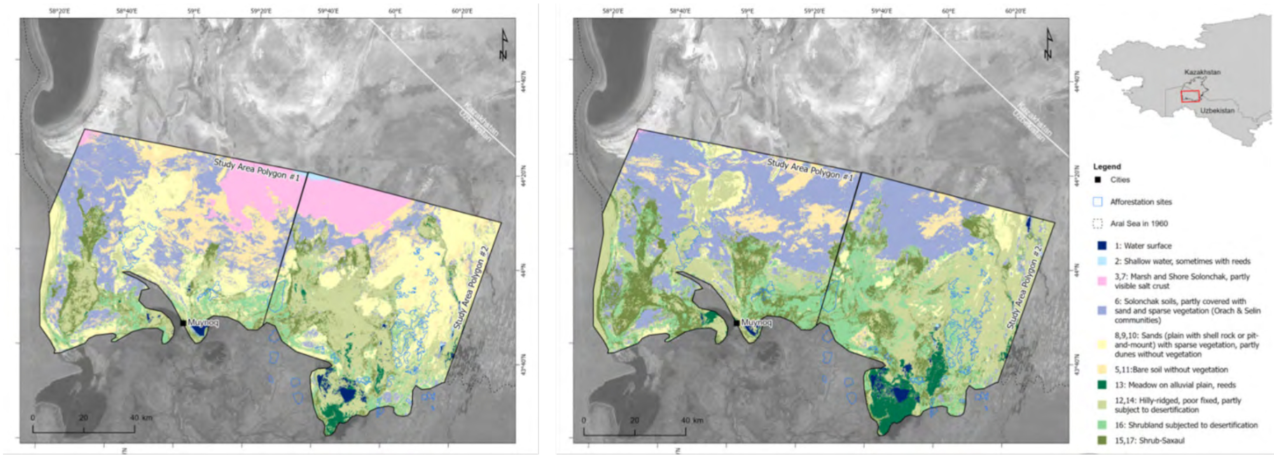

Fig. 10. Maps of land coverage (landscape) in 2006 (left) and 2019 (right)

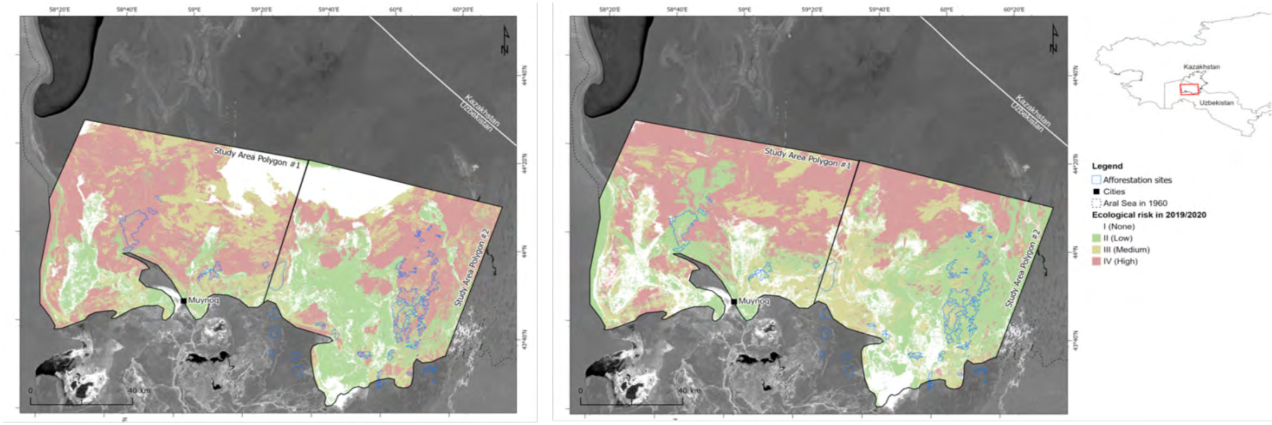

Fig. 11. Maps of environmental risk zones in 2006 (left) and 2019 (right)

It should be noted that a methodology based on observations of the Earth from space, and field measurements of the state of land cover in different years has been developed as the result of study. The proposed method is innovative in the sense that it improves the existing mapping strategies in the Aralkum, by using machine learning algorithms and satellite data at different times as input data.

In accordance with this methodology, land cover and associated environmental hazard maps have been compiled. This information can be used to spatially identify regions where measures to reduce wind erosion should be implemented, for example through the planting of shrub plantations (afforestation).

Table 4.

Summary table of areas studied in 2006 and 2019, by environmental hazard categories

Environmental Hazard Class	Description	Area (ha) in 2019	% of the technical study area in 2019	Area (ha) in 2006	% of the technical study area in 2006	Difference, 2019-2006
I	None	198053.2	15.85	213027.72	17.04	-14974.53
II	Low	373120.7	29.85	293795.93	23.51	79324.80
III	Medium	264523.7	21.16	238334.87	19.07	26188.83
IV	High	414140.5	33.14	504679.64	40.38	-90539.10
Total area:		1249838.16	100.00	1249838.16	100.00	

It is necessary to multiply this method so that it can be fully used for mapping the landscape and zones of ecological danger, both for other years and in general for the studies in the Uzbekistan part of the Aralkum Desert. To this end, it is proposed that the existing control data be supplemented with additional expeditions to the north-eastern, northern, and north-western parts of the Aralkum Desert, to gather spatially-balanced samples.

2. Main conclusions and recommendations of the study

1. Expeditions have confirmed the conclusions of past observations (2005-2009) regarding the development of three processes on the dried seabed:

- The seabed's draining and periodic fluctuations in the water level (including development of the soil formation process);
- Desertification process on the former seabed (aridization and aeolian deflation);
- Human impact:

  - Afforestation and fixation;
  - Damaging and disturbing topography.

Under these conditions the most important task is to stabilize landscapes, for which it is necessary to organize the management of the dried and drained seabed and the Aral Sea area by:

a) Afforestation of the areas under desertification, and protection control;

b) Making the former delta area, which is under the influence of river inflows and discharges from reservoirs, stable through the development of a sustainable water supply to the delta.

2. For this purpose, it is necessary to organize an obligatory water supply to the Samanbay River in volumes stipulated by ecological requirements (8 km^3 in years of average water availability, and 4 km^3 in low-water years), as well as the operation of water bodies in a year-round regime. For this purpose, it will be a great help to create a system for the automated control of water supply through the Amudarya River.

3. In order to provide a guaranteed water supply to the river delta and to maintain the hydromorphic component of the sus-

tainable development of the dried seabed, it is necessary to relocate a discharge of collector-drainage water of the Khorezm Oasis from the Daryalyk collector to the Amudarya River delta to the volume of 3 km^3, formed on the territory of Uzbekistan. These two projects should be considered a priority for the water supply of the drained bottom of the sea, and the Aral Sea region.

4. To create the additional opportunities needed in the region, and reflecting the ideas which arose during the expeditions, the following proposals should be considered:

- Organizing the constant monitoring of the state of water bodies of the Aral region, with the involvement of local youth. SIC ICWC submitted a project proposal to UNDP on establishing an exemplary procedure for the operation and maintenance of facilities. The project cost is US$500,000.
- Conducting an inventory of all wells and using this data for balneology and the development of pastures. There are more than 50 wells in total, half with hot and mineralized water. It is necessary to conduct analysis, determine the scope of practical application, and find necessary funding opportunities.
- Collecting and processing a rich range of medicinal plants, which can be a focus of public-private partnerships.
- Establishing oil and gas production and exploration sites, according to an agreement with the government. All wells after exploration or production must be brought to their original state through reclamation, which is currently not done anywhere. Developing a procedure for fulfilling the obligations of oil and gas companies to restore damage they have caused to the environment within 3 to 5 years.
- Organizing the use of existing abandoned buildings for tourism purposes, engaging voluntary NGOs and youth groups for this purpose.

5. To ensure the effective coordination of work in this area, as well as for systematic observation and making verified decisions, it is necessary to create a GIS platform on the drained seabed of the Aral Sea and the Aral Sea region. This platform will serve as a proven tool of the International Innovation Center of the Aral Sea Region, under the President of the Republic of Uzbekistan (IICAS), for the targeted introduction of innovations into practice at the regional level.

Two expeditions with remote sensing studies have covered 1.249 million hectares of dried seabed out of 2.7 million hectares on the territory of Uzbekistan. Expeditions revealed a certain decrease in the environmental risk rate at the targeted area, as well as the need to conduct expeditions to the north-eastern, northern and north-western parts of the study area. This will allow for obtaining a complete picture of the drained seabed on the territory of Uzbekistan and giving a working tool to all organizations responsible for managing the territory on a single cartographic basis, compared to the dynamics of a decade ago.

The completion of the dried seabed monitoring in 2021 and in the first half of 2022, based on the similar schedule from previous two expeditions, will allow for fulfilling the Government Decree's tasks in this part, and the creation of a reliable system-mapping document as the basis for the subsequent work of IICAS. In this regard we look forward to the support of international partners, primarily UNDP, the Ministry of Investment and Foreign Trade of the Republic of Uzbekistan, and the Ministry of Innovative Development of the Republic of Uzbekistan. The work carried out and the subsequent coverage of the entire drainage area will make it possible to create GIS maps of the dried seabed, which will serve as a cartographic basis for the implementation of the programme outlined by the President.

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