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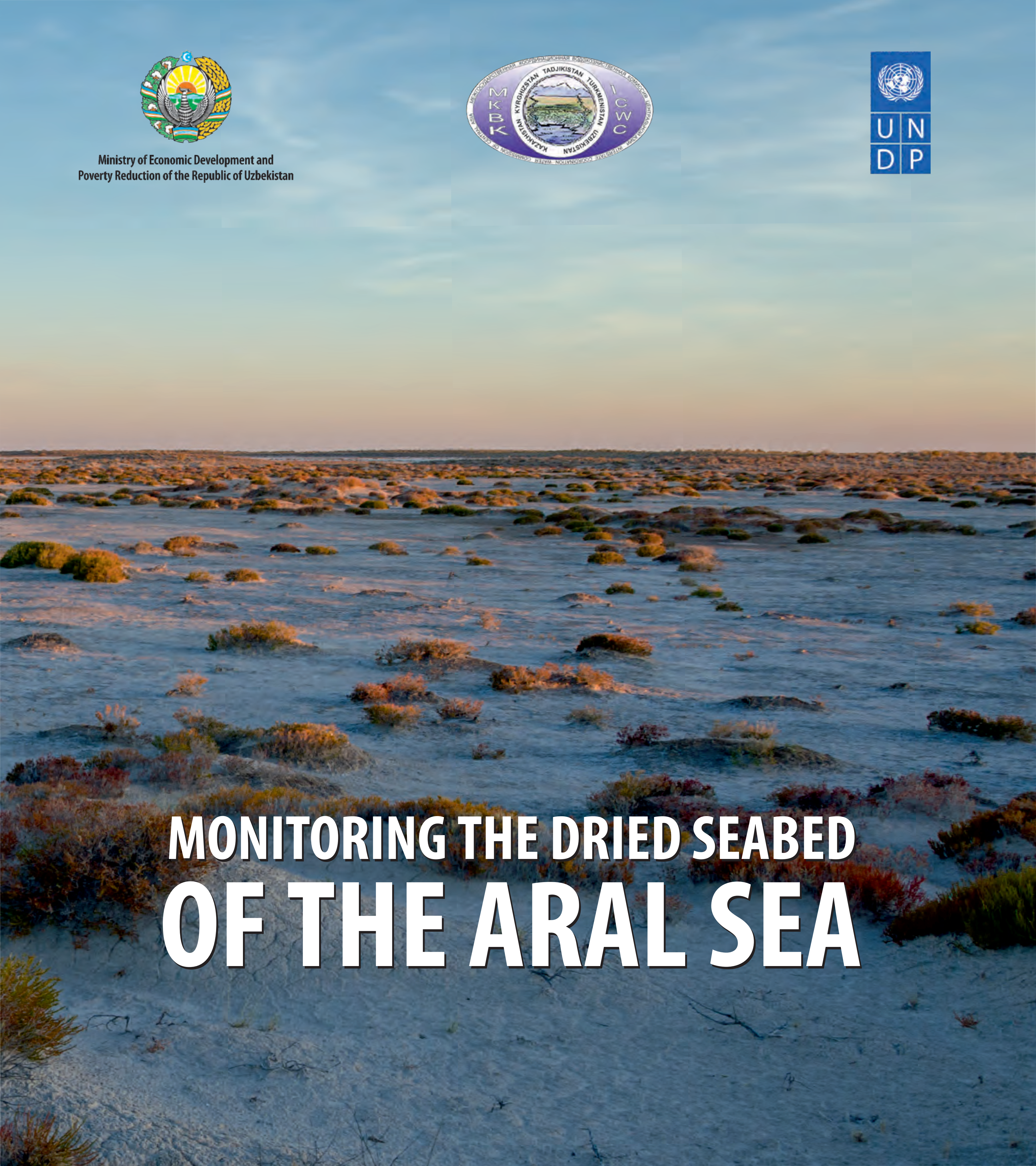

MONITORING THE DRIED SEABED OF THE ARAL SEA

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Funded by the UN Multi-Partner Human Security Trust Fund for the Aral Sea region (MPHSTF) in Uzbekistan

MONITORING THE DRIED SEABED OF THE ARAL SEA

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The authors of the book, researchers of the Aral Sea and the Aral Sea region, express their sincere gratitude to UNDP and the Ministry of Investment and Foreign Trade of the Republic of Uzbekistan for their organizational and financial support.

Introduction:
Towards a new destiny of the Aral Sea

(Embodying the idea of President of Uzbekistan Sh. M. Mirziyoyev to transform the dried seabed and the Aral Sea region into a zone of innovation and technology)

The tragedy of the Aral Sea is well known throughout the world as an example of humankind's destructive impact on nature. This has been the position of thousands of environmental activists in reference to the Aral Sea in our great country. Foreign critics of the Soviet state were particularly hypocritical in their condemnation, not noticing that all over the world, and notably in the Soviet state's main opponent, the United States, there are many examples of such destruction: The Mono Lake, the Salt Lake, the Colorado Delta and the Joaquin Delta.

The Aral Sea's ten-fold reduction in volume as the world's fourth-largest freshwater reservoir and the resulting formation of a new desert, the Aralkum, is a devastating example of the rapid degradation of nature caused by uncountable human activity to meet the needs of the rapidly growing regional population. It took only half a century to entirely eliminate a normal functioning body of water and for it to be replaced by a newly developed natural formation. Ironically, both the former Aral Sea bed and the Aral Sea region, forgotten and seemingly abandoned, have not turned into a lifeless desert. On the contrary, they have begun to form a combination of remnants and wetlands providing a new wildlife environment for animals, birds and salt tolerant drought-resistant tree species. Subsequently, the area also turned out to be a source of fossil fuel. The former boundless water space was suddenly abundant numerous exploration sites and liquid gold wells numbering over a hundred, attracting mining companies of many countries who came as hunters for this raw material. Previous to the arrival of the mining companies, the remaining local residents around the Aral Sea were engaged in fishing and fur farming on the marine reservoirs. Livestock breeders of camels and small cattle grazing on pastures of the former shores of the sea transformed the space. Herds of gazelles and kulans, as well as wild boar and wolves, migrated along the Amudarya River in the vicinity of the densely populated Bukhara and Khorezm oases and the semi-desert of northern Karakalpakstan, and the hunters soon followed. More importantly scientific researchers soon arrived and took their own initiatives, perhaps insufficiently due to minimal finances available at the time, but they took control of the processes taking place in this huge transforming territory. Representatives of nature protection, water management, hydrogeological and dendrological organizations worked together with the researchers. Each expertise attempted to help nature survive by drilling water wells for pastures, creating a system of small reservoirs and wetlands, and finally, by planting drought-resistant plants. Saxaul groves, as well as thickets of tamarix, halostachys and other drought-resistant species appeared on the drained seabed, transforming the desert.

From 2005 to 2011 a total of nine exhibitions were conducted to the region. These included a ground expedition survey organized by GTZ and the Federal Ministry for Economic Cooperation and Development (BMZ) together with SIC ICWC. Their findings revealed that as of 2008, 240,000 hectares of trees planted by Karakalpak forestry with donor assistance, but mainly at budget expense, had survived. During this time, it was evident that near and around a once dry seabed were now two hundred thousand hectares of self-overgrowing. Nature was protecting itself!

However, until 2018, the focus of work in the Aral Sea region had concentrated only on mining and maintaining the inadequate local initiatives of the surviving population. The locals of the area, composed mostly of local Karakalpaks and a few Russians, believed that a new era would dawn.

This period came with the arrival of Shavkat Miromonovich Mirziyoyev as the leader of the Republic of Uzbekistan. During his time as Prime Minister of Uzbekistan he had received UN Secretary-General Ban Ki-moon in Muynak, where he promised the population that the region would be transformed. Later when he became President, he did not forget his promises, and in his first speech at the 72nd session of the United Nations General Assembly on 19 September 2017 he said, “Overcoming the consequences of the drying sea now requires a vigorous consolidation of international efforts.” The effects of this were soon apparent. Addressing the meeting of the Heads of State in Turkmenbashi in August 2018, President of Uzbekistan Sh. Mirziyoyey proposed his initiative to the founders of the International Fund for Saving the Aral Sea to declare the region a zone of environmental innovations and technologies. The government of Uzbekistan and the UN agreed on a draft special resolution of the UN General Assembly and followed up with the President’s proposal. ‘The Aral Region - Zone of Environmental Innovations and Technologies’ project was reviewed at the high-level international conference held in Nukus on 25 October 2019. UN Secretary-General António Guterres sent a video message to the conference and noted that despite the loss of the sea and numerous negative consequences for the livelihood and health of people, that through the joint efforts of the Government of Uzbekistan and the international community, the situation can be improved. A very important step in the practical implementation of the President’s initiative was the establishment of the Multi-Partner Human Security Trust Fund for the Aral Sea region (MPHSTF) during a special high-level meeting held on 27 November 2018 at the UN Headquarters in New York. The goals and directions of the foundation aimed to catalyse and strengthen multisectoral and people-centred responses to one of the largest man-made disasters in the world, by being transformative, needs-based, human rights-based and inclusive in its purpose. The MPHSTF provides a coherent strategy for coordinating aid flows and increasing government leadership of the assistance process to achieve sustainable results. The foundation’s strategies address six clusters of interrelated problems:

a) *Environmental safety*
b) *Economic security*
c) *Food security*
d) *Health security*
e) *Social security*
f) *Inefficiency of donor assistance*

Along with this the Government of Uzbekistan developed and approved on 16 November 2018, by Resolution No. 965f, a roadmap for measures to implement the President’s instructions. One of the first activities under this programme was the substantial development of measures on the afforestation of the drained seabed to sustain the landscape and as a new climate change approach.

In 2018, the government of Uzbekistan launched a large-scale tree-planting campaign on the dried bottom of the Aral Sea to improve the ecological and socio-economic situation in the region. Significant numbers of both civilians and military personnel were involved, making it possible to cover an area of almost a million hectares in two years. Planting was carried out using airplane aerial seeding. Although the landscaping work was done mainly at the expense of the national budget, some contribution was made by UN organizations. Within the framework of the joint project 'Solving Urgent Problems of Human Security in the Aral Sea Region by Promoting Sustainable Rural Development', UNDP and UNESCO worked to strengthen the technical and institutional capacity of the state forestry body in Karakalpakstan. Special agricultural equipment and mobile wagons provided by UNDP and UNESCO were delivered to forestry enterprises growing saxaul on the arid bottom of the Aral Sea, and they were also used to create nurseries for growing more seedlings and further sowing in the surrounding area of the regional forestry body.

In addition, the project aims to strengthen evidence-based approaches and introduce international practices of effective afforestation methods.

In 2020, a series of trainings for 100 specialists of the Committee on Forestry were organized within the project and the Ministry of Innovative Development was actively involved in the roadmap's realisation. On 16 October 2018, the President of the Republic of Uzbekistan signed Decree No. PP-3975 on the establishment of the International Innovation Center for the Aral Sea Region (IICAS). The main tasks and priorities of the IICAS were defined as follows:

- *Improvement of ecosystem and sustainable livelihoods in the saline lands of the dried seabed of the Aral Sea;*
- *Conducting work on cooperation with international organizations to develop and implement innovations and solutions to a variety of problems in saline environments;*
- *Establishment of experimental fields for trails;*
- *Identification, promotion and transfer of innovative technologies and approaches, including agroforestry, afforestation, aquaculture, bioenergy, crop diversification, integrated cropping, animal husbandry, pasture improvement, drought management and mitigation, adaptation to climate change, and;*
- *Development of public-private partnership in the field of overcoming the consequences of the drying up of the Aral Sea and the ecological rehabilitation of the Aral Sea basin.*

Funding from the UNDP Multi-Partner Trust Fund, provided during 2019 and 2020, contributed to the great achievements made during the initial stage of monitoring the drained seabed. The decision of the government to resume the monitoring work was made at the insistent request and justification by SIC ICWC back in 2015. In 2017 a subsequent request was made and included a specified source of funding, specifically the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), later the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). During the extensive negotiations between the Government of the Republic of Uzbekistan and the Ministry of Foreign Affairs of the Federal Republic of Germany, monitoring did not take place. However, under the initiative of President Sh. Mirziyoyev and the establishment of the UN Foundation, it was then possible to begin this particularly important work.

The monitoring of the dried seabed involved a number of tasks that were determined by both the new period of development work initiated by the President and by an assessment of the dynamic changes in natural conditions that had occurred in this area since the last expedition in 2011. This list included:

a) *Determination of the conditions and the size of the drained area;*
b) *Approximate classification of the landscape on the newly drained area with the use of satellite monitoring;*
c) *Assessment of the landscape, soils, hydrogeological conditions, fauna and flora of the whole dried area;*
d) *The state of vegetation, especially of artificial plantations;*
e) *Scale of desertification processes and changes in landscape classes and risk zones in comparison with the state of previous monitoring of 2005-2011, and;*
f) *Development of recommendations to improve the ecological condition and productive use of the dried and developed territories.*

The first two expeditions of this project were conducted during two months of fieldwork, in October 2019 and May-June 2020 respectively. After eight months of field data processing, two consecutive detailed research reports were prepared covering an area of 1.2 million hectares of 2.7 million hectares of the completely drained seabed. (See the attached detailed cartographic materials included in this publication.)

The conducted expeditions were a small part of the large, complex measures implemented under President Sh. Mirziyoyev's initiative and will serve as a compass for future development.

In recent years, thanks to the consolidation of efforts of the government and international institutions, large-scale construction has been launched in the Aral Sea region, new jobs are being created and infrastructure is being developed. The concept 'The Aral Region - Zone of Environmental Innovations and Technologies' has been successfully prepared and is currently at the final stage of approval.

The construction of a multi-million dollar water supply complex for this area is nearing completion, being one of the elements of the renovation of the ancient South Aral Sea area.

The authors are confident that the work carried out and the subsequent coverage of the entire area of the drying seabed will provide a basis for a programme of rational nature management on the entire territory of the former seabed and the Aral Sea area.

1 A brief overview of research work on the drained bottom of the Aral Sea and similar projects

The drought of 1974-1975 sharply affected Central Asia, causing a depressed water inflow into the Aral Sea. The situation alerted Soviet scientists to the need for the sea's future conservation, and consequently two commissions on water supply were organized in the region. As of 1974 the Commission of the State Committee on Science and Technology was headed by academician Gerasimov I.P. and in 1975 the USSR Council of Ministers was chaired by the First Deputy Chairman of the USSR State Construction Committee, Borovoy K.K. The commissions were faced with two problems, firstly how to meet the water needs of Central Asia's rapidly growing population and economy, and secondly how to preserve the Aral Sea.

Gerasimov I.P, as the head of the Institute of Geography of the USSR Academy of Sciences, was a pioneer in the development of scientific works on the Aral Sea, and immediately organized expeditions comprised of outstanding geographers and environmental scientists. Kuznetsov N.T., Gorodetskaya M.E., and Kes A.I. (1980) were to clarify the regime of water content and of the entire basin. Gorodetskaya M.E. and Kes A.I. were responsible for studying the economic and geographical potential in the dynamics of the sea's transformation (1986). Kurochkina L.Ya and Kuznetsova N.T. were assigned to assess the ecological condition of the sea and its conservation potential.

Somewhat later, Zaletaev V.S., Novikova N.M. and Kuks V.I., of the same institute studied the gradual drainage, the state of the seabed and carried out mapping and zoning the territory of the drained seabed as of 1990 (1992). In the same year, Bortnik V.N., Kuksa V.I. and Tsitsyarin A.G. published a forecast of the decline in sea level up to 2015.

During this same time in 1980, scientists from the Laboratory of Salt Water Hydrobiology of the Institute of Zoology of the USSR Academy of Sciences, Plotnikov I.S., Aladin N.V. and Filippov A.A., began a long-term study of the sea's changing fauna and flora. They observed the complete disappearance of freshwater biota and the transformation of the sea into a saline body of water with a completely changed character of animal life. To date, the institute continues its research, now in freshwater and mainly in the northern region of the Aral Sea, the so-called Small (or Northern) Sea.

It should be noted that the work of the Moscow Institute of Oceanology (Zavyalov P.S.) on the study of the hydrology of the separated reservoirs of the Aral Sea was started later. In 1965, the regularities of the formation of underground waters of the lower reaches of the Amudarya River were studied from the prospective of hydrogeological justification of irrigation and drainage measures and their relationship with surface waters and the Aral Sea. The report and several maps (water table, depths of hydroisohypses deposition, groundwater surface, schematic map of hydrogeological and reclamation zoning of the Amudarya River's lower reaches at 1:200,000 scale) were prepared. Since 1971, systematic research of bottom, coastal (including a new dry area) and deltaic sediments were started by numerous research and production organizations of Uzbekistan (RSU - Reznikov S.A., Khrustalev Y.I., Vronsky V.A., GN and AS USSR - Turovsky D.S., Institute of Geology and Geophysics AS Uzbek SSR - Rubanov I.V., Ishniyazov D.P., Baskova M.A. and others).

In 1981, Rafikov A.A. and Tetyukhin G.F. published the monograph 'Decrease of the Aral Sea Level and Changes in Natural Conditions of the Amudarya Lower Reaches' and described the radical transformation of geo-ecosystems and the desertification of the Aral Sea region based on field and camera work of the Aral Sea expedition by the Geography Department of the AS of the Uzbek SSR for the period of 1977-1979. The monograph depicted symptoms of arid tendency in the development of eco- and geo-systems, decrease of groundwater levels, increase of their degree of salinity, salt accumulation in the root layer of soil, drainage of the lake-marsh and degradation of riparian sites, strengthening of wind-erosion processes, and the formation of aeolian forms of landscapes. In 1982-1988, hydrogeological studies were carried out to substantiate the forecast of changes in the hydrogeological conditions of the area in connection with the lowering level of the Aral Sea. The boundary conditions of the artesian basin in the South Aral Sea region (ABSA) were studied, including their quantitative assessment, and new data were collected of the geological structure and hydrogeological features of the Aral-Kyzylkum rampart. The area of groundwater discharge of the artesian basin in the South Aral Sea region was studied to identify the regularities of groundwater formation and to calculate their current balance, in order to forecast changes in hydrodynamic conditions.

The area of groundwater discharge of the artesian basin in the southern part of the Aral Sea region was studied to identify the regularities of groundwater formation and calculate their current balance and enabled forecast changes in hydrodynamic conditions. During these studies, a permanent hydrogeological model of the ABSA was developed based on data obtained and characterised from the ecological situation of the dried bottom of the sea.

Since 1976, many teams in Uzbekistan have been involved in research on the Aral Sea problem. Ishankulov M.S. and Vukhrer V.V. (Institute of Botany, Academy of Sciences of the Uzbek SSR) organized a detailed complex, ecological research project on the sea's eastern coast. During the same period, large-scale soil studies were carried out by the Institute of Soil Science of the Academy of Sciences of the Uzbek SSR by Prof. Sattarov D.S., Sektimenko V.E. and Popov V.G. They summarized the results of their work in the monograph 'Condition of the Soil Cover of the Aral Region in the Context of Draining the Aral Sea' published in 1993.

Comprehensive ecological, hydrogeological and engineering geological surveys (research and mapping) of 1:200,000 scale were conducted in 1989-1999 for the dried part of the Aral Sea bed and the adjacent territory within the limits of the following index charts: K-40-V, VI, K-41-I and L-40-XXXV, XXXVI, and L-41-XXXI. Within those surveys, qualitative and quantitative characteristics of modern geological processes were developed, the intensity and direction of their development were revealed, and centres of salt and dust drift were mapped. The main hydrogeological parameters of aquifers and complexes, pollution of soils, surface and ground water and vegetation with toxic microelements and heavy metals were also determined. The environmental and hydrogeological state of the territory was assessed and a set of maps (1:200,000) and an ecological-hydrogeological map of the dried bed of the Aral Sea was drawn up.

At that time, the first calculations of the volume of salts removed from the drained bottom of the Aral Sea and the negative consequences to the ecology of the Aral Sea region were made.

From 1986 to 1992, the first geo-ecological studies (1:50,000) were initiated on the left bank of the Amudarya River between the Ustyurt Plateau cliff and the old Amudarya River channel in the south and the Muynak Peninsula in the north, known as the modern Aral Sea shoreline. The current state of geological-hydrogeological and environmental conditions, hydrochemical and hydrodynamic conditions of groundwater of the first aquifer from the ground surface, as well as geomorphology, structure and structure of marine deposits were studied. As a result of the executed works, the following basic estimated parameters have been studied:

- Depth of groundwater table and groundwater heads;
- Thickness of aquifers;
- Hydrogeological parameters, and;
- Water quality, and contaminants in soil and groundwater affecting the environment.

Qualitative and quantitative characteristics of modern geological processes were given, the intensity and direction of their development were revealed, and the allocation of salt and dust drift were mapped. An ecological and hydrogeological map of the dried bed of the Aral Sea was drawn up.

The first calculations of the volume of salts carried out from the dried bottom of the Aral Sea and their negative impact on the ecology of the Aral Sea region were determined. The main hydrogeological parameters of aquifers and sites, being the pollution of soils, surfaces, groundwater and vegetation with toxic microelements and heavy metals, were identified. The environmental and hydrogeological state of the territory was assessed. A set of maps (1:50,000) was compiled.

In 1970-1980, in order to study the influence of the Aral Sea's drop in level and its influence on the depth of the groundwater table and salinity in the dried part of the Aral Sea, regional stream gauges were established at Muynak, Akkala, Aral-Buzgul and Sudochie-Adjibay. The gauges crossed all geomorphological areas and man-made complexes to the zone of regional groundwater discharge (South Aral Depression). However, the observation stream gauges' sites could not provide a consistent area characteristic in the regional changes in the dynamics of levels and chemical composition of groundwater.

Ratkovsky S.P. made the first attempt to provide a typological characterisation of forest site conditions and identified five groups of sand types in Central Asia. However, Ratkovsky's typological scheme does not reflect all types of forest site conditions in the sand deserts of Central Asia but is often the most widely referenced. Petrov M.P. proposed a comprehensive classification of sandy deserts by forest-steppe types, which considers the ratio of the 10 most important habitat factors. Studies of Kabulov S.K. (Changes in Phytocenosis of Deserts under Aridization (the Aral Sea region case), Tashkent, 'Fan', 1990) have shown that in the process of aridization of dried sea bays, a natural change of phytocoenosis takes place, which is expressed in changes in species composition, number and other bioparameters of a valuable population. The leading factors of their change are fluctuations in moisture and salinity of soils. The fundamental works of academician Babayev A.G. on consolidation of the Karakum desert sands, specifically the method of sowing in the strips formed by reed fences on moving sands, had a great influence on afforestation measures on the dried seabed.

The post-independence period for Uzbekistan and Kazakhstan meant a period of sharp decline in the work in the Aral Sea area due to the poor interest and simultaneous worsening of the economic potential of both republics. Nevertheless, the decisions of the Central Asian governments and the Board of the International Fund for Saving the Aral Sea outlined measures to strengthen co-operation on rational and economical water use among the basin countries. The measures have only been implemented partially and the decline in sea level has continued at an accelerated rate despite the forecasts and the Board's decisions. Construction of the first pioneer facility on the dried seabed was carried out in 1995-1997. It was undertaken in order to establish conditions for sustainable water supply and the improvement of Sudochie Lake conditions. However the development of most pioneer facilities occurred mainly in Kazakhstan and Uzbekistan, and was only partially completed.

In 2004, SIC ICWC prepared and submitted a feasibility study with a budget of 90 million USD to the Government of the Republic of Uzbekistan to analyse the system on sustainable watering of the entire Amudarya Delta by 2004. In order to save money, the 'Sredazgiprovodkhlopok' project for establishing small water reservoirs was presented as an alternative option. Its implementation was postponed for the next 15 years, destabilising the water supply to the delta, and was resumed only when Sh. Mirziyoyev came to power.

From 2000-2003, SIC ICWC carried out an economic assessment of the socio-economic damage of the Aral Sea on both the southern and northern sides due to a sea level decrease and the productivity loss of the sea itself and the Aral Sea region.

The results were reflected in two monographs, including 'Assessment of Socio-Economic Consequences of Ecological Disaster - Drying up of the Aral Sea' (2001) and 'Economic Assessment of Local and Joint Measures to Reduce Socio-Economic Damage in the Aral Sea Area' (2004).

From 1991 to 2005 there were practically no serious measures that would allow for the assessment of landscape degradation and transformation of the natural and economic complex of the Aral Sea and its region. In less than a few decades the world's fourth-largest freshwater body had disappeared and turned into a desert, processes that in other global contexts would have taken centuries. It is a shame that these transformations have occurred amongst a civilised society with an available scientific capacity, but due to the challenges of their own survival, an oversight and analysis of the rapid changes in nature and society were missed opportunities. Simultaneously, there were diverse surface modifications of the dried seabed developing in both positive and negative ways, and conditioned by natural changes such as the moisture level due to precipitation and groundwater, and by human activity.

As the leading research organization in the Aral Sea basin, SIC ICWC could not ignore these processes and constantly sought partners interested in this research. Therefore, the proposal of GTZ on collaborative study was accepted with understandable enthusiasm. German scientists brought a new element to the project with their use of remote-space methods of assessing landscape changes, which SIC ICWC had very limited experience with and even less technical and financial capabilities. As a result, SIC ICWC enthusiastically partnered with the German scientists who conducted the remote assessment while SIC ICWC undertook ground assessments. Between 2005 and 2011, nine expeditions were conducted on the dried seabed, which made it possible to create ground monitoring in parallel with satellite observations.

Multidisciplinary specialists conducted unique and complex research that identified the nature and direction of changes in soils, hydrogeology, landscape and soil formation features on the parent rocks in the drainage zone. The degradation of the newly formed landscape and the emergence of ecological risk zones of desertification were also studied. Particular attention was paid to the development and condition of forest plantations of drought-resistant tree species. It was discovered that of all forest plantations in the bottom of the sea totalling 338,800 hectares (according to the Forestry Department of Karakalpakstan), 240,000 hectares or 70.8 percent were preserved plantations. Remarkably the expeditions' surveyed territory revealed the existence of 233,000 hectares of self-overgrowing area. During these works, 17 landscape classes were identified and the prospects of their transformation from one classification to another were determined. Based on these results, the estimated degradation and erosion risk areas were documented.

'Comprehensive Remote and Surface Studies of the drainage of the Aral Sea bed' was a study published by SIC ICWC in 2008 that contains a detailed analysis of the sea dynamics based on both literary sources and satellite images before 2007.

1.1. The experience of developing deserts

Throughout the world, deserts are multiplying. The focus on ecological sustainability is common among countries with arid climates, and many undertake the same afforestation measures with similar species as those of the Aral Sea region. Typically afforestation is undertaken by a majority of the population living in these areas, as it creates the basis for the development of pasture-based livestock, landscaping and improvement of climatic conditions, and in particular the reduction of wind activity. Examples of large-scale works in this direction can be seen in Israel (Negev Desert), China (Gobi Desert) and in Libya (Libyan Desert).

Israel is undoubtedly a pioneer in the development of deserts. Since 1978, the Arava Desert has been home to the renowned Sde Boqer Desert Development Center, and Israel reached significant achievements in the Negev Desert where tens of thousands of hectares have been reclaimed with the development of greenhouses. Desert irrigation was initiated by the mandatory development of infrastructure including roads, communication lines and power lines (previously applied in the Arava Desert). The greenhouses use sewage water piped in from the Tel Aviv wastewater treatment plants and saline groundwater from the desert.

The ambitious projects in the Negev Desert were launched in late 2014 after the Israeli government began work in providing renewable energy. The Arava and Negev projects are located adjacent to a solar complex and are approximately 25 miles (40 kilometres) south of Be'er Sheva. The projects include various technologies and are managed by separate consortiums. The first of these is a massive 121 MW thermal solar power plant covering more than 988 hectares of land, called Negev Energy. The power plant includes 28,000 tons of steel structures and about 500,000 parabolic mirrors that collect light to be converted into energy. The plant plans to reduce about 245,000 tons of carbon dioxide emissions per year, the equivalent of removing 50,000 cars from the road, and to provide "clean" energy to as many as 60,000 households in Israel by 2020. The second project is smaller. A concentrated solar energy plant on 300-hectares includes a massive 250-metre-high solar tower, the largest such tower in the world, and is playfully dubbed the "Tower of Power." Costing an estimated 800 million USD, it includes a solar field with more than 50,000 programme-controlled heliostat mirrors that concentrate sunlight on the solar receiver's steam generator.

The third project is a 35 MW solar plant based on photovoltaic (PV) power, which uses solar cells to generate electricity. The initiative had an initial investment of about 100 million USD and was named as a project of A Shalim Sol. A fourth initiative, the Ramat Hanegev Wastewater Treatment and Decontamination Plant, is part of the government's plan to support solar installations, which also includes strengthening the infrastructure surrounding the energy production complexes. All this energy goes to serve Bedouin settlements, and the irrigation is mostly used for greenhouses. Thousands of hectares of citrus fruits are grown in the desert zone in the northern Negev with a unique irrigation system that uses treated wastewater. Along with a green approach to producing renewable and solar energy there are two other important components of the projects, namely employment and tourism. By hiring thousands of construction and maintenance workers (many from Bedouin communities of southern Israel), these initiatives contribute greatly to local employment. The project is also expected to boost regional development by promoting ecological planning and tourism, with its unique observation sites and boundless fields of greenhouses.

The greenhouses are also used to supply water to fish pools located under their awnings. Moshav En Tamar introduced this closed-loop system for breeding fish in salt water in the desert. The procedure begins with a mechanical aerator and silo with mixed fodder in each pool, with water being directed to a mechanical treatment through a micromesh, drum filter, and finally to a large biological pond where the water becomes highly enriched with nitrogen compounds released by the life cycle of the inhabiting fish. Due to the warm climate and sunny days, microalgae, as well as simple algae, grow quickly and "absorb" the pollution produced by the fish. Herbivorous fish, such as silver carp, are bred in large ponds to control the plant growth. Such a system cannot be built in a climate zone with poor sunlight since no water is poured out of the system and water is added only to compensate evaporation.

In 2009, in the Gobi Desert (Gansu Province in North-west China) a programme was launched to build greenhouses to grow cash crops of vegetables, mushrooms and grapes. Farming in the Gobi Desert has its advantages, with plenty of sunlight and substantial differences in temperature between day and night, which help the soil to accumulate nutrients. The desert's hot and dry air significantly protects plants from pests and crop diseases. The first 50 greenhouses, built on approximately 800 hectares, have been equipped with various types of high-tech systems and ecological methods.

The first 50 greenhouses are equipped with various types of high-tech systems and ecological methods. Remote control through smartphone applications is used extensively for no-till cultivation, integrated water, fertiliser management and cropping. The use of the Greenhouse Manager App makes it possible to monitor the greenhouses' environment, temperature and humidity in real time, through the adjustment of a variety of sensors installed by this application. One screen touch can open the insulating layer on the roof, allowing fresh air to enter, while the ecological methods of drip and spray irrigation systems help to reduce water consumption by nearly 50 percent, compared to traditional farming. Substrates recycled from rotten leaves, straw and livestock manure are also used.

China's Kuzupchi Desert is 18,000 square kilometres of golden dunes and barchans that wind in a sandy arc from the northern part of the Ordos Plateau in the Inner Mongolia Autonomous Region, to south of the great bend of the Huang He River. Over the centuries, climate change and human activity stripped the land of any vegetation and left thousands of locals in desperate poverty with no water supplies, no electricity, no roads and no communications. In 1988, Wang Wenbiao, a local resident and founder of Elion Resources Group Corporation who was often referred to as the "King of the Desert", initiated the large-scale ecological project called the Kubuqi Ecological and Restoration Project.

Annually, the project's team plants trees on about 34,000 hectares of land in the Kuzupchi Desert, currently covering approximately 6,000 square kilometres. Afforestation is still the main method of combating desertification in the

Kuzupchi, but times have changed and afforestation must now also bring in financial benefits. The agro-afforestation initiative in the Kuzupchi Desert has already transformed into a high-tech large-scale production chain and is considered a main agricultural production site. The soil here is “treated” with liquorice whose medicinal roots have nitrogen fixation capacity that improves soil fertility. Huge plantations of potatoes, aubergines, melons, tomatoes, watermelons, sunflowers, maize and even lavender generate profits that benefit the local population.

The Chinese authorities plan to create a “green belt” within six years to stop the desertification of the Tengger Desert. According to the Xinhua News Agency, which has published photos of the work that has begun, the belt will be one kilometre in width and 500 kilometres in length. The Tengger Desert is the fourth largest desert in China, and it has several freshwater lakes that partially slow the desertification of the area. Planting of low maintenance plants resistant to dry and hot conditions is also used to stop desertification.

Trials currently underway in China allow scientists to study the ability of mosses and lichens to control the spread of lifeless desert soil and to identify if these plant species can intensify agriculture on the Tengger Desert in the Ningxia Hui Autonomous Region. The portal **http://agroxxi.ru** has reported that “the new method shows promising results in terms of stabilizing the desert and helping to improve soil fertility.”

The confidence of Sh. Mirziyoyev’s ideas of turning the dried seabed into a zone of ecological innovation are realistic, as similar innovations in desert development have already been realised in various countries. For instance, Jordan is using Israeli technology, Qatar and Egypt are using the Sahara technology developed and implemented by Norway, and in the Libyan Desert the pivot irrigation method is being applied.

2 Description of the study area

2.1. The Aral Sea – modern dynamics and research

As a closed, drainless water body, the Aral Sea is precariously placed between the formation and interspersion zone of the basin and its deltaic part. Humankind's requirement for sustained development has contributed to the sea's downfall, resulting in the degradation of the delta and desertification.

This is typical not only for the Aral Sea, but also for the Victoria and Chad lakes in Africa, Urmia Lake in Iran and even for the Gulf of Mexico where the water-abundant Colorado River once flowed, and for the San Joaquin River Delta in the Gulf of San Francisco in the United States.

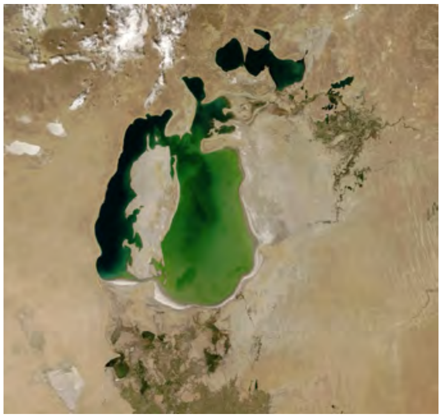
Differences amongst these examples exist since the bottoms of closed reservoirs are drained and a desert is formed on the base of continental bottom rocks. In the case of "sea desertification", the bottom remains under water, but fauna disappears. Both of the aforementioned bays have nearly lost their fish populations due to the loss of fresh water, nutrients, and the biota characteristic of the fresh-water delta.

The changes in the characteristics of the Aral Sea up to 2006 were described in SIC ICWC's previous publication of the results of the first stage expeditions (Complex Remote Sensing and Ground-Based Studies of the Dried Aral Sea Bottom – 2008), as well as a number of other studies devoted to the water regime and economy of the Aral Sea region (Economic Assessment of Local and Joint Measures to Reduce Social and Environmental Damage in the Aral Sea Zone – 2004). It should be noted that if during the first 10 years the sea level decrease was on average 20 centimetres per year (1 metre decrease per 5 years), then from 1975 to 1980, the sea level had already fallen by 3.26 metres, being on average a reduction by 0.65 metres per year. Initially the problem was not noticed until irrecoverable losses appeared as the sea's water quality deteriorated, freshwater fish disappeared, navigation ceased and most importantly, the sea vanished, leaving dead marine sediments behind.

In this paper, the desiccation of the Aral Sea is considered in the context of the new land formation on the exposed seabed (Fig. 2).

The tragic dynamics of the sea's disappearance are illustrated without the ability to prevent its further loss. Currently in Uzbekistan, there is an increase of seasonal droughts due to the negative impact of the drying process on the climatic conditions of the region. The Aral Sea catastrophe is exacerbated by the continental

Fig. 2. The Aral Sea



25 August 2000

15 August 2001

20 August 2002

12 August 2003

16 August 2004

12 August 2005

climate which increases the dryness and heat in the summer and prolongs the cold and severe winters.

To date, the water balance of the remaining Aral reservoir is in an unbalanced state due to the limited, and in some years, the lack of flow of the Amudarya and Syrdarya rivers. As a result, there has been a further drop in sea level, a reduction in its surface area and an increase in the concentration of elements dissolved in it. Fig. 3 shows how the water bodies of the Aral Sea have changed over the past 20 years. In 2007, the southern Aral Sea split into eastern and western parts but remained loosely connected at both ends. By 2009 after a severe drought, the shallower eastern part had nearly disappeared. From 2009 to 2018, water levels fluctuated annually depending on the water content of the year. The existence of the Eastern Reservoir (it can no longer be called a sea) is determined mainly by the tributary of the Amudarya River. Data of various water levels collected from space from 2010 to 2019, have allowed for an assessment of the actual dynamics of changes of the western and eastern parts of the Aral Sea's wetlands and the open water surface[1].

The monitoring data (Table 1) show that due to the unstable water inflow, the water surface

1 http://www.cawater-info.net/aral/data/monitoring_amu.htm

15 August 2006

16 August 2007

18 August 2008

16 August 2009

26 August 2010

15 August 2011

19 August 2012

25 August 2013

19 August 2014

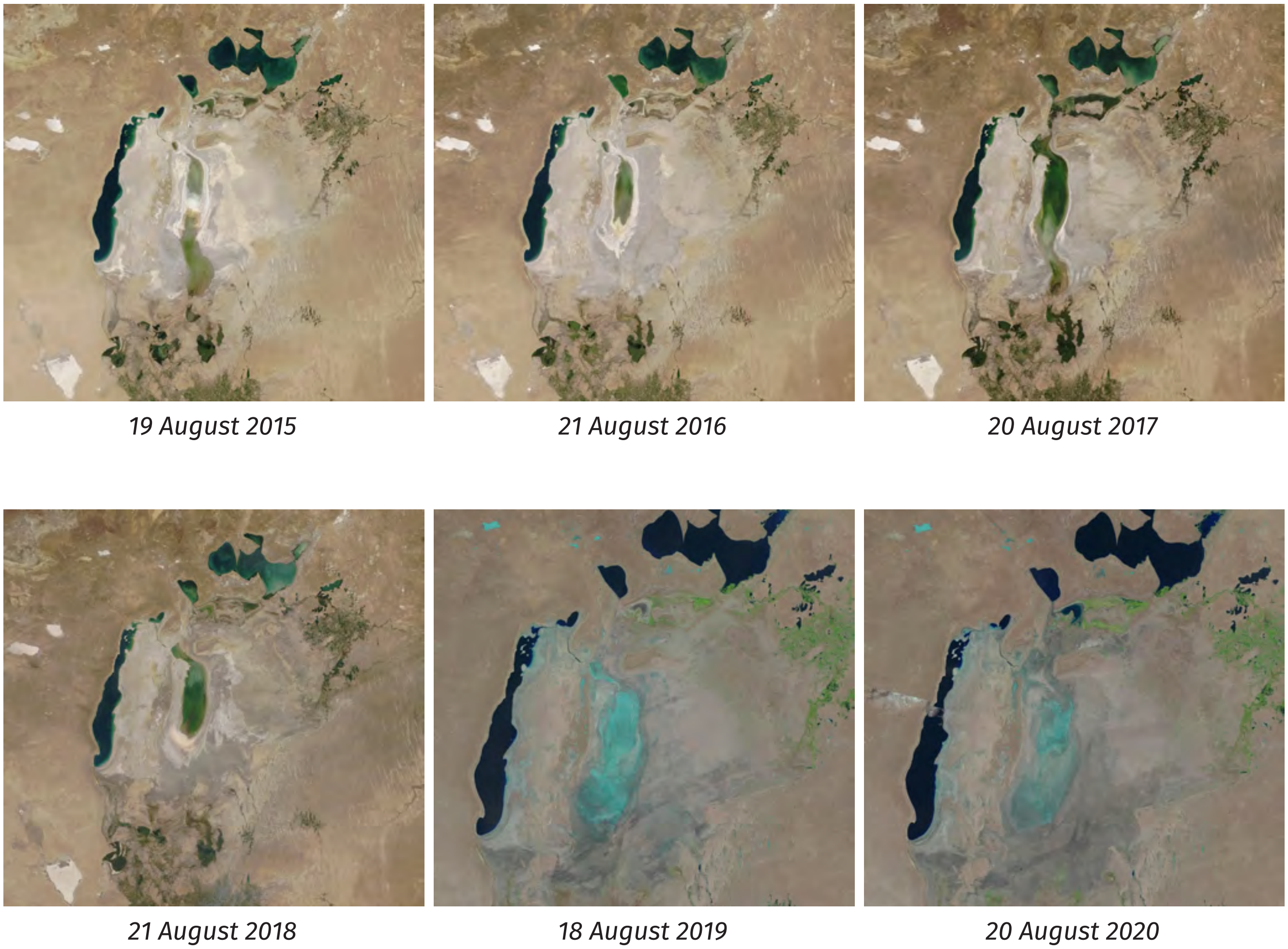


Fig. 3. Changes in the water bodies of the Aral Sea in August 2000-2018

area of the western and eastern parts of the Aral Sea has changed dramatically over the years depending on the water content of each given year. By 2018 and 2019, compared to the high-water years of 2010 and 2017, the water surface area of the western part decreased from 380,000 to 265,000 hectares. There is a similar situation in the eastern part where the area decreased from 533,000 to 128,300 hectares in 2018 and to 16,700 hectares in June 2019.

The decrease in the water surface area has meant the areas of wetlands have increased. Compared to 2010, the area of wetlands in the western part of the sea increased by 114,000 hectares by 2019, and in the eastern part, the increase amounted to 516,000 hectares.

Table 2 shows data on the total inflow to the Aral Sea, while Fig. 4 shows the dynamics of water supply to the Aral Sea and the deltas of the Syrdarya and Amudarya rivers for 2011-2019. Fig. 5 shows the dynamics of water discharge into the Great Aral Sea in 2011-2019.

From the above data, it becomes clear that the current situation of the Aral Sea is completely dependent on the inflow through the Amudarya River to the eastern and western reservoirs and the inflow of releases from the smaller sea. Simultaneously, when the western part of the

Table 1.

Comparison of open water surface areas and wetlands of the Aral Sea (2010-2019) by thousand ha

	August 2010	August 2011	August 2012	August 2013	August 2014	August 2015	August 2016	August 2017	November 2018	June 2019
Western part of the Aral Sea by thousand ha										
Wetlands	182,34	165,86	161,25	224,78	186,99	264,55	265,54	283,15	293,0	296,5
Water surface	379,59	396,08	369,66	360,69	337,52	315,78	295,81	278,2	268,4	264,81
Eastern part of the Aral Sea by thousand ha										
Wetlands	964,14	1243,9	1214,53	1155,3	1019,59	1183,95	1340,79	1036,02	1353,0	1480,1
Water surface	532,68	252,94	215,99	184,31	103,22	149,19	156,04	460,81	128,3	16,7

sea is at low water content, a constant decrease in the water level continues, and it still retains a depth of more than 20 metres. Mineralisation is growing and has reached the current level of 130 g/l.

The shallow eastern reservoir is completely dependent on wastewater and ranges from almost completely dry to a volume of 17 billion m3 with a marked difference of almost 3 metres, making the western and eastern reservoirs highly saline with a salinity of 130 to 350 g/l.

The ongoing changes in the physical and chemical regimes of the Aral Sea affect the current state of its biological systems. It should be noted that, despite the huge losses in the species diversity of the biota suffered during the ecological crisis, the modern biological communities of the Aral Sea cannot be called dead or dying. The sea has developed a very specific, but quite an active ecosystem consisting of plankton and benthos species that have managed to adapt to the enormous salinity. Their total biomass is significant. There are even attempts at commercial extraction of the dominant representative of the zooplankton of the Aral Sea, the gill-legged crustacean Artemia. (The evolution of biological communities determined primarily by changes in the physical and chemical regimes of the sea should be the focus of further research.)

A detailed data analysis of the dynamics of changes to the sea's drained bottom on the Uzbekistan and Kazakhstan territories is given in Fig. 6. Table 2 and Fig. 4 show how strongly interrelated the sea's drained bottom is with the water supply.

Water supply significantly changes the eastern reservoir's water surface area as it is completely dependent on the discharge water and directly affects the area of the drained bottom of the Great Aral Sea. The water entering the eastern part is partially accumulated in this reservoir, partially enters the western part, and is partially lost due to evaporation and filtration. The eastern part is characterised by an increase in the water surface area with a total inflow to the sea of more than 8 km^3 per year. With an inflow less than 6 km3 per year, the water surface area of the sea decreases (at present, the water surface level is 26.3 metres). This was clearly seen when in 2017 the total volume of water discharged into

Table 2.

Total inflow to the Aral Sea, million m^3

Years	*The Northern Aral Sea*		*The Southern Aral Sea Region*		**Total volume of water discharged into the Great Aral Sea**
	Total water supply to the Small Aral Sea via the Syrdarya River, hydrological post (h/p) Karateren	Including the discharge from the Small Aral Sea to the Great Aral Sea	Total water supply to the Amudarya River delta, Samanbai h/p, taking into account the discharge of the collector and drainage network (CDN)	Including the discharge from the Amudarya River delta into the Great Aral Sea	
2011	4636	3462	1933	1041	**4503**
2012	4588	2004	10679	3533	**5537**
2013	4444	2424	3388	2126	**4550**
2014	5127	2570	4270	520	**3090**
2015	4545	2440	8685	4522	**6962**
2016	4332	2816	4106	1874	**4690**
2017	7906	6661	11583	6057	**12748**
2018	3009	3310	1715	846	**4156**
2019	3697	830	4037	1217	**2047**

the Greater Aral Sea was 12.7 km3 (Table 2) and the area tripled accordingly – from 156,040 to 460,810 hectares (Table 1).

The western part is characterised by a trend of decreasing water levels (currently, the water surface level is 24.7 metres) and water surface area, which presents different intensities of falling depending on the inflow of water to the sea and water availability in the eastern part (level difference between the eastern and western parts).

As can be seen, the main consequences of the drying up of the Aral Sea, in addition to the decrease in water volume and water surface, were manifested in the formation of a huge salt desert on more than 5.5 million hectares which replaced the dried seabed.

Since the last SIC ICWC expedition in 2011, the area of the drained bottom of the Aral Sea has increased from 4.611 million to 4.998 million hectares. As such, the drained bottom has increased by 0.386 million hectares.

The organization management of this complex human-natural system is a major issue of the continuing monitoring of the drained bottom of the Great Aral Sea in Uzbekistan's territory. The drained bottom is a unique laboratory of nature. The origin, development and replacement of some formations by others, or their combination, reflects the evolution of the landscapes themselves and depends primarily on provincial or local features of the dried seabed, the composition of bottom sediments, their salinity, the depth of occurrence and groundwater salinity.

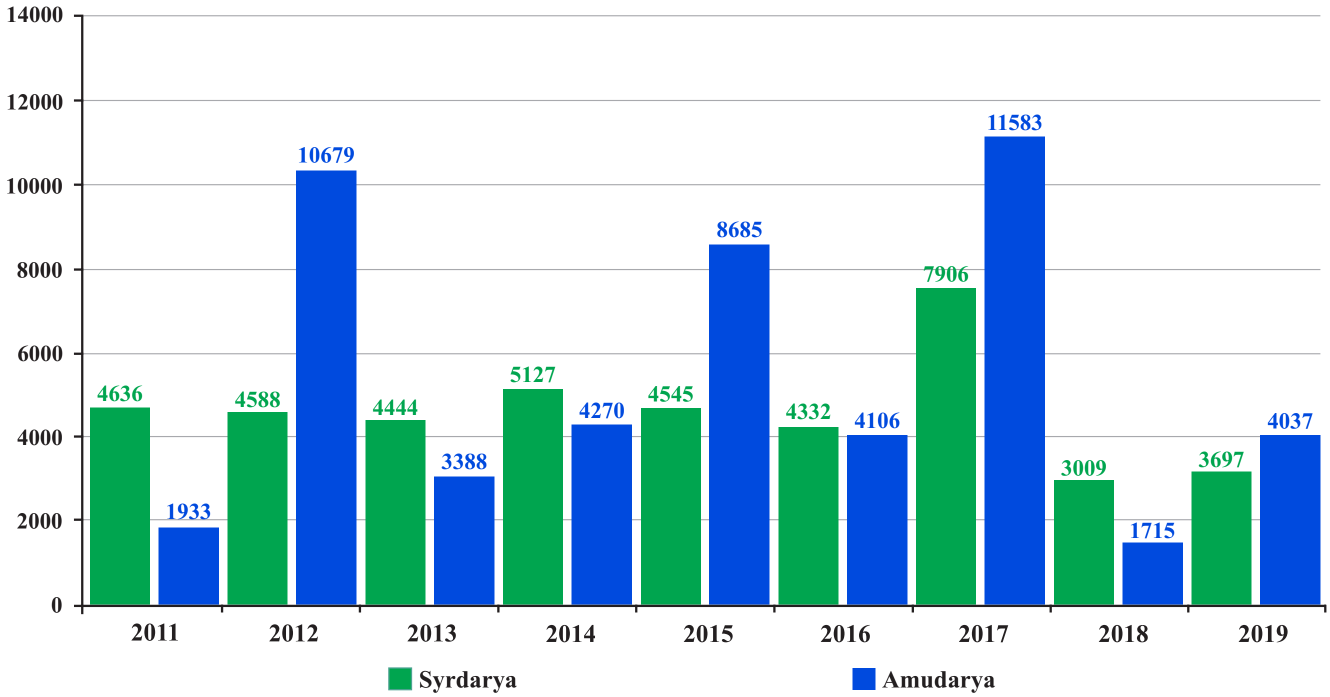


Fig. 4. Dynamics of the water supply to the Syrdarya and Amudarya rivers' deltas for 2011-2019, million m³

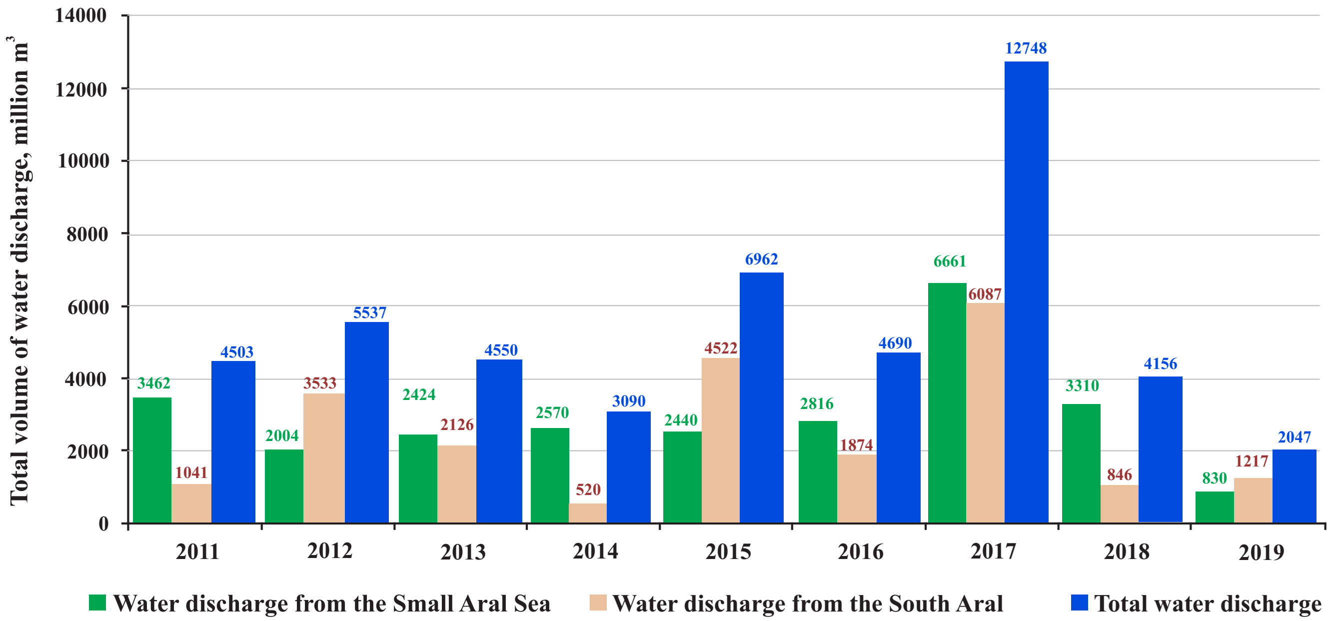
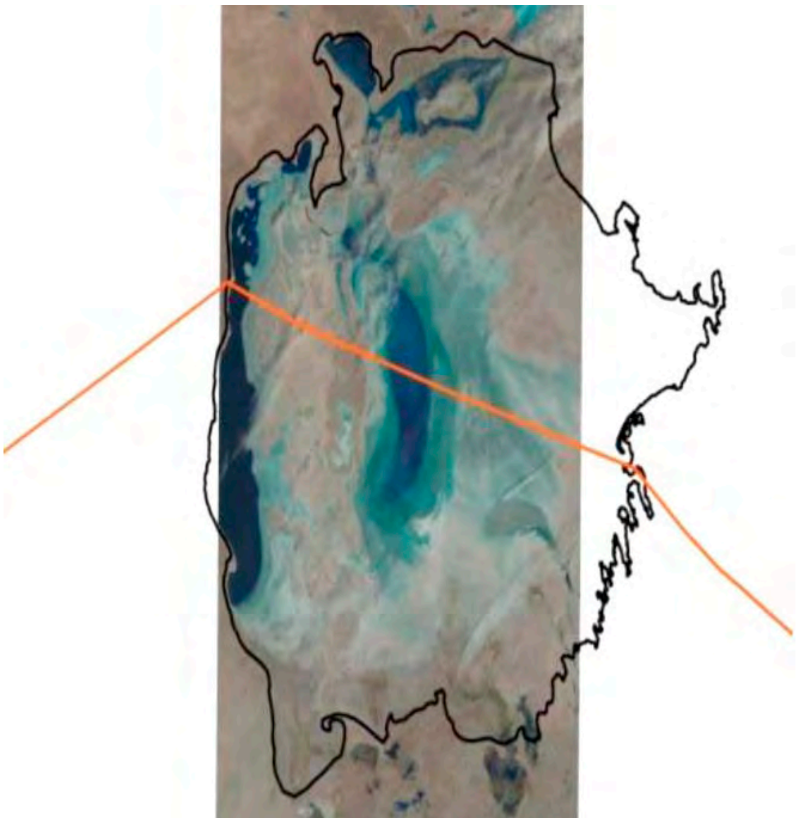


Fig. 5. Dynamics of water discharge into the Great Aral Sea in 2011-2019, million m³



Years	The total area of the drained bottom of the Great Aral Sea (km²)
2005	37661,5
2006	41028,6
2007	40562,5
2008	44666,6
2009	46232,5
2010	42955,7
2011	46112,7
2012	46971,5
2013	47349,3
2014	48950,1
2015	48063,9
2016	48645,5
2017	44747,2
2018	48018,1
2019	49981,6

Fig. 6. Dynamics of changes of the drained bottom of the Great Aral Sea (excluding the Northern Aral Sea) from 2005-2019

2.2. General description of the area

The hypothesis about the area's prehistoric period is based on the geological works of Russian researchers of the late 19th and early 20th centuries. They confirmed that in the Post-Pleocene epoch, the Great Aral Sea flooded a portion of the Karakum Desert between the chink of Ustyurt in the north, the mouths of Murgab and Tejen in the south and the foot of Kopetdag in the west. The eastern part of the connected Aral-Caspian Sea had, in their opinion, the chink of the Unguzov coastline as the border of the former Karakum Gulf. This united sea covered a wide strip of the modern Caspian region up to the bottom of the western spurs of the Kopetdag. At that time, the Aral part flooded the entire Sarykamysh depression and formed a bay up to Pitnyak, which is now occupied by the modern Amudarya River delta and the Khiva Oasis. The Uzboy was a channel connecting both these water areas, but apparently, its present shape with large gradients was formed as the Caspian Sea separated from the Aral Sea and the difference in their water surface elevations increased. During the subsequent geological period to the present day, the united Aral-Caspian basin was divided into its constituent parts and gradually was reduced to its present size. First there was a watershed between the Aral-Sarykamysh and the Caspian Sea, then the Uzboy channel gradually formed. From the geological point of view, the absolute age of the sea is 139±12,000 years. In the Neogene period, powerful tectonic movements in Central Asia formed three deep depressions in the center of the Turan Plain, specifically the Aral, Khorezm, and Sarykamysh. During the Early and Middle Pleistocene, all of these depressions developed in subaerial conditions.

The current SIC ICWC expeditions include an invited dendrologist from the International Innovation Center for the Aral Sea basin under the President of the Republic of Uzbekistan. The aim of the expeditions was to resume the

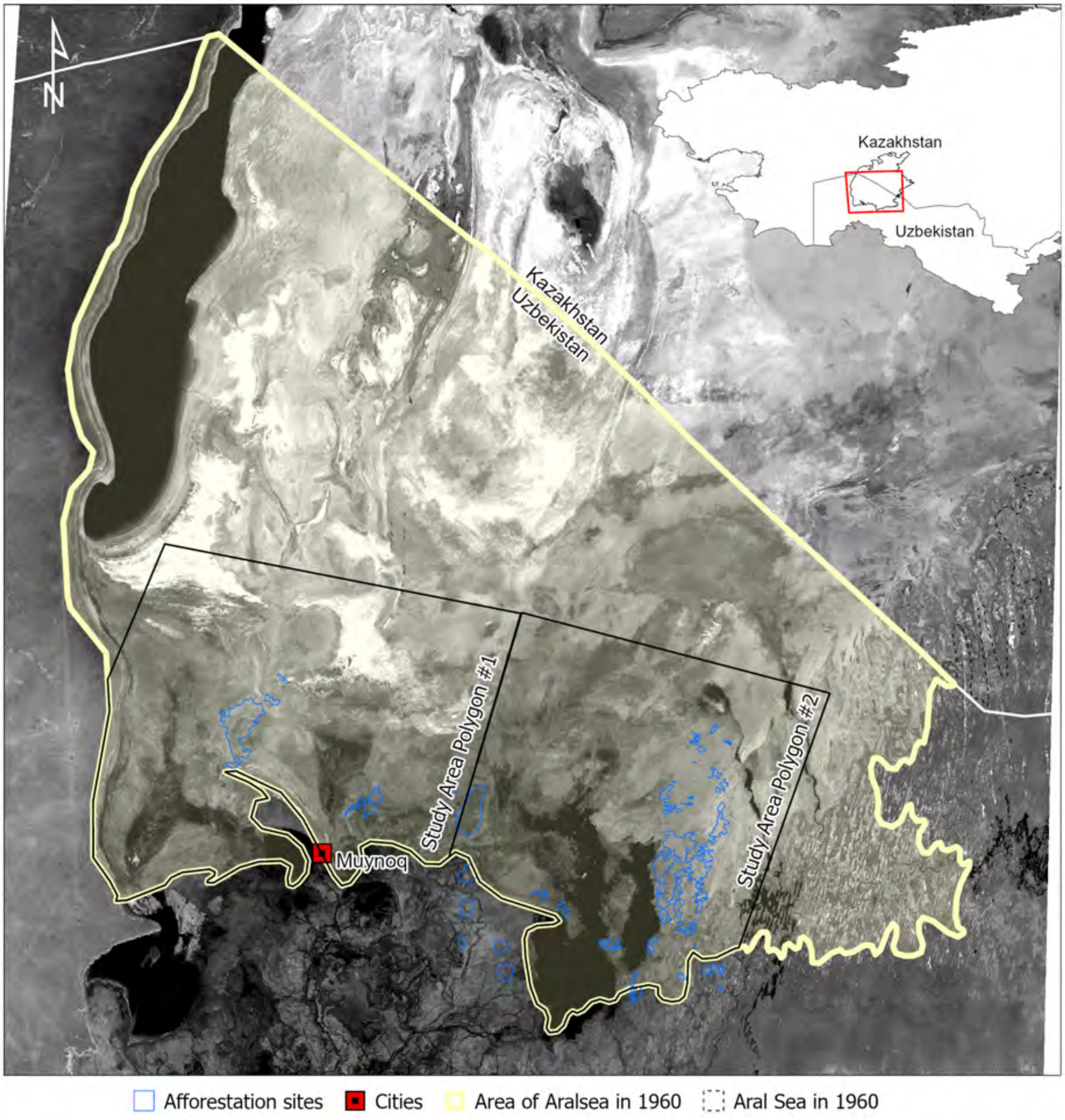


Fig. 7. The Uzbek part of the Aralkum (the territory within the Aral Sea coastline), 1960. Two polygons of the study area are shown. An image from the Landsat 8 satellite taken in October 2019 is shown in the background.

monitoring of the dried seabed in the territory of Uzbekistan, which had been started earlier in 2005-2011. Unfortunately, observations were interrupted until the second half of 2019 due to lack of the necessary funding. The total area of the sea within Uzbekistan for this project is 3,086,176.08 hectares, of which the current drainage area is 2,879,192 hectares.

The work area, located in the northern zone of the Turan plate, is enclosed between the geographic coordinates 430331-440201 NL and 590201 and 600251 EA, and is a flat or slightly wavy plain with a general slope to the north/north-west. The newly formed aeolian high plain occupies a significant area of recent sand dunes.

The research was carried out on two sites. The first is located at the Amudarya River's left-bank from the eastern chink of the Ustyurt plateau to the Amudarya River (Ustyurt Aral Basin) and the Amudarya River's right-bank to the Kokdarya channel to the north-western edge of the Kyzylkum (South Aral Basin). In the south, the work area of the first site is limited by the territory of Muynak city and the sea line (1960), as well as the Kazakhdarya channel. In the north it is impassable because of the dried dunes and solonchaks of the dried bottom of the Aral Sea, and the Djiltyrbas Lake in the east. The second section is from the Djiltyrbas Lake to the Kokdarya channel on the eastern border, in the south - collectors KC-3 and Karauzyak. In the north, there are also impassable solonchaks of the dried Aral Sea bed.

The main settlements in the work area connected with Nukus by roads are the cities of Kungrad, Muynak, Takhtakupyr, and the villages of Shagyrlyk, Aral, Kazakhdarya, Chimbay and Karauzyak.

The predominant part of the population, made up of Karakalpaks, Uzbeks, and Kazakhs, is concentrated in the zone of irrigated agriculture. In the drainage zone, the bulk of the population is engaged in cattle-breeding, fishing and less frequently in agrarian farming.

Over the past 15 years, commercial companies from China, Korea and Malaysia have carried out large exploration activities on the dried seabed to find and develop oil fields. Today there are 45 exploration and production wells of various countries on the former seabed and a large soda factory has been built near Kungrad.

Based on a number of government decisions, significant work on developing Muynak city and streamlining the Amudarya River delta has been undertaken. This has helped to stop migration from the Aral Sea region and an active population has emerged.

2.3. Climate

The study area is located in the northern part of the arid belt of subtropical latitudes of the northern hemisphere, which affects the overall dry climate, manifested in the absence of precipitation in the long summer period and sharp continental conditions with typically high amplitudes.

The territory of the region is open to the invasion of various air masses, causing sharp changes in the weather. The peculiarities of atmospheric circulation are the main reason for the high natural variability of the climate. In addition, this variability is affected by various anthropogenic impacts, a significant one being the reduction of the Aral Sea.

Analysis of maximum temperature changes has also shown the presence of upward trends in most months. It is interesting to note that in summer and autumn, the tendency to higher minimum temperatures is more significant than to maximum temperatures, and in summer, a decrease in maximum temperatures was recorded at a sufficiently large number of stations. In the segment of changes in minimum temperatures (November), the climatic contribution to the drying of the Aral Sea can be traced. This contribution is expressed in smaller trends towards an increase in minimum temperatures in the Aral Sea region. This is a consequence of the aridization effect (a decrease in humidity in the sea retreat zone), which causes an increase in the daily amplitude of air temperature (Muminov F. A., Inagamova S. I., 1995). This example indicates that the impact of sea retreat on the microclimate of the area in some months is already manifested in changes in climatic norms.

High air temperature and low precipitation determine high evapotranspiration values of up to 1,900-2,000 millimetres/year, many times (17-30) greater than the total sum of precipitation.

Below is a description of the climate according to data from meteorological stations in Kungrad, Nukus and Chimbay:

Winter in the study area is moderately cold, with little snow and mostly cloudy weather. Persistent frosts begin in mid-December and in the coldest month, January, the air temperature reaches -2.4 °C to -9.60 °C during the day, from -10 oC to -20 °C at night, while the maximum air temperature reaches -22 °C to -28 °C. Severe frosts come with the arrival of the Siberian anticyclone and can last 3-4 months (for instance: 1968-1969, 1993-1994). Precipitation in winter is mainly in the form of snow, however the thickness of the snow cover is usually no more than 5-8 centimetres. The relative humidity is approximately 55-80 percent.

Spring (March-May) is characterised by unstable weather, cloudy, windy weather with maximum precipitation. Air temperature during the day is 4 °C to -15 °C. Precipitation is in the form of short but heavy rains in the range of 9.0-37.4 millimetres. Relative humidity is about 26-65 percent.

Fig. 8. Meteorological station on Lazarev Island, expedition photo, 2006

Fig. 9. Meteorological station on the dried-up bottom of the Aral Sea

Summer (June-September) is dry and hot. Daytime temperatures range from +27 °C to +30.4 °C, with maximum temperatures of 40 °C to 45 °C and night-time temperatures of 10 °C to 23 °C. Precipitation is in the form of short but heavy rains in the range of 0.6-6.7 millimetres. Relative humidity is about 25-48 percent. In the second half of June, due to intensive warming of air and ground surface, a thermal depression begins and reaches its greatest values in July-August.

Autumn (October-November) is dry and mostly clear. Temperatures range from 6.5 °C to 20 °C during the day and from 5.5 °C to -5.4 °C at night. Night frosts begin in late October. Precipitation is in the form of rain and snow. Winds throughout the year are predominantly north-easterly and easterly. The prevailing wind speed is 4-6 m/s. Strong winds of 15-22 m/s are rare and occur mostly in the autumn-winter period. The amount of atmospheric precipitation varies from 4.0 to 41.3 millimetres.

The two meteorological stations located closest to the sea and the dried seabed are 'Aktumsuk' and 'Lazarevo'. Table 3 shows data on the Aktumsuk meteorological station. The meteorological station on Lazarev Island finished its operation in 1987 (Fig. 8). The two stations were

Table 3.

Average long-term meteorological information according to the data of the Aktumsuk meteorological station for the period 2000-2018

Parameters	Month												
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Год
Average month air temperature, °C	-8.1	-7.3	1.7	11.1	19.3	25.0	27.2	25.7	18.1	9.1	1.5	-4.8	9.9
Absolute minimum air temperature, °C / year	-35.7 /2006	-34.1 /2014	-25.3 /2011	-11.5 /2005	0.8 /2018	0.1 /2018	7.1 /2014	5.7 /2015	-4.4 /2017	-15.7 /2014	-21.5 /2016	-28.3 /2012	-35.7 /2006
Absolute maximum air temperature, °C / year	10.0 /2007	13.1 /2016	25.5 /2001	32.6 /2000	37.1 /2014	40.9 /2014	43.4 /2017	43.0 /2006	40.0 /2017	29.0 /2006	28.0 /2006	22.0 /2006	43.4 /2017
Average monthly precipitation, mm	4.2	4.5	11.0	9.2	6.0	3.5	3.1	2.4	1.5	4.3	6.6	6.4	62.7
Average wind speed for a month, m / s	3.9	4.0	3.8	3.5	3.4	3.4	2.9	2.7	2.7	2.8	3.1	3.6	3.3

Average frequency of wind directions by 8 points, %

N	NE	E	SE	S	SW	W	NW
10	18	28	8	7	5	20	4

installed on the dried seabed in the "zero" area and on the coast of the East Sea by the Chinese Academy of Sciences (Fig. 9).

Comprehensive work with a series of observations has been carried out at the stations since 1931 and show the effect of anthropogenic influences in the Aral Sea basin on the moisture regime. Six stations were selected and their initial data were released (Spectorman T.Yu., Nikulina S.P., 2002). Nukus covers the irrigated lower reaches of the Amudarya River. The Tamdy station reports on the central Kyzylkum, while Tashkent follows the foothill zone in an area with the strongest influence of urbanisation. Jizzakh, on the Golodnaya Steppe, is an area where there has been an intensive increase of irrigated land in recent decades. Chimbay and Muynak characterise the conditions of the Aral Sea, and Muynak is a former coastal station.

The project considered the change in moisture deficit as a very climate-sensitive indicator of drought. In the absence of local anthropogenic impacts, this indicator captures the trends of increasing aridity in the autumn-summer season. Fig. 10 shows the graphs of changes in the average humidity deficits for the autumn season at the selected stations.

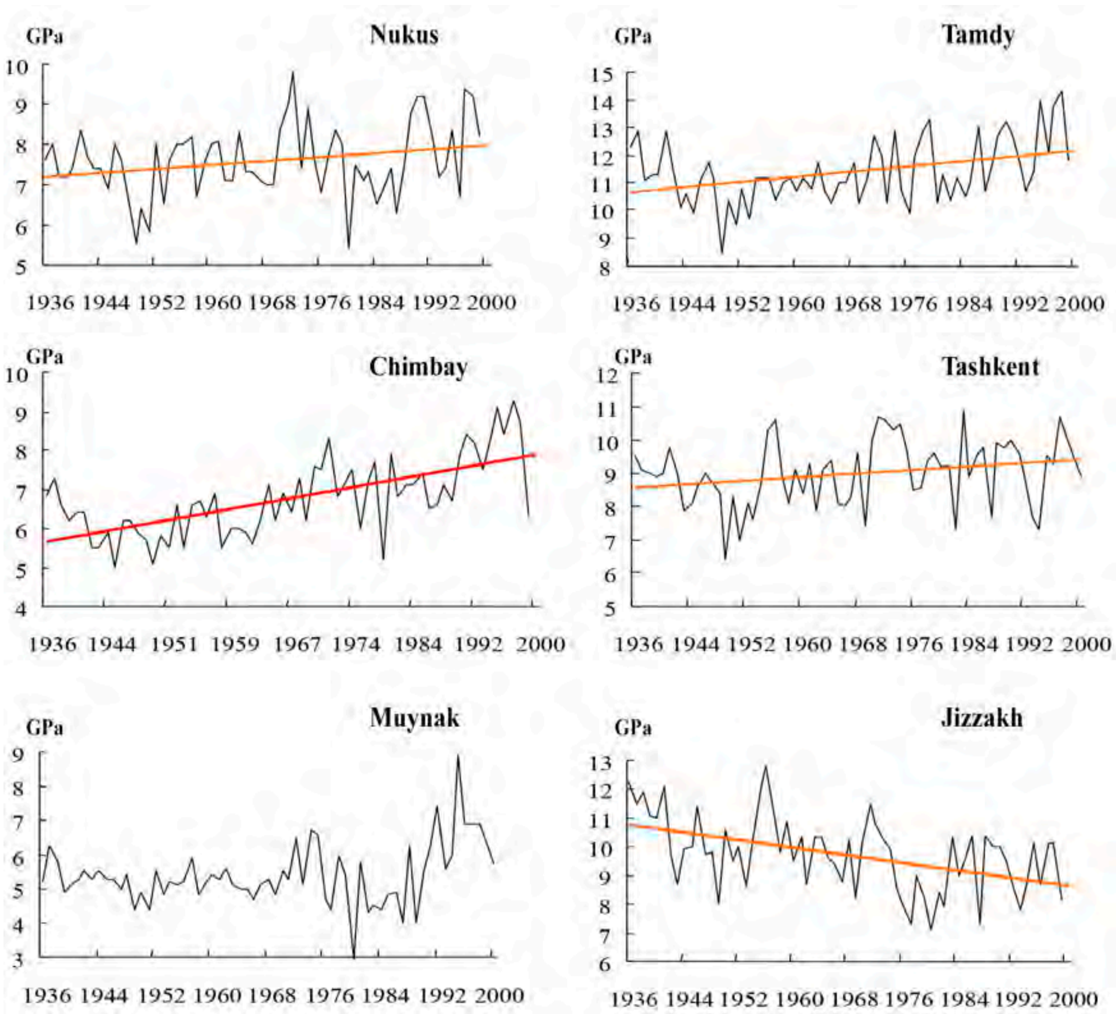


Fig. 10. Changes in the average moisture deficit for the autumn season at some stations

Even though the Nukus station is located near irrigated massifs, the trends of humidity deficit changes are similar to those observed at the Tamdy desert station. There are no trends in the winter and spring months, but there are trends of deficit increase in summer and fall. At the Tashkent station, trends of humidity deficit growth are traced practically in all seasons, and the Jizzakh station records anthropogenic decrease of humidity deficit (Spektorman T.Y., 2002).

In the Aral Sea region, the trends of humidity deficit change are practically unambiguous with coastline retreat. An increase in humidity deficit in all seasons of the year and an increase in the range of fluctuations are fixed. Even visually, a violation of the uniformity of observation series related to the regression of the Aral Sea is noticeable. Anthropogenic impact on climate, both at a global level (increased concentration of greenhouse gases in the atmosphere) and at a local level (urbanisation, increased irrigated areas, creation of reservoirs and irrigation-discharge lakes, and the shrinking of the Aral Sea), make it difficult to identify the global warming signal and increase the uncertainty of climate scenarios in the Aral Sea region.

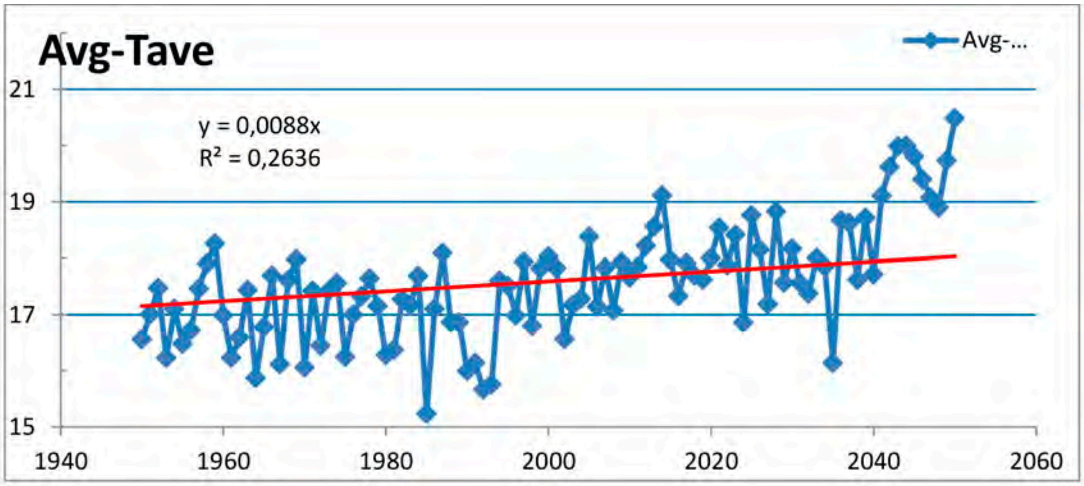


Fig. 11. The scenario of changes in the average annual temperature in the Aral Sea region according to the REMO model

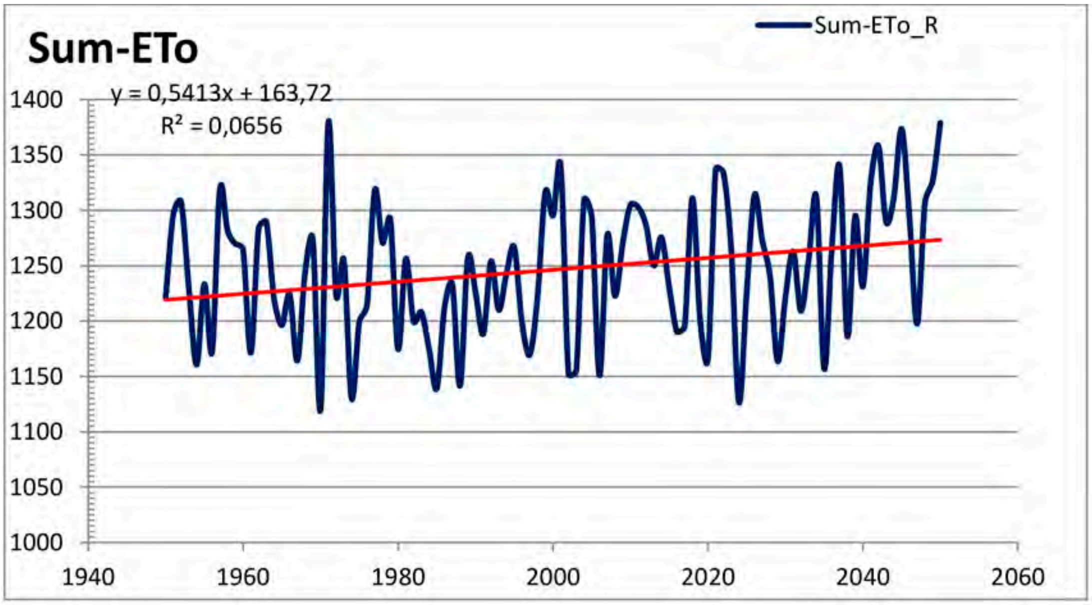


Fig. 12. Scenario of evapotranspiration change (ETo) in the Aral Sea region according to the REMO model

Modern developed models of general atmospheric circulation and regional models built on this basis allow for generating scenarios of climate change. The REMO model (D. Jacob & R. Podzun, 1997) of the Potsdam Earth Institute is used to estimate the climatic parameters of the Aral Sea region until 2050. So far, trends found in the analysis of the results show (Figs. 11 and 12) an increase in annual temperature and potential evapotranspiration in the future under conditions of further sea drying. In the conditions of the Aral Sea region and the dried bottom of the Aral Sea, this indicates increasing aridization of the climate, as well as growing desertification processes and increasing environmental risks.

2.4. Geomorphological processes on the dried bottom of the Aral Sea

The area of works extends to the northern zone of the Turan plate. It includes the eastern part of the Ustyurt Plateau to the old channel of the Amudarya (Akdarya) in the east, the dried bottom of the Aral Sea and Sudochie Lake in the north, and the Muynak and Shegakul polder zone in the south.

The work area is a flat or slightly wavy plain with a general slope to the north/north-west.

A characteristic feature of the relief is the alluvial delta plain of the Amudarya River, which occupies a large area. The surface of the plain descends very flat to the north towards the Aral Sea. Absolute heights of the Amudarya alluvial delta plain vary from 70 metres in the south-eastern part of the former Muynak Peninsula to 25-30 metres in the north-east and north-west. In the coastal zone, the Aral Sea forms levelled saline surfaces at 50-40 metres. Takyrs are widely distributed in the north-eastern part of the alluvial delta plain of the Amudarya. The aeolian newly formed upland plain occupies a significant area of the modern desert.

The relief is ridge-like and the ridges have a submeridional orientation and are usually traced at a distance of 0.2 to 1-2 kilometres. The largest modern ridges reach a height of 3-5 metres with a width of 0.1-0.3 kilometres. The main ridges are 1-3 kilometres apart, covered with sandy and sandy-clay loam and loam solonchaks extending to Muynak elevation, meadow, swamp-meadow and marshy soils in the Amudarya Delta plain.

The former Muynak Peninsula has the shape of a sickle, with its convex side facing to the north-east.

The heights of its surface vary from 58 metres on the coast to 86 metres in the central part. The northern side faces the severe Surgil Lagoon, and the salt marsh of the same name, is relatively flat. The Surgil Lagoon (now solonchak), is separated from the modern small sea and is a classic coastal bar known as “Tigroviy Hvost” (Tiger’s Tail). The lagoon stretches for more than 50 kilometres. In the south it is overgrown with kandym, tamarix and saxaul, and has been perfectly preserved after the sea’s regression. The dried seabed, which has retreated by 60,100 kilometres over the decades, has become the world’s youngest saline desert, the ‘Aralkum’. It is a grey, uniform and highly saline sea plain with a very slight (0.000256) slope to the north. A large area is completely devoid of shrubbery and covered only with dry saltwort, and in the recently emerged dried spaces, not even saltwort grows. Sandy loam and loam are covered with a salt-gypsum crust with numerous plugs and swelling ridges and white thenardite dry hydrate. The former sandy beaches are now intensively winnowed and have become massifs of mobile or partially fixed kandym and saxaul hummocky-dune sand with a height of 1-3 metres. An extensive, meridionally elongated massif of mobile sands is located to the north of the former Muynak Peninsula. It is confined to a former underwater shoal, bordered by a horizontal line of 30 metres.

The area of the second expedition belongs to the middle zone of the Turan Plate and covers the areas of the Amudarya River delta, the north-western outskirts of the sandy Kyzylkum Desert, to the eastern chink of the Ustyurt plateau. It is a flat or slightly wavy plain with a general slope to the north/north-west.

A characteristic feature of the relief is the presence of numerous residual elevations (Kyzyljar, Kushkanatau, Beltau, etc.) and drainless depressions (Ulken Karasor, Balykbay, Kokchatengiz, Karateren, Dautkul, etc.) with a difference in elevations of 20-40 metres relative to the plain. In the southern and south-eastern parts of the study area are low mountain ranges of Sultanuzdag, Kokcha, Buzgul, and others.

The alluvial delta plain of the Amudarya River occupies a significant territory (more than 44,000 km^2) from the Tuyamuyun gorge to the Aral Sea, a length of about 400 kilometres. Its width compared to the Sarykamysh depression and the Aral Sea (according to V.V. Akulov, 1959) is 320 kilometres.

The surface of the plain is very flat on one side towards the Aral Sea, and westward towards the Sarykamysh it is a depression. Absolute height of the alluvial delta plain of the Amudarya River varies from 100 metres in the south/south-eastern part of it, to 35-55 metres in the north and north-west. In the coastal strip of the Aral Sea leaves aligned solonchak surfaces at elevations of 45-35 metres.

Takyrs are widespread in the north-eastern part of the Amudarya's alluvial delta plain of the total area of which measures approximately 1,500 km2. The flatness of the territory is disturbed by active watercourses, and uplands formed by Neogene and older rocks. The Aeolian upland plain occupies a significant area of the Kyzylkum part of Karakalpakstan.

Its surface declines gently to the north towards the Aral Sea. The relief is ridge-like, has a submeridional orientation, and is usually located at a distance of 3-4 kilometres. The largest ridges reach a height of 6-8.0 metres and a width of up to 0.5 kilometres, with main ridges separated from each other by 3-5 kilometres.

2.5. Geological and hydrogeological characteristics of the study area

The study area is located on the border of two major hydrogeological structures of the first order. In the west is the Ustyurt, while in the east is the Syrdarya. They are separated by the Aral-Kyzylkum rampart. In fact, structures of the second order, the North Ustyurt and South-Aral artesian basins included in the research area, adjoin the rampart.

To the west of the Aral-Kyzylkum rampart, there are two hydrogeological zones of very difficult and hard water exchange, and an upper zone of free water exchange. The first two are confined to Permo-Triassic, Jurassic, and Cretaceous reservoirs, while the upper one covers the Miocene, Pliocene, and Quaternary reservoirs. The upper Cretaceous-Paleogene layer is the regional water bearing separating different hydrodynamic zones in the lower and upper hydrogeological floors. East of the rampart, in the Meso-Cenozoic formations, one hydrogeological zone is distinguished as a free water exchange zone covering the entire section of the sedimentary sequence from the Upper Jurassic to Eopleistocene-modern sediments. However, here the upper Cretaceous-Paleogene formations are also considered as a regional aquiclude. The peculiarity of the distribution of aquifers and complexes are direct connections with the natural factors intensively developed in the study area. Based on the conditions of occurrence and feeding, distribution and discharge, and the geological and lithological composition of water-bearing rocks, aquifers and complexes were allocated and characterised. Previously, wells were drilled for water supply for livestock, forestry and farming by different organizations and in some southern areas, on a contractual basis. Considering the presence of livestock wells, this report chapter is compiled by the materials of the research of the adjacent areas.

2.5.1. Aquifer complexes

Based on the analysis of the geological structure and hydrogeological conditions of the study area, the following aquifers and aquiclude horizons and complexes are distinguished as the low-water-bearing alluvial-marine Upper Quaternary and modern complex, aquiclude alluvial-lake Upper Quaternary and the modern complex, the aquiclude Eopleistocene aquifer, the aquiclude Akchagyl local-aquiclude complex, the aquiclude Senon-Paleogene complex, and the aquiclude Upper Cretaceous complex. Information on the lower aquifer complexes is not given due to their insufficient study and suitability for the national economy.

Alluvial-marine Upper Quaternary modern complex with low water content

Groundwater in these sediments throughout the area is the first from the surface, the depth of the level varies between 0-3 metres in the northern and polder zones, and 3.2 metres in the rest of the area. Water-bearing rocks are sandy loam, loam, clay, silt, and silty sands. The thickness is within 0.2-7.0 metres. Groundwater in terms of salinity, refers to saline and brine in the range of 35 to 200 g/l. According to O.A. Alekin, the chemical composition of water is mainly chloride class sodium and less often calcium.

Aquiclude alluvial-lacustrine upper quaternary and modern complex

The aquiclude is spread throughout the entire area and contains groundwater. North of the native shore, the aquiclude is underlain by alluvial-marine and is hydraulically connected. Mainly sands and sandy loams with interlayers of irregularly alternating clays and loams represent the aquiclude complex. The thickness of the complex is 5-18 metres. The depth of groundwater occurrence is 3-5 metres and has a free surface. Interrelation of surface waters was studied by the previous authors using two sections of wells, consisting of 5 wells each, equipped on the north-western margins of the Rybatsky and Djiltyrbas bays.

The groundwater is highly saline and brine with a salinity of 40-70 g/l. It is somewhat lower in the southern part, adjacent to polders Sudochie, Djiltyrbas and the canals Kungrad, Muynak, Amudarya, Kazakhdarya and Kokdarya, with salinity from 1.5-3.0 to 13-28 g/l. The chemical composition is mainly of the chloride class of the sodium group.

Of particular importance in conditions of desertification and the dynamics of harmful exogenous geological processes in the Aral Sea region is the further study of groundwater confined to the upper hydrogeological level. It lies above the regional Senonian-Paleogene water table and is characterised by free water exchange with surface and atmospheric waters.

The peculiarity of the distribution of upper aquifers and complexes is a direct connection with the natural factors intensively developed in the study area.

Eopleistocene aquifer

The aquifer is ubiquitous in the studied area. It is absent (eroded out) only in some parts of the Aral-Kyzylkum berm. The rest of the territory is overlain by deposits of alluvial-lake and alluvial-marine complexes. Clays and marls of the Santonian-Oligocene complex from the ACWR to the Ustyurt cliffs underlie the base of the horizon by chalk sandstones within ACWR, clays, sandstones, and salts to the east of ACWR. Sands mainly represent the water-bearing rocks and sandstones with a total thickness of 18-30 metres of the horizon water and are hydraulically interconnected with the waters of the overlying sediments.

Groundwater levels are usually 0.5-1.0 metres below the levels of upper aquifer complexes. In the south-eastern right-bank part of the territory, water lies first from the day surface level at a depth of 4.1 metres. Well flow rates do not exceed 3.0-3.5 l/s. The filtration coefficient of sands and sandstones is 1.4-4.9 metres per day. Groundwater salinity is 34.3-84.4 g/l (quantity of salts in a litre of solution) over most of the area. According to the chemical composition, waters are mainly of the chloride class of the sodium group.

Akchagyl local aquiclude complex

The Akchagyl deposits are spread in the right-bank (eastern) part of the Amudarya River. They are overlapped by Eopleistocene sediments and underlain by rocks of regional Paleogene clays (50-120 metres thick). The overlying layer lies at the depth of 22-34 metres from the day surface. Groundwater level of the complex, depending on the depth of the sampled collector, is set at 1.55-6.6 metres. Waters are weakly pressurised and the head height above the overlying layer is 24-28 metres. Specific well flow rates are 0.1-0.15 l/s metres. Sandstone filtration coefficients are 0.11-0.66 metres per day. Horizon waters are saline and brine with mineralisation of 22-85.5 g/l. According to chemical composition, the waters are of the chloride class of the sodium group. Underground waters have no practical value.

Aquiclude Senonian-Paleogene Complex

The Senonian-Paleogene sequence is a regional aquiclude layer, which separates mainly groundwater with free hydraulic surface and pressurised water of the middle hydrogeological stage in the considered regions. Its section is composed mainly of clays, marls and marl calcareous clays, and within the section there are thin interlayers of clayey limestone and clayey sandstone. The thickness varies from 545 to 975 metres.

These are widespread everywhere, absent only within the Aral-Kyzylkum berm where the impermeable complex is eroded and located under alluvial-marine, Upper Quaternary and modern sediments or under Eopleistocene sediments. It emerges on the surface of the Ustyurt, Kyzyljar and Beltau hills.

Upper Cretaceous aquifer complex

The groundwater of the Upper Cretaceous sediments in this territory has an area-wide distribution. They come to the day surface within the Ustyurt, Kyzyljar, the former Muynak peninsula of the Aral-Kyzylkum shaft, the Beltau and Kushkanatau elevations, and in other submerged areas penetrated by all exploration-mapping and reference wells. The exception is the vaults of some brachyanticlinal and local geostructures of the Aral-Kyzylkum rampart where the water-bearing rocks of the complex are partially eroded or drained due to their hypsometric position (60-80 metres, kPa).

The depth of the aquifer roof varies from 0.0-5.0 metres (within the uplands) to 37-57.0 metres and more (in the troughs). The revealed thickness is 50-130 metres. As the aquifer complex dips towards the Aral depression, groundwater gradually sinks and becomes subartesian.

Since the water-bearing layers of sands and sandstones have a monoclinal dip, complicated by a whole series of folds, several latitudinal and sublatitudinal troughs and uplifts are formed in the area under consideration.

The section of the aquifer is composed of a layer of unevenly interstratified sands, sandstones, clays, and siltstones. The reservoir properties of sandstones are generally low, total porosity 20-36 percent, saturation porosity 21-28 percent, and a filtration coefficient 0.125-3.05 metres per day.

According to experimental filtration and laboratory studies, the water content of the aquifers is relatively low. The flow rates of the well during trial pumping are 0.5-5.0 l/s and more, with a decrease in the water level of 12-15 metres.

The mineralisation of underground waters of the Amudarya River's left bank complex, starting from the ACWR to the Ustyurt cliff, varies widely both in area and depth. These are salty waters and brines with a solid residue of 37.8 g/l, up to 142.4 g/l. Waters belong to the chloride class of the sodium group of the second and third types. Waters of the complex of this part are practically not used due to their high mineralisation.

Groundwater salinity of the Amudarya River's right bank complex is much more favourable and varies within ACWR up to 10.2-15.0 g/l, moving away from ACWR towards western Kyzylkum from 2.5-5.0 g/l. The least mineralised waters of the complex, with a dry residue of 2.0-3.0 g/l, are developed within the central part of the South Aral region work area of the water pressure basin. As the distance from the Aral-Kyzylkum berm towards eastern Kyzylkum, for instance in the eastern part of the work area, mineralisation of horizon groundwater decreases to 1, 7-2, 5 g/l.

According to the chemical composition, the groundwater of Upper Cretaceous aquifer complex is chloride-sulphate, magnesium-sodium. Within the ACWR and Aral Sea water area, the composition changes to chloride-sodium. Waters of this complex are used for distant-pasture cattle breeding and forestry, and other similar purposes.

2.6. Soil

The flat character of the dried seabed relief creates a virtually undrained area, close groundwater occurrence, capillary capacity of soils, and intensive evaporation which contributes to salinisation of the Aral Sea drainage area. The reason for significant salinisation is salt deposits on the Aral Sea bed under a thin (0.5-1.5 metre) silt layer (V.V. Rubanov, 1977). Chalov P.I. (1968) and then Weinsberg I.G. (1972) obtained the first information on the presence of salt on the Aral Sea bed. The formation of a salt layer under bottom sediments is related to salt deposition from seawater as its salinity increases. The bottom sediments themselves, deposited under the sea to a depth of 1 metre and being the parent rock of soil formation (Brodskaya N.G., 1952), are represented in the central and western parts by marls, and in the peripheral parts by sands and siltstones.

The main part of the drainage area is occupied by solonchaks. The specific conditions of soil formation on the dried seabed predetermined a special subtype of solonchaks called coastal solonchaks. After discussions, local soil scientists considered it possible to classify the solonchaks of the dried seabed as soils. Further studies confirmed the validity of this decision.

A study of the dried seabed showed that the chain of solonchak transformation ends in the formation of desert-sandy soils under the saxaul, not only under artificial plantings, but also in self-overgrowing areas.

The evolution of solonchak soils passes through the stages of excessively hydromorphic soils (marshes) → moderately hydromorphic solonchaks → semi-hydromorphic solonchaks → semi-automorphic solonchaks → automorphic solonchaks. At the last stages of soil development (Sektimenko, 1991), solonchak processes caused by hydromorphic conditions are faded, and the role of the arid-zonal factor increases many times under the influence of which the further development of soils follows the typical desert type.

Soil formation begins when the seafloor is exposed.

Fig. 3 in Chapter 2 shows the dynamics of the Aral Sea bed drainage and changes in the shoreline position by years.

In 1990, a soil study of the dried seabed was carried out by the Institute of Soil Science, and a soil map was developed based on the results of this study.

By the 1990s, the groundwater in the previously surveyed area had lowered to at least 4-7 metres and had a very high salinity of up to 50 g/l. Hydromorphic and semi-hydromorphic solonchaks were transformed into semi-automorphic and automorphic ones.

The newly formed hydromorphic soils moved after the receding seawater edge.

As a result of four expeditions on the dried seabed during 2005-2007, conditions of further changes in the seabed cover were studied. A soil map (Dukhovny V.A. et al., 2008) was developed and an analysis was performed of soil cover changes over 15 years.

Since 1990, there has been an increase (Table 4) of automorphic solonchaks by more than 50,000 hectares due to the lowering of the groundwater table and the transition of hydromorphic soils into their automorphic counterparts.

As a positive sign, 233,500 hectares of desert-sandy soils were formed. However, the area's under sands significantly increased from 172,000 to 322,000 hectares, indicating the in-

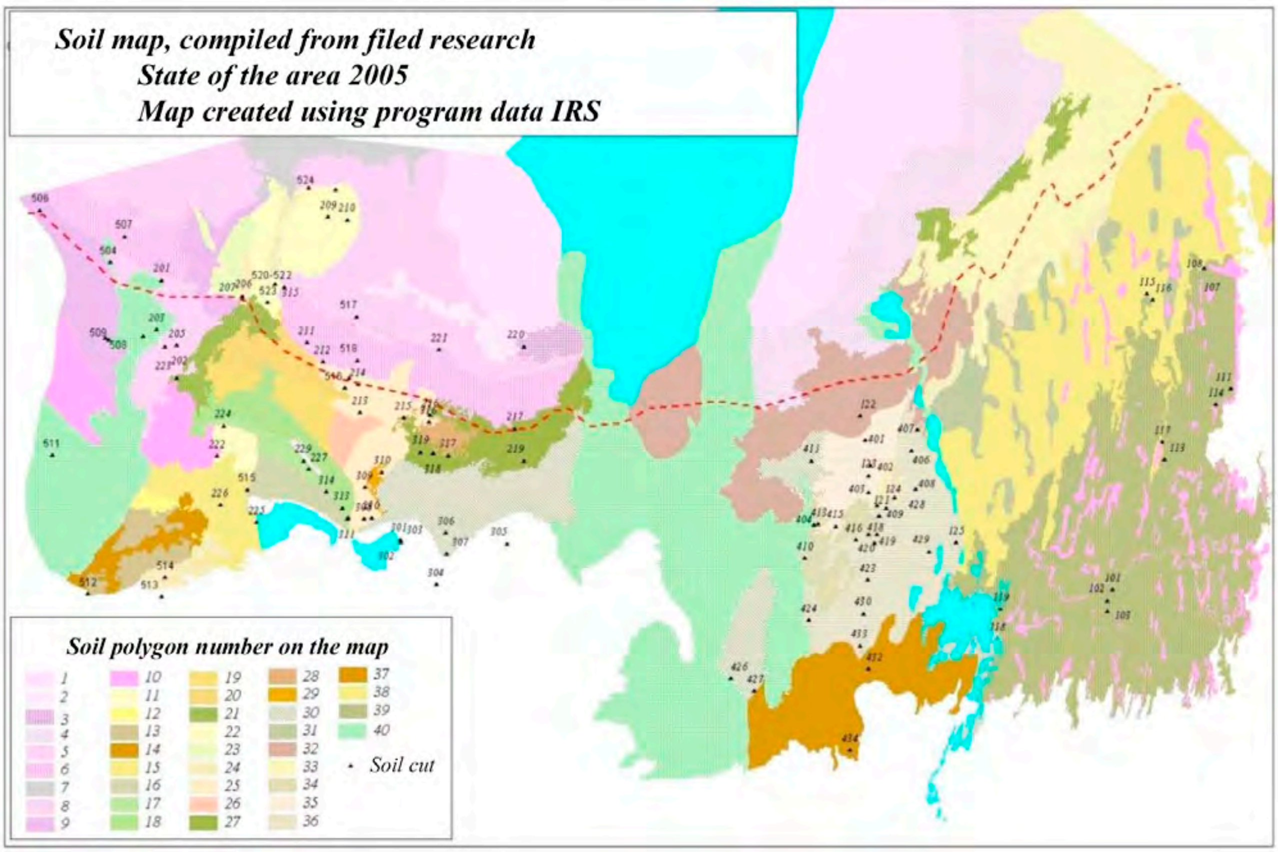


Fig. 13. Soil map, as of 2005

tensification of erosion processes on the dried seabed (Dukhovny V.A. et al., 2008).

Local soil scientists considered the exposed soils as soils which differ from zonal soils by their specific features. These peculiarities consist in dynamism of soil-forming process development both in space and time, in underdevelopment and weak differentiation of soil profile, low biogenicity, predominance of organic matter destruction processes and almost full absence of their accumulation, and as a result, the specificity of water-salt regime of young soils. These features allowed the soil cover of the dried part of the Aral Sea bed to undergo a century-long development cycle in a short period of time (Sektimenko, 1991; Stulina & Sektimenko, 2004).

Table 4.

Changes in the soil cover of the dried Aral Sea bed

Soil Groups	1990	2005	
		In the area covered by the survey in 1990	In the drying zone from 1990 to 2005
Hydromorphic and semi-hydromorphic	763204	276340	372568
Automorphic and semi-automorphic	114443	165834	8304
Desert sand		233460	4381
Sand	172348	321745	81888
Desert meadowlands		52616	45
	1049995	1049995	467186

3 Afforestation to combat erosion – background and status

3.1. Review of the performed works

Aridization caused by the drying of the Aral Sea, its intercoastal lakes, and deltaic inundation of the Amudarya and Syrdarya rivers, together with desertification of vast areas of dried-up seabed and river deltas, has resulted in deterioration of environmental conditions in the sea's region.

Vegetation emerged in the dried-up area after sea recession produced a positive impact of relief from environmental disaster. Within the first three years, salinity of seabed's dried-up clay soils stood at 0.9-1.2 percent. This paved the way for the intensive growth of salt-resistant plants such as glasswort (Salicornia), sea blite (Suaeda) and other halophilous vegetation. During the fifth and tenth years the salinity of the seabed's dried-up clay soils reached 3.45 to 4 percent, eliminating chances for seed regeneration and growth even for salt-resistant plants. Therefore, most of the sea area that dried-up between 1980 and 1998 now contains bare and bleak vegetated sites. In the fourteenth through eighteenth years, salinity of the seabed's dried-up clay soils reduced to 2.6 to 3.5 percent, due to aeolian salt and dust transfer and atmospheric precipitations.

In recent years, the dry-up process intensified and led to a vast land surface area developing from beneath the sea and remote from various desert plants seed sources. Considering the emergence of various benthal deposit types in the area, it is essential that relevant methods are adjusted to local conditions to perform vegetative reclamation facilitating the overgrowth of self-organized vegetation.

Considering intensive desertification and lack of potable water, vegetative reclamation becomes an affordable, reliable and environment-friendly way to reduce albedo (reflectivity). It also reduces the intensity of soil blowout and aeolian saline dust transfer with a simultaneous increase in vegetative productivity of the dried-up Aral Sea bed and the Amudarya River desert cone delta.

Tables 5 to 7 reflect data on the vegetative reclamation of the dried-up seabed as performed since 1980s to 2020.

Table 5.

2000-2008 donor funded reafforestation Works on the Dried Aral Sea bed

№	Name of the organization	Years of production	Total area, ha	Including	
				Sowing, ha	Planting, ha
1	GTZ (Germany)	2000	1300	200	1100
		2001	4300	1500	2800
		2002	5300	2500	2800
		2003	5500	2800	2700
		2004	3450	2000	1450
		2005	2465	1500	965
		2006	2585	1800	785
		2007	2100	1600	500
	Total		**27000**	**13900**	**13100**
2	IFAS (Nukus branch)	2002	450	450	
		2003	339,7	339,7	
		2004	2551	2551	
		2005	2012,8	2012,8	
		2006	582,6	582,6	
		2007	2667,93	2667,93	
		2008	1250,88	1250,88	
		2009	1145,13	1145,13	
		2010			
		2011	97,54	97,54	
		2014	1632	1632	
		2015	1126,5	1126,5	
		2016	849	849	
		2017	405	405	
		2018	721,4	721,4	
	Total		**15831,48**	**15831,48**	
3	National Association 'Priaralie'	2004	321,5	321,5	
	Total		**321,5**	**321,5**	
4	Separate directorate for enterprises under construction -1 (National Association 'Priaralie')	2004	1000	1000	
		2005	1729	1729	
		2006	1796	1796	
		2007	1775	1775	
	Total		**63000**	**63000**	

№	Name of the organization	Years of production	Total area, ha	Including	
				Sowing, ha	Planting, ha
5	KOFUTIS (Uzbek-French company)	2004	1450	1450	
	Total		**1450**	**1450**	
	TOTAL		**50903**	**37803**	**13100**

Table 6.

State Committee on Forestry of the Republic of Karakalpakstan's 1988-2019 reafforestation works on the Dried Aral Sea bed

№	Production years	Total area, ha	Including			
			Mechanical sowing	Planting	Aero-sowing	Promoting natural renewal
1	1988 г. и ранее	71730,0	58730			
2	1989	11343,5	11260	83,5		
3	1990	13240	12940	300		
4	1991	9835	8768	1067		
5	1992	6760	6438	322		
6	1993	8729	8374	355		
7	1994	10358	10180	178		
8	1995	11353	11012	341		
9	1996	14872	14322	550		
10	1997	14865	14131	734		
11	1998	14823	14127	696		
12	1999	5751	5036	715		
13	2000	15080	14500	580		
14	2001	16384	15491	893		
15	2002	11870	11150	720		
16	2003	15769	14635	1134		
17	2004	6972,5	6305	667,5		
18	2005	16812	13756	2056		1000
19	2006	14962	7207	3908		3847
20	2007	14400	7375	3015		4010
21	2008	14924	7690	3022		4212
22	2009	15330	6545	4060		4725
23	2010	12602	3375	4527		4700
24	2011	16794	3600	5094		8100
25	2012	16781	3665	5141		8075

№	Production years	Total area, ha	Including			
			Mechanical sowing	Planting	Aero-sowing	Promoting natural renewal
26	2013	16822	3600	4705		8517
27	2014	17338	3575	5058		8705
28	2015	18242	3475	5403		9364
29	2016	18894	8162	5390		5342
30	2017	19043	9733	5410		3900
31	2018	19064	11505	4359		3200
32	2019	460875	119440	15285	326150	-
	Total	**952618,0**	**450002**	**85769**	**326150**	**90697**

An area of over 1 million hectares of the dried seabed was prepared for planting in 2019 (Fig. 14), with 700 hectares of forest seed distributed by intensive aero sowing.

Uzbekistan has started to implement afforestation measures in order to halt the drifting sands on the Aral Sea's dried seabed, since 1980. Twenty years later international organizations also took up the task, particularly the German Development Cooperation Agency (later called the Deutsche Gesellschaft für Internationale Zusammenarbeit, GIZ), the International Fund for Saving the Aral Sea (IFAS), the World Bank, the Global Environmental Facility (GEF), the Japan Fund for Global Environment (JFGE), the Embassy of Japan, and others.

Table 7.

2015-2019 Artificial forest plantations of the Aral Sea's dried seabed

№	Name of forestry enterprises	Total area (ha)	Including				
			2015	2016	2017	2018	2019
1	Buzatau	3097	555	701	601	620	620
2	Chimbay	10185	1937	2020	2073	2075	2080
3	Karauzyak	11733	2230	2344	2382	2387	2390
4	Takhtakupir	12095	2435	2555	2593	2252	2260
5	Muynak	40523	7840	8029	8149	8350	8155
6	Kazakdarya	16435	3245	3245	3245	3200	3500
7	Kungrad	2300	2300				2300
8	Nukus	380	380			180	200
9	Khodjeilinsk	119	119				119
10	Nukus (specialised)	10					10
11	Shumanaysk	10					
12	Kanlykulsk	55					
	Total	**96942**	**18242**	**18894**	**19043**	**19064**	**21699**

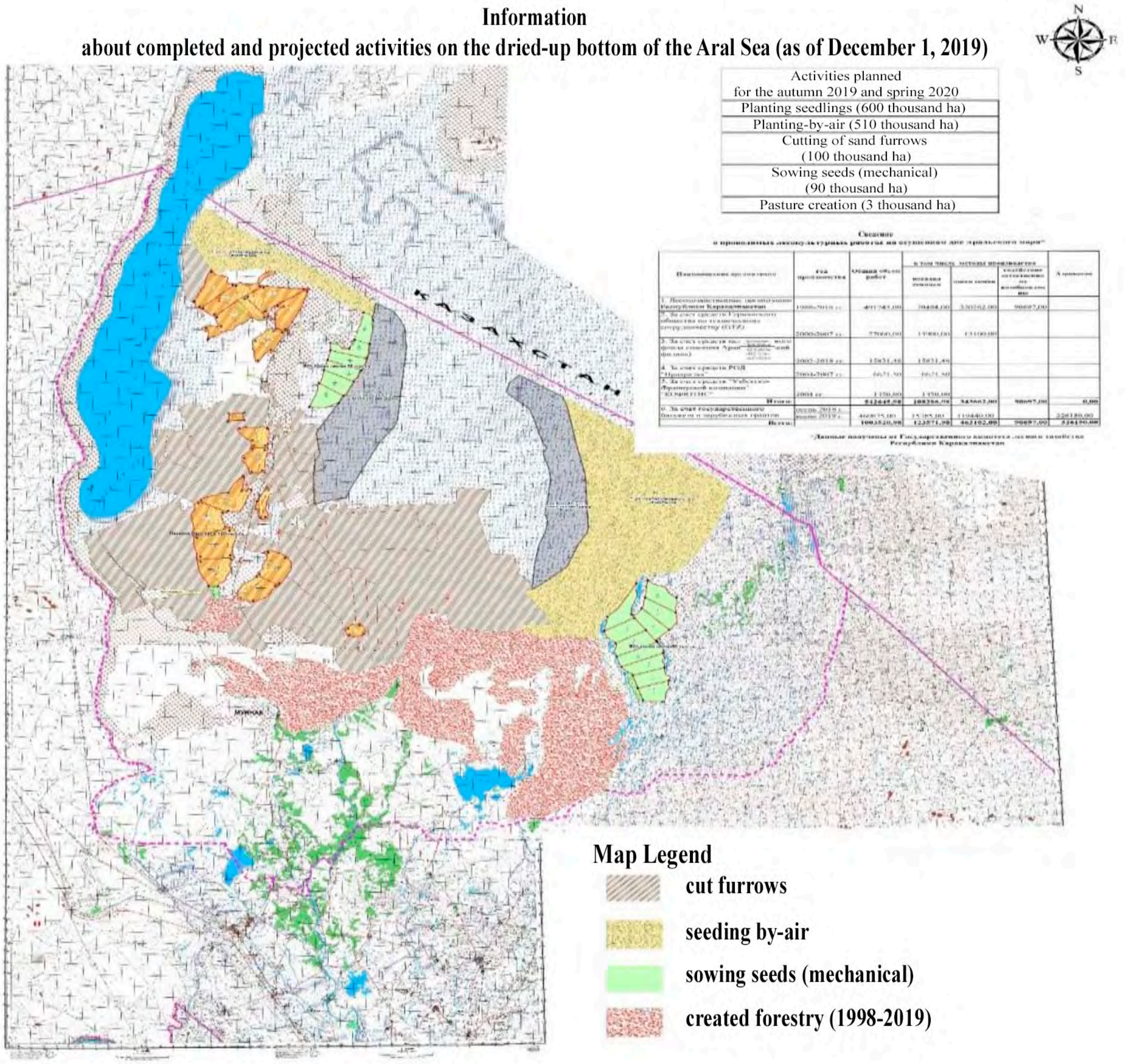


Fig. 14. Information on the work designed for and implemented on the drained bottom of the Aral Sea (as of 1 December 2019)

3.2. Conditions for forest growth in Central Asia and the role of afforestation in the Aral Sea region

In Turkmenistan on 24 August 2018, the Summit of the Heads of the States, founders of IFAS, in an effort of recent political good will, prioritised the issues of the environmental health of Central Asia's transboundary rivers and the problem of the Aral Sea.

Countries of the region currently have opportunities to progress in restoring rivers and ecosystems and recovering them both domestically and regionally. It goes far beyond the understanding that sustainable development and upgrading living conditions depends on preserving natural resources.

The President of the Republic of Uzbekistan at the IFAS Summit proposed the initiative to proclaim the Aral Sea region as a zone of environmental innovations and technologies as a guideline for further actions. This involves a drastic transformation of the Aral Sea's disaster solution ideology. It involves not just drawing attention to the environmental crisis in order to mitigate its negative consequences, but also putting in place a mechanism to eliminate the crisis completely.

Thus, it was proposed to consider the Aral Sea region as an integral water-and-ecology system with possible divisions into subzones of the north and south. This will enable a consolidation of efforts of the Aral Sea basin countries, including Afghanistan, for innovation-driven development.

Experts proposed the protective planting of vegetation able to grow in severe desert soil and climate conditions with minor precipitations. This efficient method combats salt and dust transfer, fixing drifting sands and limiting its adverse impact on the environment, rehabilitates ecological conditions, and further develops a sustainable basis for shieling.

Desert plants absorb carbon dioxide and emit oxygen, though to a lesser extent than conifer and foliose trees. Still, they can fix drifting sands and create a favourable environment for flora and fauna within the protected area.

By the end of the 1980s, the first examinations for further forest planting of the dried seabed were undertaken by the 'Uzgiproleskhoz' research institute. A detailed design was developed and served as a basis for further forest reclamation works. Since the beginning of research to 2018, Uzbekistan afforestation projects have covered over 500,000 hectares. Recently, the Government of Uzbekistan turned its focus to stopping the sea's drifting sands and significantly increasing afforestation, with the last two years of the project covering 1,164.3 hectares of dried seabed. The changes occurring here are striking in their dynamism, which makes it necessary to address the issues of conservation of this unique zone and to prevent possible negative impacts. The dried seabed and the Aral Sea region currently serve as a platform for the application of innovative methods of nature transformation. In addition, the zone is a unique laboratory for scientists, who can observe and study processes that usually take centuries.

One of the tasks of the comprehensive expedition of SIC ICWC in 2019-2020, organized with financial support from UNDP and with participation of the Aral Sea Innovation Center, was to study the seabed's soil cover and state of the vegetation. Comparisons were made between some environmental indicators of recent years and the previous period.

Two expeditions of the surveyed areas that belong to the state forest fund of the Muynak and Kazakhdarya forests carried out artificial planting and the sowing of forest crops.

Undersoil features and the thickness of aeolian sands affect forest growing conditions. Adjacent thick impermeable rocks limits trees and shrub growth. In permeable loose rocks, plant roots develop better with higher productivity. Thus, referring to the topsoils of aeolian sands only while classifying is not advised.

Key factors affecting forest growing conditions are the upper layers' humidity conditions, groundwater depth, as well as its salinity. Higher porosity and smaller moisture-holding capacity prevent sufficient amounts of water from accumulating in the upper layers required for sowing and planting. Abundant atmospheric precipitations penetrate the capillary pores creating water reserves on the groundwater level.

Precipitations in the desert area account for 80-180 millimetres annually, with 50 percent coming during the colder seasons. Maximum precipitation is not clearly distinguished. Precipitation on the dried-up Aral Sea bed barely reaches 100 millimetres annually. Atmospheric precipitations are not observed in the summertime. A flushing soil regime emerges in this condition. The average wetted depth of sandy soils is 100 centimetres, in loamy sands it is 70 centimetres, and in clay loams it reaches almost 60 centimetres. In the springtime, a 1 metre layer of loamy sand dries up, but sandy soils preserve a layer of ground where humidity level exceeds wilting ratio.

Precipitation is the prevailing part as water balance increases under desert woodland with Haloxylon aphyllum. A three years' average for precipitations totalled 107.4 millimetres, for condensation, 25 millimetres, and for hydrometeors, 7.4 millimetres. An average annual moisture amount is 139.8 millimetres. Moisture is evaporated by 76.2 millimetres and transpiration by 62.6 millimetres. Gravitation-driven precipitation moisture downstream weathering zone in case desert woodland, from the top of the soil to the groundwater table, with Haloxylon aphyllum, is lacking.

Thus, the main feature of the water regime of barchan sands is the soaking of the entire aeration zone by precipitation, which determines the formation of a leaching type of soil water regime and the accumulation of moisture in groundwater. In overgrown hilly sands and under high-density haloxylon desert woodland, atmospheric precipitations are completely isolated from groundwater and a nonpercolative water regime with thick impermeable horizon is formed. This feature determines the specific nature of the desert sands forest reclamation works.

The quality of groundwater affects the vegetation range. For saline water, even at small groundwater depth (up to 2 metres), only salt-resistant species such as tamarix, haloxylon, salsola richteri and calligonum can grow. Groundwater can be divided into three groups according to quality, including freshwater with dissolved solids up to 2 g/l, light-salted water with dissolved solids up to 3 g/l, and saline waters with dissolved solids over 3 g/l.

When assessing the forest site's conditions, it is necessary to consider the nature of the relief. This determines agricultural techniques and the use of mechanised planting. There are three types of barchan sands, including small-barchan of up to 1 metre high, medium-barchan of 1 to 3 metres, and large-barchan of above 3 metres. The speed and type of mobile sands' movements are determined as progressive, oscillatory and oscillatory-compulsive, and depend on the thickness of sand accumulations, sand overgrowth and the wind regime of the area.

In different climatic conditions, the above typology of sands will have its own characteristics.

Several subtypes of sands are distinguished within the climatic belt according to the character of forest-styled conditions, including intra-coastal, littoral and prioazial sands. Methods of fixation and afforestation of moving sands on coastal plains and within inland deserts have their own features. Seaside sands are better wetted and therefore characterised by more favourable silvicultural conditions. The salinity of the surface horizons of seaside sands is usually higher but is not critical for the development of a number of salt-tolerant plants. Prioazis and intra-oasis sands have even more favourable forest-styling conditions, which is determined by the close occurrence of desalinised groundwater and periodic moistening of sands due to the discharge of irrigation water outside the oases. Under such conditions, the possibility of afforestation and consolidation of mobile sands increases significantly. Oasis sands are used for growing not only forest plantations, but also (after minor reclamation) agricultural crops.

4 Research methods

4.1. The objectives and team of the research expeditions: Organization of work

The results of nine expeditions from 2005 to 2011 revealed continuous changes in the newly formed landscapes, both in the direction of stabilisation and the development of risk and desertification processes due to the draining of the Aral Sea bed and the maintenance of the ecological balance in the recently developed Aralkum Desert. Despite the increasing scale of stabilisation works, the real improvement of ecological conditions has lagged behind due to the destructive action caused by the machinery and transport of various teams and organizations searching for organic raw materials and undertaking their extraction.

Monitoring the state of the dried seabed became urgently necessary in order to observe natural and anthropogenic interferences in the natural regeneration, as well as preventing the seabed's further degradation by assisting nature in its self-improvement. Monitoring also prioritised the protection of this unique entity from destruction.

The uniqueness of the processes occurring on the dried seabed in the form of significant areas of self-overgrowing and soil formation on the bedrock with the parallel development of microbiological processes has been discovered and published. The results of previous expeditions have established self-overgrowing by seed spraying for tree plantings on an area of more than 200,000 hectares, almost equal to the entire artificial forest plantations recorded at those dates. Moreover, processes that in other evolutionary contexts take decades or even centuries to occur, continue at an accelerated rate throughout this area as it dries up, and this can be observed on an annual basis.

Proceeding from these important findings, and considering the absence of observations for eight years, the expedition was assigned both practical and scientific tasks:

- Identifying conditions and dynamics of changes on dried-up areas;

- Approximate classification of landscape on newly dried-up areas, using remote observation data;

- Landscape, soil, hydrogeology, fauna and flora conditions of dry-up areas, especially that of artificial forest stands;

- Identifying desertification scope, landscape class and risk zone changes and comparing the outcomes of previous monitoring conducted during 2005-2011;

- Forming recommendations on improving environmental conditions and the efficient use of dried-up and developed areas.

Out of necessity, it was decided to evaluate the condition of the area planned for afforestation first, and to simultaneously evaluate the past results from the position of their preservation. The availability of funds for only two expeditions of the planned five determined the scope of the expeditions. The studied territory included the dried seabed from the Amudarya Riverbed (delta and avandelta) to the Kokdarya River and Toguzarkan Channel, from the mark of 53 metres (the sea level of 1960) to the current water level of the East Sea. The shore of the sea, consisting of wet clay with salt, was actually possible to approach and was accordingly investigated.

The first expedition was conducted in the 'Muynak zone' on the territory of 600,000 hectares from the Ustyurt chink to the Amudarya riverbed, and from the mark of 53 metres to its present level (Fig. 15). The expedition took place from 20 September to 20 October 2019.

The second expedition was conducted in the 'Djiltyrbas zone' from 28 May to 26 June 2020, on the territory of 600,000 hectares.

The expeditions were multidisciplinary.

Fig. 15. Area of the dried-up seabed and routes of the first and second expeditions

The expedition team (Fig. 16) included:

1. Head of the expedition and soil scientist - Stulina G.V.
2. GIS specialist - Zaitov Sh. (Kenjabaev Sh.)
3. Ecologist - Eshchanov O.
4. Dendrologist - Ganiev M.Sh.
5. Hydrogeologist - Esembaev G.
6. Botanist - Sherimbetov S.
7. Soil scientist - Idirisov K.
8. Worker (GIS) - Ruziev I.
9. Worker - Zueva N.
10. Worker - Aydjanov J.
11. Driver - Stepanov V.
12. Driver - Zuev S.

Composition of the work and research methods

Work plan:

- Remote sensing: Determination of surface classes based on satellite images;
- Hydrogeology: Level and mineralisation of groundwater;
- Soil: Genetic description, texture, humus, carbonates, gypsum, salinity, salt composition, soil type;
- Vegetation: Composition, conditions of natural vegetation and artificial plantings, assessment of vegetation, assessment of self-overgrowing;
- Ecology: Landscape sustainability, risk classes.

Fig. 16. Expedition members on the dried bottom of the Aral Sea

Transportation

Three vehicles were used on the route of the expedition, specifically a Mitsubishi Pajero Sport Jeep, a Nissan Patrol Jeep, and a Ural-577 (Fig. 17).

Expedition routes

The expedition routes (Figs. 20 and 21) were chosen based on uncontrolled classification of satellite images in approximation to the routes of previous expeditions. The route of the first expedition covered 2,500 kilometres. Considering the large territory of the survey, four tent camps were organized (Figs. 18 and 19). The mileage of the vehicles for the second expedition was 2,850 kilometres and two camps were organized.

Results of the ground expeditions:

- Full description of 2,142 points on the ground for the identification of satellite images was completed;
- Botanical description of the vegetation was made, and plant formations were identified;
- Description of the state of natural vegetation and artificial plantings, including species composition, height, and projective vegetation coverage on all tiers was prepared;
- Self-overgrowth processes were defined;
- Fifty-six soil profiles were placed, on the basis of which a morphological description of the soil profile was performed and soil samples were selected according to genetic horizons;
- The existing hydrological network of four wells and eleven self-discharging wells was monitored, groundwater levels were measured, and water was taken for analysis;
- A description of the ecological condition of the area and a preliminary environmental risk assessment was carried out

Fig. 17. Expedition vehicles

Fig. 18. Expedition camp

Fig. 19. Field lunch

Fig. 20. The route of the first expedition

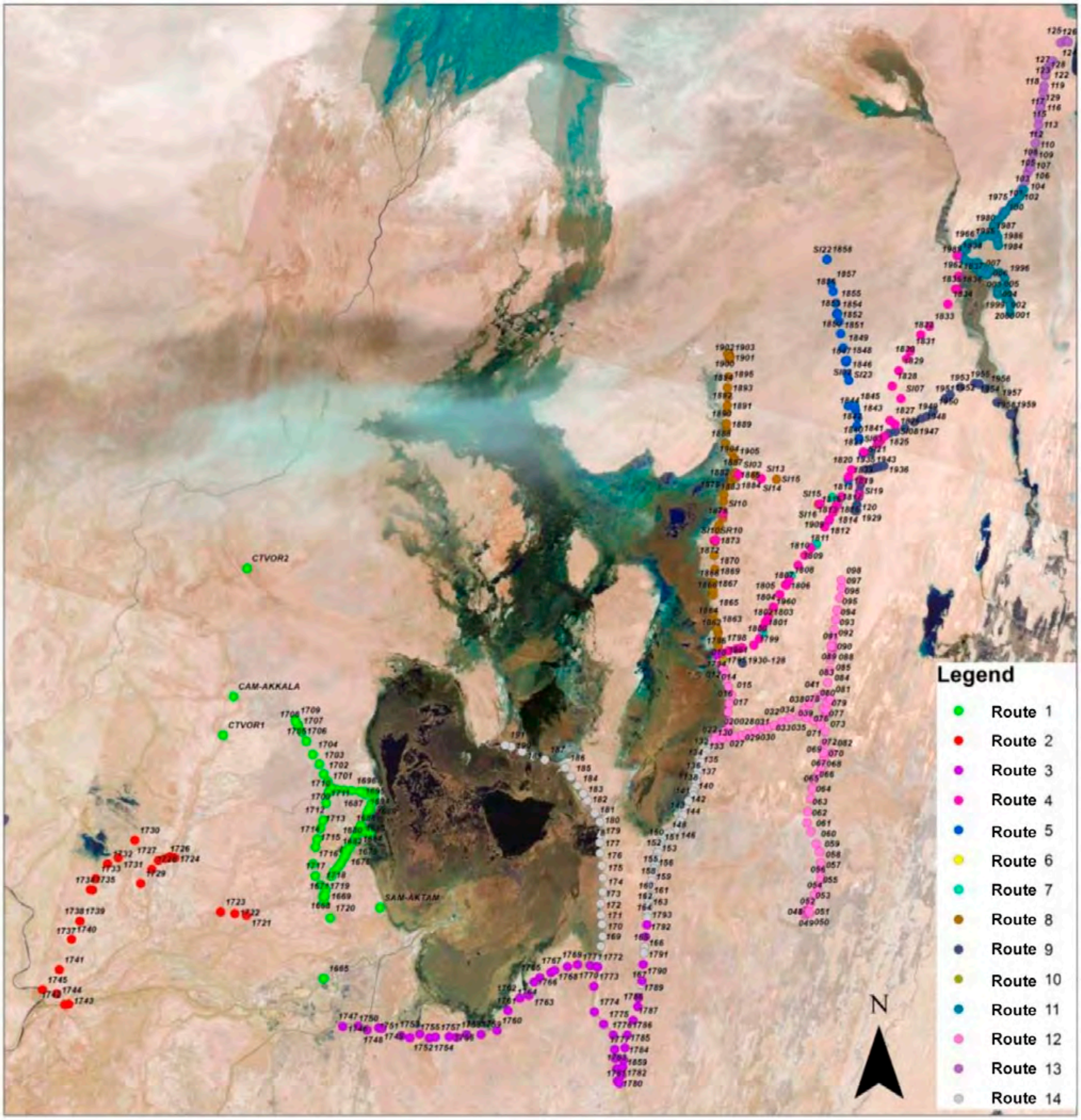


Fig. 21. Route of the second expedition

4.2. Field research methods

4.2.1. Methodology of soil research

Soil surveys consist of:

1. A field study of soil cover along expedition routes;

2. Laboratory analysis of selected samples;

3. Analysis of the obtained data, and development of soil maps.

The field study included a description of the area, selection of key sites, laying of soil sections, morphological description of the soil profile by genetic horizons, and soil sampling. Soil description was made based on a standard sample. Soil samples were submitted to the laboratory to determine the chemical and physical condition of soils, the content of salts by the full composition of the water extracted, its anionic and cationic composition, organic matter content, gypsum, and carbonate content, and the mechanical (granulometric) composition of soils.

The soil survey had several objectives:

1. Study the soil cover of the dried seabed and develop a soil map as of 2019;

2. Analyse the soil cover with consideration of vegetative cover, and identify areas of possible vegetation planting;

3. Compare soil maps of 1990 and 2006, determine changes and assess trends.

Each key site has geographic coordinates, and information is included in the summary table of field observations.

4.2.2. Vegetation study methodology

Characteristics of the natural vegetation cover in the context of ongoing changes are given in the geobotanical description of the territory, with consideration of the features of vegetation and soil-groundwater conditions that define the areas subscribed in terms of salinisation and desertification, and prediction of their foci.

Description of vegetation cover begins with a preliminary survey study area for general orientation, as well as establishing the ecological relationships of plant communities with local conditions, which include topography, soils, moisture features, soil salinity and other matters. After a thorough examination, the most typical site of the phytocenosis with a certain representativeness, uniform floristic composition and habitat conditions was selected.

Significant place was given to phytomeliorative survey of land and specifically, to the planting and sowing of saxaul, as well as shrubs and semi-shrubs, in order to create pastures. Based on the detour and inspection routes of the area and the state of saxaul and other types of vegetation, several sites have been selected for geobotanical description of soil sections.

Geobotanical description has been made simultaneously on three sites in three repetitions:

a) Best survival rate

b) Average survival rate

c) Poor survival rate

4.2.3. Hydrogeological research methodology

The types, volumes, sequence and methodology of the hydrogeological survey should be justified and carried out considering the geological and hydrogeological conditions of the study area and the successful solution of the basic and additional tasks set before the survey (Klimentov P.P. et al. Methodology of

Hydrogeological Research, Vysshaya Shkola, Moscow, 1978, 408 p.). They include the collection of previously given geological, geomorphological, hydrological and hydrogeological observations. Various types of ground-based visual observations are carried out during route surveys of the mapped area, which are one of the main integral types of work in the hydrogeological survey. The material obtained as a result of route surveys is important for studying and evaluating the upper aquifers (penetrated by the erosion network, mine wells and shallow wells) and compiling an appropriate hydrogeological map. The level and salinity of groundwater may have required the drilling of pits along the adopted route.

4.2.4. Environmental survey methodology

The main method of the environmental survey is the study of the dried seabed's landscapes, direct observation, condition assessment, description of the selected field routes (automobile and visual), as well as a description of the topography of the terrain at points, and soil cover. The routes of the expedition are marked with sections or the individual segments to describe the characteristic images. Descriptive methods are one of the main methods used in environmental monitoring. Direct observation of the objects under study, recording the dynamics of their state over time and the evaluation of the changes recorded, allows for predictions of possible processes in the natural environment.

Descriptive methods are used in the registration of the main features of the objects under study, mapping of ecological phenomena, and the inventory of valuable natural objects. These methods are key in ecological monitoring.

It is especially important in ecological studies to identify the factors that determine the status of the environment. For the Aral Sea, the direction of processes is significant. The volume of drainage, intensity of drainage, change of species composition, state of vegetation, salt transfer, surface desalinisation, change of biogeocenosis and others matters all determine the environment's status.

The next step of ecological monitoring is the ecological zoning of the area.

Its purpose is to systematise data on the ecological conditions of territories and to assess their complexity and heterogeneity. Recently, environmental specialists have been increasingly using ecological zoning in their work since it not only has scientific value, but also important practical value. In general, the research can be called "ecological landscape monitoring."

Automatic and remote devices are important for the continuous monitoring of and distinguishing of positive and negative changes of the dried seabed. It is possible to identify zones of varying degrees of environmental risk, and to study the changes taking place in the ecosystem.

5 GIS and remote sensing as a basis for field surveys

5.1. Methods

In environmental research, the integration of remote sensing with ground-based measurements is of growing interest. To this extent, Geographical Informational System (GIS), Earth Observation (EO) and Remote Sensing (RS) satellites in space are viewed as successful and intensively developing innovative assets. The directive of the President of the Republic of Uzbekistan No. R-5209 stated that "…measures to develop satellite research and technologies in the Republic of Uzbekistan" (12 February 2018) confirmed that the introduction of RS is significant. This chapter describes the preparation of field surveys based on RS and GIS data, and will show surface measurements for landscape class testing on the dried-up Aral Sea bed with the GPS navigator, as well as imaging and populating a field report with obtained information.

GIS is a software package for spatial data development (data on an object's geographical location), visualisation, search and analysis (Lo & Yeung, 2004). In most cases, it uses geographic coordinates such as latitude and longitude, identified with the GPS (Global Positioning System) navigator. The World Geodetic System (WGS 84) has been used in the Republic of Uzbekistan since 2018.[1] RS supervises and measures energy and polarisation characteristics of radiation emitted by objects from various diapasons of the electromagnetic spectrum, to identify the location, types, features and temporal variability of environmental objects without direct contact (Campbell, 1996; Jensen, 2004).

Data on the same survey area (ground environmental site investigation surveys, measurement of soils' hydrophysical property features, statistical data, cartographical materials, and aerial and satellite survey materials), as obtained from various sources, provide a bulk of miscellaneous information with a different scope. Due to the complexity of data processing, analysis and storage, the role of GIS-based cartographical databases in the geo-environmental assessment of utilized areas are increasing. This enables researchers to develop a single e-base of spatial and alphanumeric data, increase selectivity and efficiency of data processing and analysis, and produce soft and hard copies of comprehensive cartographical documents.

Considering the above, all geospatial data (including space imaging) have been transformed in the framework of the WGS 84 coordinate system. The following methods were employed as

1 Resolution of the Cabinet of Ministers of the Republic of Uzbekistan No. 1022 'On application and open use of international geodetic systems of coordinates within the territory of the Republic of Uzbekistan' dated 26 December 2017.

major methodical tools to analyse the survey area's geo-environmental status:

- Soil and vegetation cover condition assessment methods, reflecting data of the RS optic systems (Kozodyorov & Kondranin, 2008);
- Ecosystem monitoring, simulation, and assessment methods (Lopez & Frohn, 2017);
- Our previous developments (SIC ICWC, 2008).

Obviously, expeditions collecting field measurements on site must be thoroughly planned and optimised. Expeditions often cover large and remote areas, meaning they require both logistics and infrastructure. To determine the test areas of the study, the available data was analysed, and the primary processing of remote sensing data (including unsupervised classification) was carried out. Based on these materials, expedition routes were determined and a field form describing the area with fixed GPS coordinates of field observation points was compiled. The GPS recording of ground measurements and field observations enables a detailed analysis of geospatial data. The data, in the form of monitoring point matrices, are used to decode, calibrate, verify, and validate the mapping results from RS data. The following describes the steps of field survey preparation:

5.2. Field survey preparation

Stage 1: Defining a landscape mapping legend

Легенда отражает семантическое «oThe Legend reflects semantic "summarising/generalisation" of a certain geographic area. The real world can be considered as a "continuum" with significant granularity of various information. Thus, the process of categorising is a process of minimizing this complexity. It is important for "map producers" to ensure that the minimal requirements for the correct use of the Legend are met:

- Clear and undoubted identification of a class;
- No class-related semantic in clarity, meaning the class (semantic) edge is not overlapped with other legend classes.

In this study we used an already defined legend containing 17 classes from the previous 2006 study

Currently the Minimum Mapping Unit (MMU) is used instead scale mapping and defines "the smallest earth surface reflected on the map, i.e., representation." Thus, MMU is not just a more accurate parameter for cartographic edges of the map, but also affects its specific details.

It is recommended to visit only areas with a homogeneous land cover of at least 1 hectare (or within a radius of 100 metres), which is defined as MEC. In this study, the spatial resolution of satellite images (in our case LandSat with a resolution of 30 * 30 metres) must be considered when determining the MEC.

Stage 2: Identifying field measurements scope based on legend class

A sample unit is a unit of area that is observed in a field. It can be an outline of fields or land (in the sense of a polygon), an artificially defined segment (in the form of squares, rectangles or from image processing software such as eCognition), sections, points, or others.

The sampling unit of the field measurements in the selected classes is the reference unit, and it associates the spatial location on the ground with the corresponding location on the map. The shape and size of the sampling unit must be determined so that observations in the field can be spatially related and compared to the ground resolution of the corresponding spatial unit on the land cover map, which are classified either as pixels or polygons.

The option for polygon sampling is to automatically generate observation points or areas

Table 8.

Land cover map legend class (SIC ICWC, 2008)

NN	***Class***
1	**WATER**
1.1.	Water surface
1.2.	Shallows, sometimes with reeds
2	**SOLONCHAKS**
2.1.	Marches without vegetation or with soleros communities
2.2.	Wet seaside with seashells, sometimes with isolated specimens of sarsazan and sclerosal
2.3.	Crusty-plump and crusty without vegetation, sometimes with single specimens of shrubs (karabarak, comb)
2.4.	Salt marshes with a blown sand cover with sparse swan and selina communities
2.5.	Sor salt marshes of closed depressions without vegetation, sometimes framed by sarsazan forests
3	**SANDS**
3.1.	Plain (with shells) without vegetation or with sparse shrubs (saxaul, comb)
3.2.	Dune without vegetation
3.3.	Shallow hilly (weakly fixed) with sparse communities of wormwood, shrubs and selenium crops
3.4.	Hilly and hilly-ridge without vegetation and weakly fixed
3.5.	Hilly, hilly-ridge fixed with ephemeral-wormwood-shrub communities
4	**PLAINS DELTA AND ACCUMULATIVE**
4.1.	Meadows on alluvial plains (reed, herb-grasses) on alluvial-meadow, bog-meadow and meadow-bog soils
4.2.	Desertifying hydromorphic cereal-halophytic forbs with shrubs
4.3.	Shrub thickets (halophytic: tamarix, karabarak)
4.4.	Desertifying shrub
4.5.	Shrub-saxaul (desert forests/artificial plantations)

within selected polygons. The coordinates of the points are used to distribute the observation areas within the selected polygons of the class. This technique can be adapted according to the size of the polygon or land cover class, for instance by assigning more than one observation site on large polygons. The sampling unit is still a polygon, but the use of multiple representative observation sites allows the observation of polygons that are too large to be observed at a single observation point.

To get an overview, in 2019 an unsupervised k-means image classification method was applied to determine the boundaries of spectrally homogeneous regions/contours representing homogeneous landscape types. A more detailed description of the unsupervised classification method is given in Chapter 5.5. The extracted polygons are assigned to one of 17 land cover classes (Table 8) and are the target-sampling units of the field measurements. Within each target-sampling unit, one or more locations will be visited during the field campaign (large polygons may require the collection of GPS data over multiple locations).

Stage 3: Sampling design

The sampling design describes the protocol by which sampling units are selected for field observation. The purpose of the sampling scheme is to define a proper and transparent selection process that creates a representative sample of the map and efficiently allocates available resources. There are two different types of sampling schemes, including probability sampling and non-probability sampling. Examples of non-probability sampling are usually used to collect training data for map classification. An example would be a "survey of the terrain along the road," where the researcher observes "suitable" land cover patterns and position along the road.

Here, the number of measurements after probability sampling, based on the unsupervised classification map, is preselected in order to first stratify the study area to better control the number of measurements per map class and to ensure that all classes are well represented for analysis. The number of samples that are selected from each stratum can be the same for each, or based on different criteria, such as being proportional to the number of samples per stratum

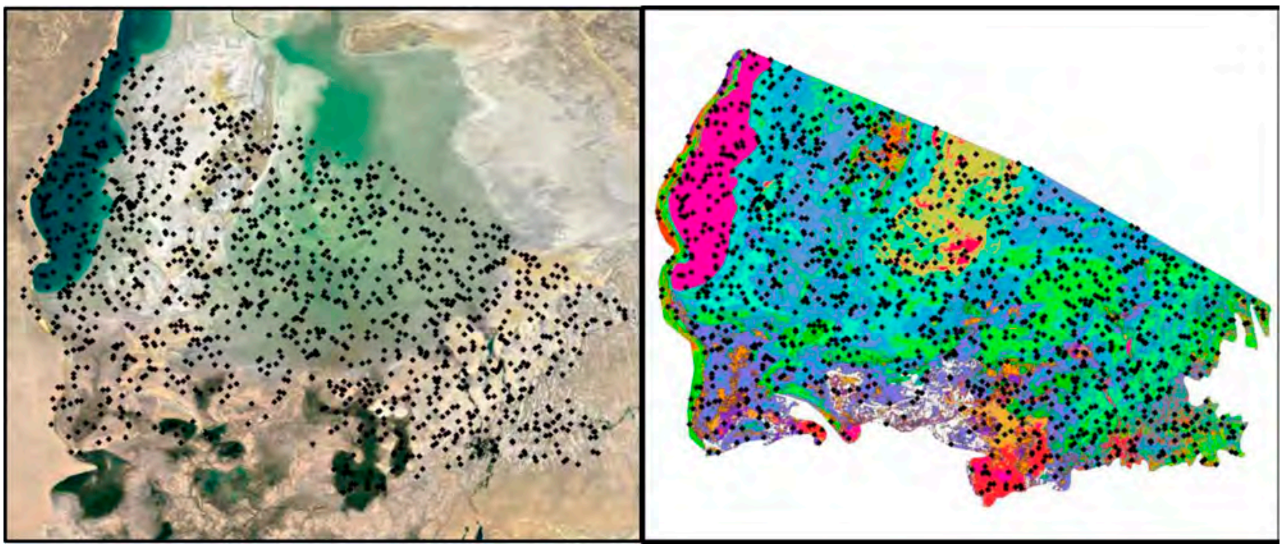


Fig. 22. Example map of selected samples (left: Google Maps as background; right: unsupervised classification as background)

Table 9.

Preliminary sample quantities by volume of map classes or object area

Land cover map classes and polygon area	Required number of samples
< 12 classes or < 4,000 km^2	50
> 12 classes or > 4,000 km^2	75-100

or area. We selected samples proportional to the area of the stratum (Fig. 22).

Stage 4: Selecting the number of samples

One of the most important questions when planning field measurements is to determine how many samples are needed in total and how many samples should be allocated to each layer (map class) to get a satisfactory estimate of map accuracy. In general, the more samples collected, the higher the reliability of the estimated map accuracy result, but for a certain number of samples, the level of reliability that additional samples can create is negligible. Moreover, field studies are expensive, so it is desirable to find the optimal number of samples to collect as a compromise between the required level of reliability and available resources for ground measurement.

Often the number of measured samples offered for verification (comparison) is derived from non-statistical analyses, empirically, or simply from the experiments of experts. For example, the approach proposed by Congalton (1991) determines the number of samples per map class or strata according to the number of classes and the size of the test plot. This "rule of thumb" should provide a guideline for estimating the appropriate number of all samples needed (Table 9).

Following this approach we planned to take a minimum of 1,275 samples, since the total area of the study site is less than 4,000 km2 (about 2.2 million hectares), and the number of uncontrolled land cover classes under study is 17 classes (i.e., 17x75 = 1,275 samples).

Stage 5: Survey instructions

The survey guideline defines what data are collected in the field and how they should be appropriately collected. Field measurement, or benchmark data collection, is a fundamental step in confirming the accuracy of any model results. The accuracy assessment assumes that the field data collected are accurate (reflecting the reality of the study area) and representative/representative but based on an independent sample of land cover.

Expeditions in 2019-2020 were expected to follow previous and known routes with good accessibility as much as possible, for instance the same routes as 2006, 2007 and 2009 (Fig. 23). It is recognised that not every pre-selected sampling point can be reached. Water points (water-logged areas) close to the shoreline, where soils are likely to be wet and inaccessible to vehicles, as well as sand dunes, dunes, and dense vegetation along the road, will be omitted. Also, if the point is located in the middle of a polygon or close to the boundary between two class polygons, it may be necessary to adjust the route.

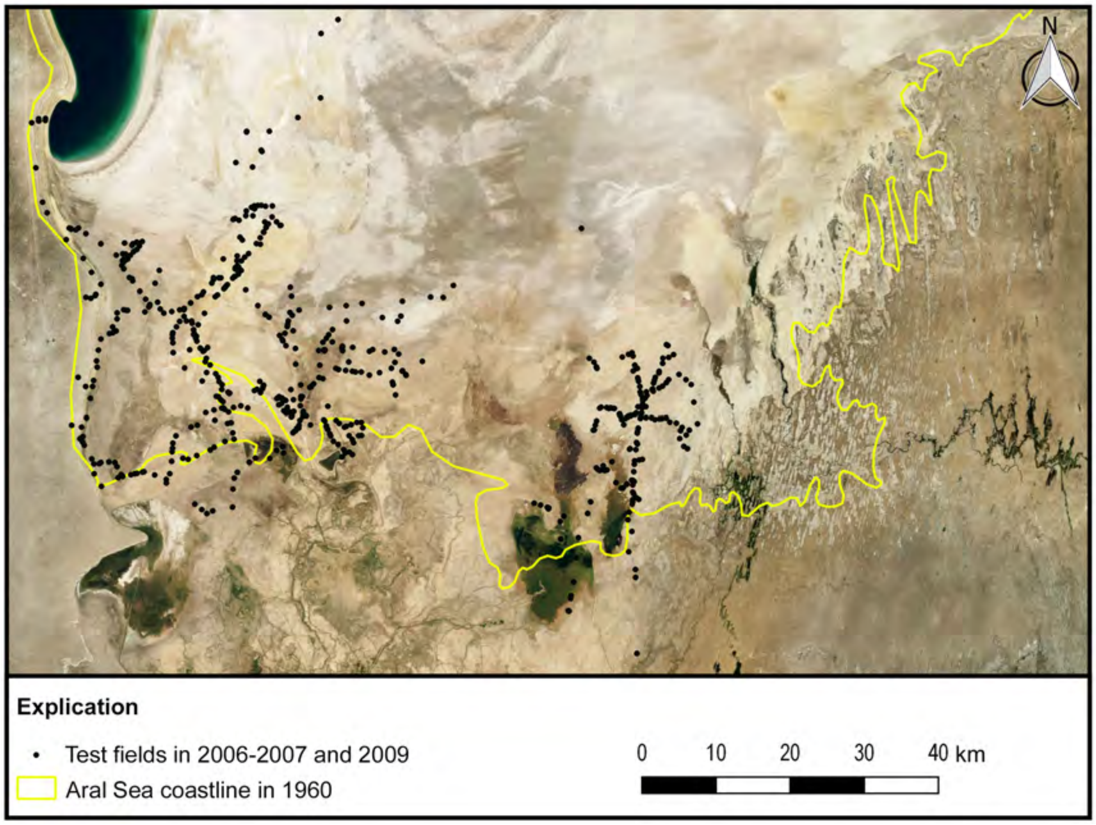


Fig. 23. Location of field points of the previous routes from the expeditions to the dried Aral Sea bed in 2006, 2007 and 2009, on a background of Google Maps

Stage 6: Conducting field work

The following is the fieldwork required to determine GPS coordinates of typical landscapes of the area:

- Daily preparation and planning of the route using prepared maps of previous expeditions (Fig. 24);
- Marking GPS coordinates of points with visual inspection of vegetation cover, soil features and landscape description within a radius of 50-100 metres:
  - Digital photos (at least four in each direction: north, east, south and west);
  - Input of data from the GPS navigator, photos into the computer and backup after each trip (route);
  - Daily comparison of collected GPS points for each of the 17 classes prepared by the method of unsupervised classification..
- Daily entry of visual observations in the field book (Table 10).

Table 10.

Field book for entering visual survey data

Полевая форма для картирования земельного покрытия/пользования в ККР, 2019-2020 гг.

ID участка:	Дата:		Выполнил (ФИО):
	Время:		

ID Точек:	№ Фото.:	Направление:

GPS:		Ф/аппар.:	
Etrex Vista H.		EOS D20	
Etrex		Др.	

Облачность:		Сокр.: 0/1/2/3: нет
Местность:		Сокр.: п/ск/х: плоская / слегка холмистая / холмистая
Почва/Литология:		Сокр.: нс/к/х: несвязная / корка / холмистая

Точка полигона (WP):	
Начало WP#:	Конец WP#:
Начало WP#:	Конец WP#:

Заполнить если первая фаза не «голая почва»

Натуральная наземная растительность:

	Форма: (Д/К/Н)	Покрытие: (З/О/Р)	Высота: (см)	Пространственное распростр.: (НП/КС)	Форма листьев: (ШЛ/ИЛ/БЛ)	Основной вид растительности:	
Основной слой:							
Второй слой:							
Третий слой:							

Сокр.: Д/К/Т: дерево/куст/травяной ; З/О/Р: закрытое/открытое/редкое ; НП/КС: непрерывная/кусок; ШЛ/ИЛ/БЛ: широколист / игольчатый / безлистный

Натуральная водяная растительность:

	Форма: (Д/К/Н)	Покрытие: (З/О/Р)	Высота: (см)	Сезонность воды (>4/2–4/3Т)	Форма листьев: (ШЛ/ИЛ/БЛ)	Основной вид растительности:
Основной слой:						
Второй слой:						
Третий слой:						

Сокр.: Д/К/Т: дерево/куст/травяной; З/О/Р: закрытое/открытое/редкое; >4/2–4/3Т: >4 месяц затопляется/2–4 мес. затоп./затопленный; ШЛ/ИЛ/БЛ: широколист / игольчатый / безлистный

Возделанная и управляемая земля

Наземная / Водяная:	Вода: (P/DV/WL)	Форма: (Д/К/Н)	Форма листьев: (ШЛ/ИЛ/БЛ)	Травянистый: (Да/Нет)	Тип культуры: (П/НП)	Название культуры:

Сокр.: УВП/СВВВ/ЗБ: устойчивая во время вегет. периода/суточная вариация во время вегет./заболоченная; Д/К/Т: дерево/куст/травяной; ШЛ/ИЛ/БЛ: широколист / игольчатый / безлистный; П/НП: продовольственная культура/ не продовольственная культура

Натуральная наземная без растительности:

Голая почва:	Пухлая / подвижные пески: (Б/П)	Структура (П/И/Г)	Соли: (К/Н/Н)	Тип корки: (С/И)	Редкая вегетация: (Д/Т)	Порода:
Непривязанная						
Затвердевшая	XXX					

Сокр.: Б/П: барханы / плоский; П/И/Г: песок/ил/глина; К/A/N: корка/накопление/нет; С/И: соль / ил; Д/Т: древесный/травяной

Натуральная водяная без растительности:

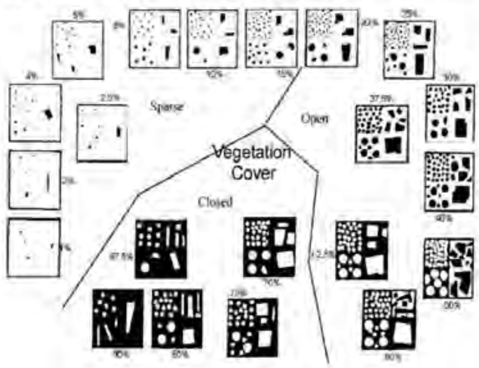
Физическое состояние: (Т/С)	Продолжительность (М/НМ)	Приливная площадь (По/Пе)	Глубина: (Г/НГ)	Sediment load:

Abbr.: Т/С: течет/стоящий; М/НМ: многолетний/не многолетний; По/Пе: почва/пески; Г/НГ: глубокая/не глубокая

Искусственно без растительности:

Стройки:	Без строительства:

Саранча:	*Да*	*Нет*
Имеется:		
Кладка яиц:		
примечание:		



5.3. Expedition routes

Routes for the expedition were determined considering the changes of the previously studied eco-landscape (studies that were conducted in 2006-2007 and 2009). In total, 33 routes were organized during 2019-2020, and 2,142 sites/points were visited (Table 11, Fig. 24).

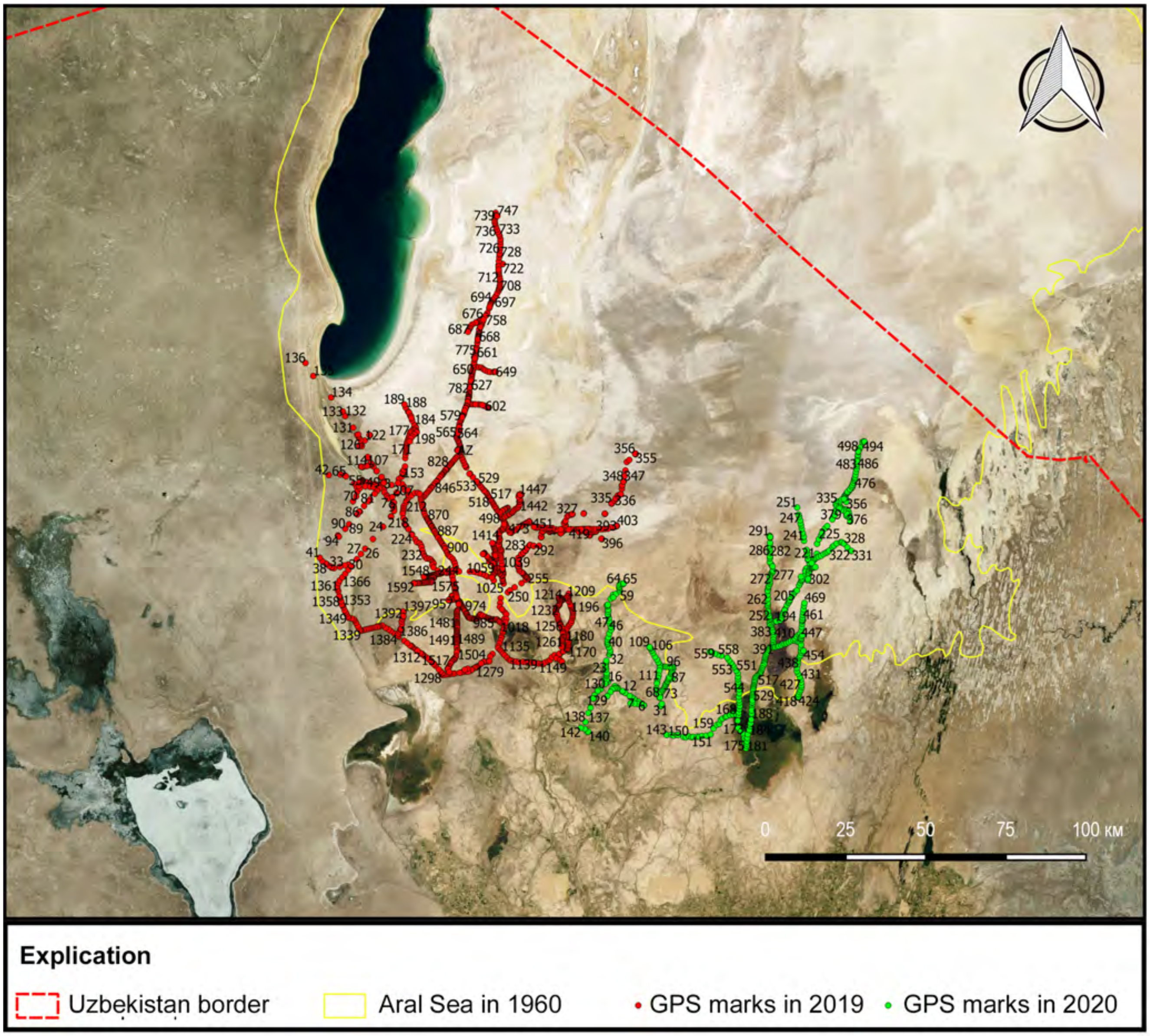


Fig. 24. Travel routes and number of sites/points visited during the two expeditions in 2019-2020, on a background of Google Maps

Table 11.

Routes and number of points of the two expeditions in 2019-2020

№	Name of the route	Number of points (numbering)
1st expedition, 2019		
1	Route #1: From Camp #1 towards Polder Adjibay-1 and back in a circle. Direction from Camp: South and South-West.	44 (T.1-44)
2	Route #2: From Camp #1 to the road to Chinka. Direction from Camp: South-West and West.	51 (T.45-94)
3	Route #3: From Camp #1 to the West Sea shoreline. Direction from Camp: North and North-West.	42 (T.95-136)
4	Route #4: From Camp #1 towards the Sudochie-Adjibay hydrogeological site. Direction from Camp: North.	67 (T.137-203)
5	Route #5: From Camp #1 in the direction of the Mejdurechenskaya Reservoir (through the “Tigroviy Hvost” (Tiger’s Tail)). Direction from Camp: South.	46 (T.204-249)
6	Route #6: From Camp #2 towards Polder Adjibay-2 (between Muynak Dam and Rybatsky to the old riverbed of Injeneruzyak). Direction from the camp: North and North-East.	66 (T.250-315)
7	Route #7: From Camp #2 towards the dried bottom of the East Sea (along the Amudarya riverbed). Direction from Camp: North and North-East.	41 (T.316-356)
8	Route #8: From Camp #2 towards Polder Djiltyrbas-1, along the coastline (Berdybek). Direction from Camp: East.	63 (T.357-419)
9	Route #9: From Camp #2 towards the zero marker. Direction from Camp: North and North-West.	124 (T.420-550)
10	Route #10: From Camp #3 in the direction of the island “Revival”. Direction from Camp: North.	270 (T.551-819)
11	Route #11: From Camp #4 (from «Nulyovka»/zero marker) to the north-western part of the Muynak reservoir. Direction from Camp: South.	92 (T.820-911)
12	Route #12: From Camp #4 to the «Aral» village and then the experimental area of the International Innovation Center for the Aral Sea Region and around the Muynak reservoir. Direction from camp: South, South-East.	112 (T.912-1023)
13	Route #13: From Camp #4 along the shoreline (through «Tigroviy Hvost»). Direction from Camp: North.	94 (T.1024-1117)
14	Route #14: From Camp #4 to the Amudarya riverbed (through Parlantau). Direction from Camp: North-South and South-North (circle).	152 (T.1118-1269)
15	Route #15: From Camp #4 to the Northern part of the lake Sudochie (along the dam). Direction from the Camp: West and North.	104 (T.1270-1373)

№	Name of the route	Number of points (numbering)
16	Route #16: From Camp #4 in the direction of the unstable ecological zone - sand dunes through Sudochie Lake. Direction from the camp: West and North.	24 (T.1374-1400)
17	Route #17: From Camp #4 in the direction of the "Neftyanoy burovoy". Direction from Camp: North.	53 (T.1401-14 53)
18	Route #18: From Camp #4 to Kyzyljar, and the Tek Uzek Canal. Direction from Camp: South.	72 (T.1454-1525)
19	Route #19: From Camp #4 to the North-East of Sudochie Lake. Direction from Camp: South and South-West.	72 (T.1454-1525)
2nd expedition, 2020		
1	Route #1: From Camp #1 to Akkala (along the Varashilov Canal to the bank of the new Amudarya River channel (Urdabay channel)). Direction from Camp: West-North-West-North.	69 (T.1-69)
2	Route #2: From Camp #1 to Akkul. Direction from the camp: North.	55 (T.70-120)
3	Route #3: From Camp #1 to the Kazakhdarya Dam (Amudarya channel). Direction from Camp: West-South-West.	22 (T.121-142)
4	Route #4 (crossing): From Camp #1 to Camp #2 (central camp of forestry). Direction from the camp: South-South-East-North.	49 (T.143-191)
5	Route #5: From Camp #2 to the temporary bridge of Kokdarya. Direction from the camp: North-North-East.	43 (T.192-233)
6	Route #6: From Camp #2 to soil section #22 from 2005. Direction from Camp: North-East-North.	18 (T.234-251)
7	Route #7: From Camp #2 to soil section #21 from 2005. (Along the border of barchans with a height of 6-8 metres). Direction from the camp: North.	42 (T.252-293)
8	Route #8: From Camp #2 to the Northern Camp of the forestry enterprise.	4 (T.294-297)
9	Route #9: From Camp #2 to the right bank of the Kokdarya.	36 (T.298-331)
10	Route #10: From Camp #2 to soil sections from 2005.	2 (T.332-333)
11	Route #11: From Camp #2 to the left bank of the Kokdarya.	47 (T.334-380)
12	Route #12: From Camp #2 to the Route - Wellhead of the Hydrogeological Service.	89 (T.381-469)
13	Route #13: From Camp #2 to the Chinese Canal "Gazarkent".	29 (T.470-499)
14	Route #14: From Camp #2 to the Djiltyrbas Dam.	62 (T.500-561)

5.4. Satellite data pre-processing

In preparation for the field studies and to determine the routes for studying the landscapes of the dried Aral Sea bed, the preliminary analysis and processing of satellite images from Google Earth (ver. 7.3.2.5776) and satellite images from Sentinel-2, Landsat 5 Thematic Mapper (TM) and Landsat 8 OLI (Operational Land Imager) were downloaded from the EarthExplorer (https://earthexplorer.usgs.gov) archive, and a search was performed. After registering on the site, this archive can be accessed both to simply browse the catalogue and to directly retrieve stored materials.

Google Earth bases its data on satellite images from Landsat (resolution 15 m/pixel), GeoEye-1 (0.41 m/pixel) and QuickBird-2 (resolution 0.68 m/pixel), obtained from DigitalGlobe (Stupin, 2011). All these images have the Universal Transverse Mercator (UTM) cylindrical projection using the WGS 84 coordinate system.

The operator of the Sentinel-2 mission is the European Space Agency (ESA), which makes the imagery data publicly available to any user. The Sentinel-2 imagery is systematically processed at Level 1C by the Data Processing Center (PDGS). The Level 1C product consists of 100x100 km2 tiles (orthoimages in UTM/WGS84 projection).

The Landsat 5 and Landsat 8 missions are operated by the USGS Earth Resources Observation and Science Center (EROS Center) in partnership with NASA. The Landsat 8 image has a Level 1 systematic processing (after geometric and atmospheric correction and radiometric calibration) and consists of tiles with a preliminary scene size of 170 kilometres (north-south) and 183 kilometres (west-east) in UTM/WGS 84 projection (EROS, 2015). It should be noted that all satellite and remote sensing systems have four types of resolution.

1. Spatial resolution determines the linear dimensions (pixels) of an image, i.e., the ground surface area covered by a pixel image. A large area covered by a pixel means a low spatial resolution and vice versa. The spatial resolutions of Sentinel-2, Landsat 5 and Landsat 8 are presented in Table 12.

2. Spectral resolution corresponds to the number of EM spectrum bands and the size of survey zones registered by the survey equipment. Spectral resolutions of Sentinel-2, Landsat 5 and Landsat 8 channels (band) are given in Table 12.

3. Temporal resolution determines how often the sensor acquires images of a certain area on the Earth’s surface. While Sentinel-2 receives images every 10 days, Landsat 8 receives images every 16 days.

4. Radiometric resolution corresponds to the width of the dynamic range of the used spacecraft sensor, i.e., the number of sampling levels corresponding to the transition from black to white colour (sensor sensitivity to the value of received EM energy).

Table 12.

Spatial and spectral resolutions of Sentinel-2, Landsat 5 TM (Thematic Mapper) and Landsat 8 OLI (Operational Land Imager) satellite images

Channels *	Spectral resolution range, µм	Spatial resolutions, м
Sentinel-2 (Immitzer et al., 2016)		
Band 1 – Coastal/aerosol	0.430 - 0.457	60
Band 2 – Blue	0.440 - 0.535	10
Band 3 – Green	0.537 - 0.582	10
Band 4 – Red	0.646 - 0.684	10
Band 5 – Red Edge 1	0.694 - 0.713	20
Band 6 – Red Edge 2	0.731 - 0.749	20
Band 7 – Red Edge 3	0.769 - 0.797	20
Band 8 – Near infrared (NIR1)	0.773 - 0.908	10
Band 8A – Near infrared (NIR2)	0.848 - 0.881	20
Band 9 – Water vapor	0.932 - 0.958	60
Band 10 – Cirrus	1.337 - 1.412	60
Band 11 - Infrared short wave (SWIR1)	1.539 - 1.682	20
Band 12 - Infrared short wave (SWIR2)	2.078 - 2.320	20
Landsat 8 OLI (EROS, 2015)		
Band 1 – Coastal/aerosol	0.435 – 0.451	30
Band 2 – Blue	0.452 – 0.512	30
Band 3 – Green	0.533 – 0.590	30
Band 4 – Red	0.636 – 0.673	30
Band 5 – Near infrared (NIR1)	0.851 – 0.879	30
Band 6 – Infrared short wave (SWIR1)	1.566 – 1.651	30
Band 7 – Infrared short wave (SWIR2)	2.107 – 2.294	30
Band 8 – Pancromatic (PAN)	0.503 - 0.676	15
Band 9 – Cereus (Cirrus)	1.363 - 1.384	30
Band 10 – Thermal IR (TIR1)	10.60 - 11.19	100
Band 11 – Thermal IR (TIR2)	11.50 - 12.51	100

Channels *	Spectral resolution range, µм	Spatial resolutions, м
Landsat 5 TM (Source: https://landsat.gsfc.nasa.gov/the-thematic-mapper/)		
Band 1 – Blue	0.45 – 0.52	30
Band 2 – Green	0.52 – 0.60	30
Band 3 – Red	0.63 – 0.69	30
Band 4 – Near Infrared (NIR)	0.76 – 0.90	30
Band 5 – Infrared short wave (SWIR1)	1.55 – 1.75	30
Band 6 – Brightness thermal (temperature)	10.40 – 12.50	120
Band 7 – Infrared short wave (SWIR2)	2. 08 – 2.35	30

** The channels highlighted in colour are used to analyse the data.*

The Sentinel-2 image was used exclusively for the preparation and planning of the expedition, while Landsat 5 and Landsat 8 were used to create maps in 2006 and 2019/2020, respectively.

In total, five tiles of the Landsat image cover the whole territory of the Uzbek part of the Aral Sea (water area of 1960, Fig. 25, left). Forty-seven images in 2019 (Fig. 26) were used to create the classification and risk zone maps, while in 2006 thirty-three images from four Landsat tiles (tracks 160-161, lines 29-30) were created. Although some tiles partially cover the general area, they were used to fill in the gaps and

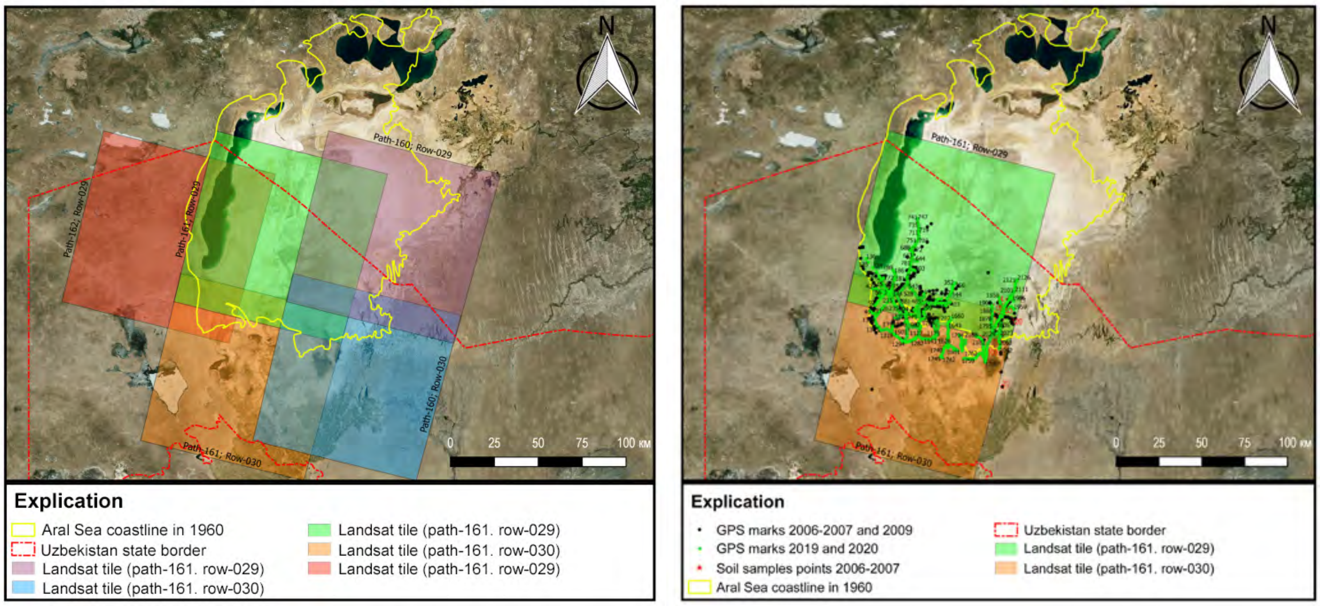


Fig. 25. Map of Landsat's five-tile coverage of the Uzbek part of the Aral Sea (left) and two tiles of the study area of all expeditions (right),on a background of Google Maps

achieve complete coverage within the two 2019-2020 expeditions.

In 2019-2020, two tiles from Landsat 8 with cloud cover of up to 20 percent (path 161, lines 29-30) were used to analyse the spectral brightness ratio of the reflecting surface (surface reflectance, mainly OLI sensor 1-7) of ground objects (landscapes), and to develop a linear regression of the supervised classification modelling so that clouds do not cover the study area (Table 13). All of the 2006-2007 and 2009 expedition points, as well as those for 2019-2020, are within these two Landsat tiles (Fig. 25, right).

The U.S. Geological Survey (USGS) provides Landsat 8 surface reflectance data for the Operational Land Imager (OLI) / Thermal Infrared Sensor (TIRS) sensors on request through EarthExplorer. Surface Reflectance products are already processed at the EROS Center at a spatial resolution of 30 metres. The EROS Science Processing Architecture (ESPA) interface corrects these images on demand. All Landsat 8 images from the site archive are converted into reflectance values (surface reflectance), so they can be directly used for analysing the spectral brightness coefficient of reflecting the surface of ground objects, as well as for calculating vegetation indices.

Quantum GIS software (QGIS, ver. 2.18.24) and R language (RStudio, ver. 3.4.0) were used to process these images.

Table 13.

List of Landsat 8 images used to analyse the spectral brightness coefficient of the reflecting surface (surface reflectance) based on field data from Expeditions 1 and 2, 2019-2020

Date	Tile paths		Cloudiness, %	Angle of azimuth of the sun, o	Sensor (channels)
	Path	Row			
20 March 2019	161	29	8	151.73	OLI (Band1-Band7)
20 March 2019	161	30	12	150.61	OLI (Band1-Band7)
7 May 2019	161	29	0	145.68	OLI (Band1-Band7)
7 May 2019	161	30	3	143.66	OLI (Band1-Band7)
23 May 2019	161	29	8	142.34	OLI (Band1-Band7)
23 May 2019	161	30	6	139.98	OLI (Band1-Band7)
8 June 2019	161	29	0	138.98	OLI (Band1-Band7)
8 June 2019	161	30	0	136.32	OLI (Band1-Band7)
24 June 2019	161	29	0	136.87	OLI (Band1-Band7)
24 June 2019	161	30	0	134.13	OLI (Band1-Band7)
11 Aug 2019	161	29	3	143.58	OLI (Band1-Band7)
11 Aug 2019	161	30	20	141.65	OLI (Band1-Band7)
12 Sept 2019	161	29	0	153.60	OLI (Band1-Band7)
12 Sept 2019	161	30	9	152.34	OLI (Band1-Band7)

Date	Tile paths		Cloudiness, %	Angle of azimuth of the sun, o	Sensor (channels)
	Path	Row			
28 Sept 2019	161	29	8	158.00	OLI (Band1-Band7)
28 Sept 2019	161	30	18	157.00	OLI (Band1-Band7)
14 Oct 2019	161	29	6.5	161.39	OLI (Band1-Band7)
14 Oct 2019	161	30	1.3	160.58	OLI (Band1-Band7)
2 Feb 2020	161	29	0.1	154.52	OLI (Band1-Band7)
2 Feb 2020	161	30	0	153.72	OLI (Band1-Band7)
22 March 2020	161	29	4.8	151.54	OLI (Band1-Band7)
22 March 2020	161	30	8.5	150.39	OLI (Band1-Band7)
9 May 2020	161	29	0.44	145.08	OLI (Band1-Band7)
9 May 2020	161	30	0	142.99	OLI (Band1-Band7)
25 May 2020	161	29	0	141.66	OLI (Band1-Band7)
25 May 2020	161	30	0	139.22	OLI (Band1-Band7)
10 June 2020	161	29	0	138.44	OLI (Band1-Band7)
10 June 2020	161	30	0	135.74	OLI (Band1-Band7)

5.5. The Unsupervised Classification Technique

Classification is one of the main tasks of satellite images processing, and it requires the use of specialised software packages. Image classification techniques involve the process of quantifying data from images and grouping points or parts of an image into classes designed to represent different physical objects or types. The result of the image classification process is classification maps.

Two types of classification are known:

- Classification without training (unsupervised classification)
- Classification with training (supervised classification)

In this section, we will look at the methodology of unsupervised classification. Unsupervised classification (sometimes called the clustering algorithm) is used in the absence of a priori information (ground data) about the survey object and is mainly used for the preliminary selection of test fields for determining the survey route. As cluster analysis belongs to digital automated methods of processing space images, it allows for singling out contours with non-contrast spectral brightness structure, such as vegetation, open soil and water, and other objects.

The most popular among unsupervised classification (clustering) algorithms are k-means and ISODATA algorithms. In our case, we used the k-means algorithm in the Quantum GIS software package (QGIS, version 2.18.24) (Theiler & Gisler, 1997). For this purpose, the combined method of Iterative Minimum Distance and Hill-Climbing in the software module QGIS - SAGA GIS (2.3.2) was chosen (Forgy, 1965; Rubin, 1967). This method selects the distribution of expectation values (i.e., iterations) for images clustering. Given the available class-legend map of land cover from 2006, which contains 17 specialised classes (Table 8), we selected 17 clusters and 100 iterations. During the first iteration of clustering, the space is evenly divided into regions, each centred on the average vegetation index (NDVI) values of the clusters. After iteration, the real mean values of spectral features on the obtained clusters are calculated, because their mean values vary depending on the predominant brightness of the pixels caught in them. Then a second iteration is performed, during which the clustering is repeated with new mean values and the cluster boundaries are calculated. After that, the new mean values are determined, and a new iteration is performed. Such recalculations are repeated until all pixels with a given probability (convergence threshold) fall into a cluster (Table 14).

The NDVI raster layers of the two tiles (path 161, lines 29-30) calculated from the two-channel ratio ((Band5-Band4)/(Band5+Band4)) (Rouse et al. 1973) of the Landsat 8 OLI image from 12 September 2019, were the basis for automatically dividing the image pixels into 17 groups of similar pixel spectral characteristics (Fig. 26).

Table 14.

Statistical parameters of Landsat 8 OLI image clustering, 12 September 2019

Cluster ID	NDVI average value		NDVI standard deviation	
	P161R029	P161R030	P161R029	P161R030
0	0.364	0.3052	0.048	0.0235
1	-0.903	-0.7393	0.024	0.0393
2	-0.992	-0.6514	0.015	0.0231
3	0.245	0.2320	0.025	0.0189
4	0.178	-0.5704	0.017	0.0246
5	-0.826	0.1730	0.021	0.0157
6	-0.751	-0.4818	0.021	0.0273
7	0.126	0.1230	0.012	0.0127
8	-0.677	-0.3807	0.021	0.0297
9	0.092	-0.2768	0.009	0.0316
10	0.640	0.3973	0.094	0.0324
11	-0.607	0.0841	0.021	0.0092
12	0.064	-0.1632	0.008	0.0331
13	-0.533	0.0570	0.034	0.0108
14	0.039	0.6952	0.006	0.0593

Cluster ID	NDVI average value		NDVI standard deviation	
	P161R029	P161R030	P161R029	P161R030
15	-0.246	0.5373	0.082	0.0439
16	0.023	-0.0482	0.007	0.0317

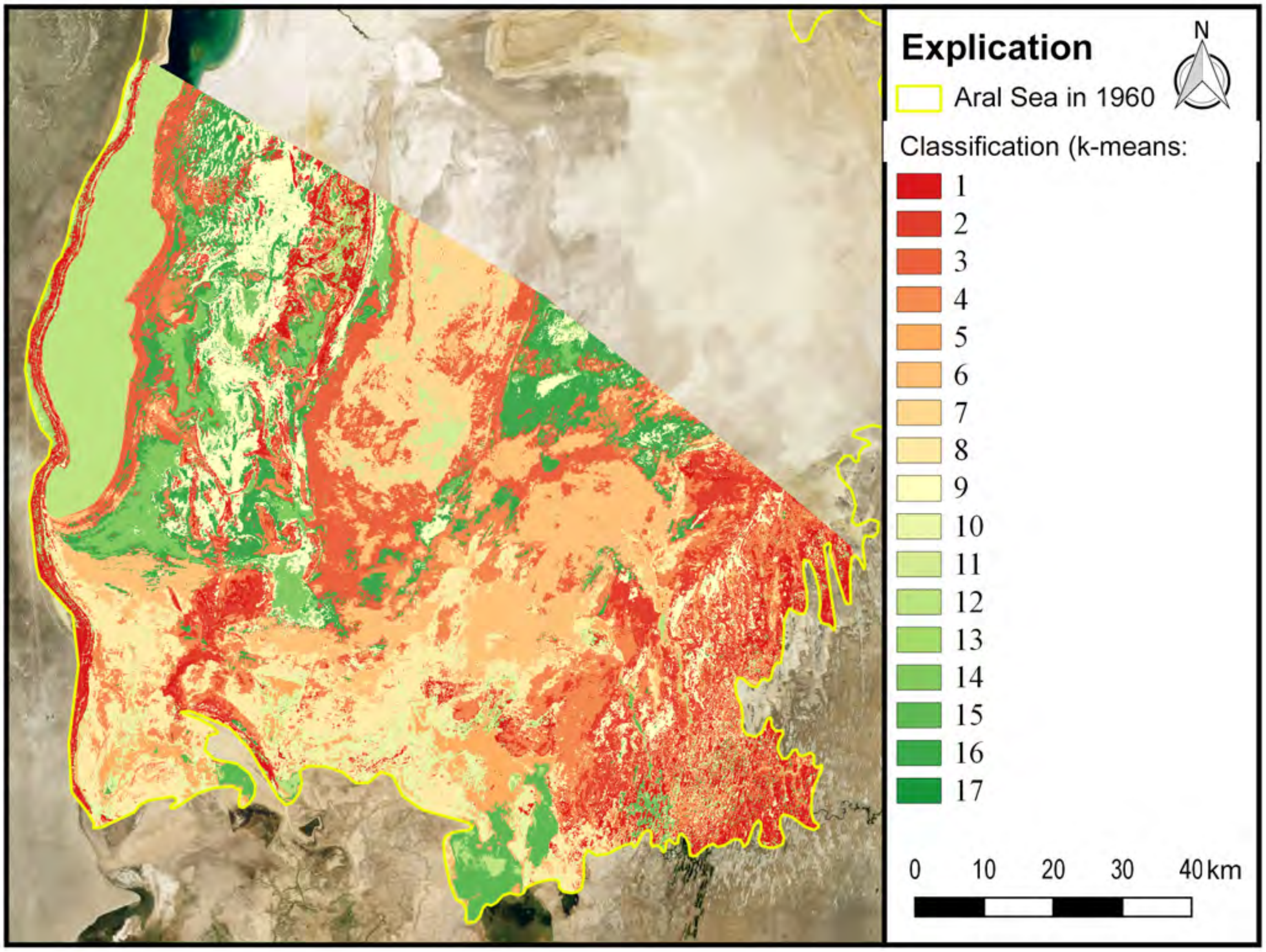


Fig. 26. Map of uncontrolled classes based on Landsat 8 OLI from 12 September 2019 on a background of Google Maps

6 Results

Comprehensive studies of the dry bed of the Aral Sea have allowed for a clear understanding of many aspects of its present condition. Based on the analysis of the obtained materials, experts have described the area, reflected on the main causes of desertification, identified environmental risk zones, and proposed ways for preserving the unique, natural site.

This chapter includes the results of hydrogeological, soil, environmental, botanical and dendrologic studies.

Special attention is paid to the use of satellite images and Geographic Information System (GIS), which has allowed for a dynamic evaluation of a large area.

6.1. Hydrogeological studies results

The studied objects were the unconfined water basins located at the unconfined and confined left and right riverbanks of the Low Amudarya unconfined water and confined groundwater deposits of the Ustyurt and South-Aral region artesian basins. Areas and sites showing man-made impacts on groundwaters at the dried part of the Aral Sea in Karakalpakstan were also included in the survey.

Mainly, the studies were conducted in two areas. The first research area was located on the left riverbank of the Amudarya River from the eastern cliff of the Ustyurt Plateau to the Amudarya River (Ustyurt Artesian Basin) and the right riverbank of the Amudarya River from the Kokdarya River channel to the north-western edge of the Kyzylkum Desert (South Aral Region Artesian Basin). This research area was bounded by irrigated lands in the south, impassable dried sand-dune shores of the Aral Sea in the north, and the Djiltyrbas Lake in the east. The second research area stretched from the Djiltyrbas Lake to the Kokdarya River channel at the eastern boundary, and the KS-3 and Karauzyak collectors in the south. In the north, there are also impassable saline lands of the Aral Sea's dried bed.

The main tasks were to study the current status of groundwater hydrogeological conditions, predict changes, and the hydrogeological processes induced by natural and man-made factors.

During the research, in order to achieve the objectives of the targeted tasks, the groundwater table and quality were measured. Their transformations caused by natural and man-made factors were recorded to predict revealed changes in the groundwaters, their interaction with the environment, as well as to develop recommendations for elimination of the consequences caused by negative processes. All targeted tasks were solved by means of surveys of the area and observation points, by measuring the groundwater table, and sampling water from the wells encountered during the two survey expeditions.

6.1.1. Analysis and evaluation of study results

As previously mentioned, aquifers of present-day marine sediments on the southern shore of the retreated part of the Aral Sea are bound from the south by contours of the water table at the absolute elevation of 50 metres, from the north by the Aral Sea, from the east by an old river channel of the Akchadarya River and the northern shore of the Kyzylkum Desert, and from the west by the Ustyurt cliff. These are what can be conventionally called the Northern-Ustyurt and Southern-Aral hydrogeological regions of ground and confined waters.

Hydrogeological conditions are characterised here by the distribution of aquifer systems of the marine New Aral (ma) and underlying alluvial-lake Amudarya (al) and marine (m1) Holocene deposits, and all have ubiquitous distribution within the dried seabed.

The groundwater regime within the Aral Sea's dried bed is influenced both by the drop in the sea's level, which is the regional base of its discharge, and by periodic discharges from Sudochie Lake and Rybatsky Bay.

The hydrochemical status of groundwater is formed under the influence of climatic, hydrological and land improvement factors, as well as irrigation.

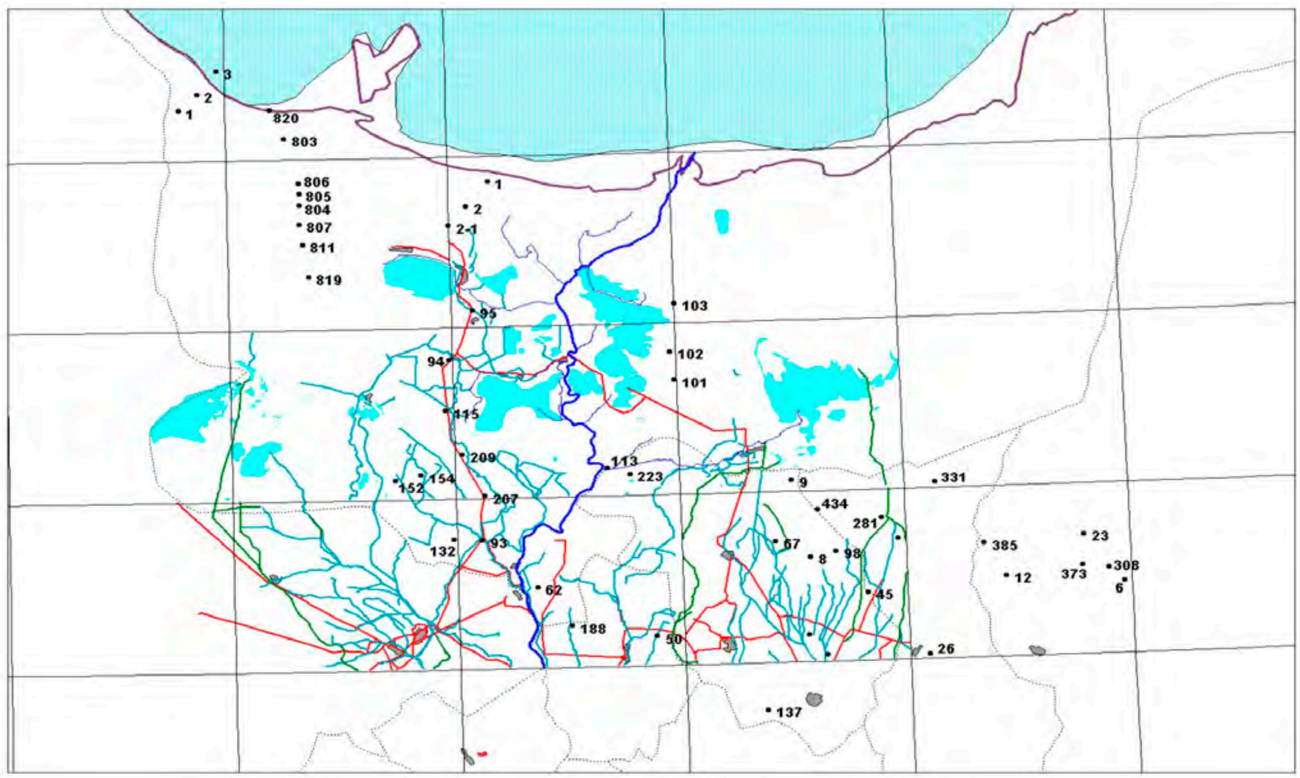
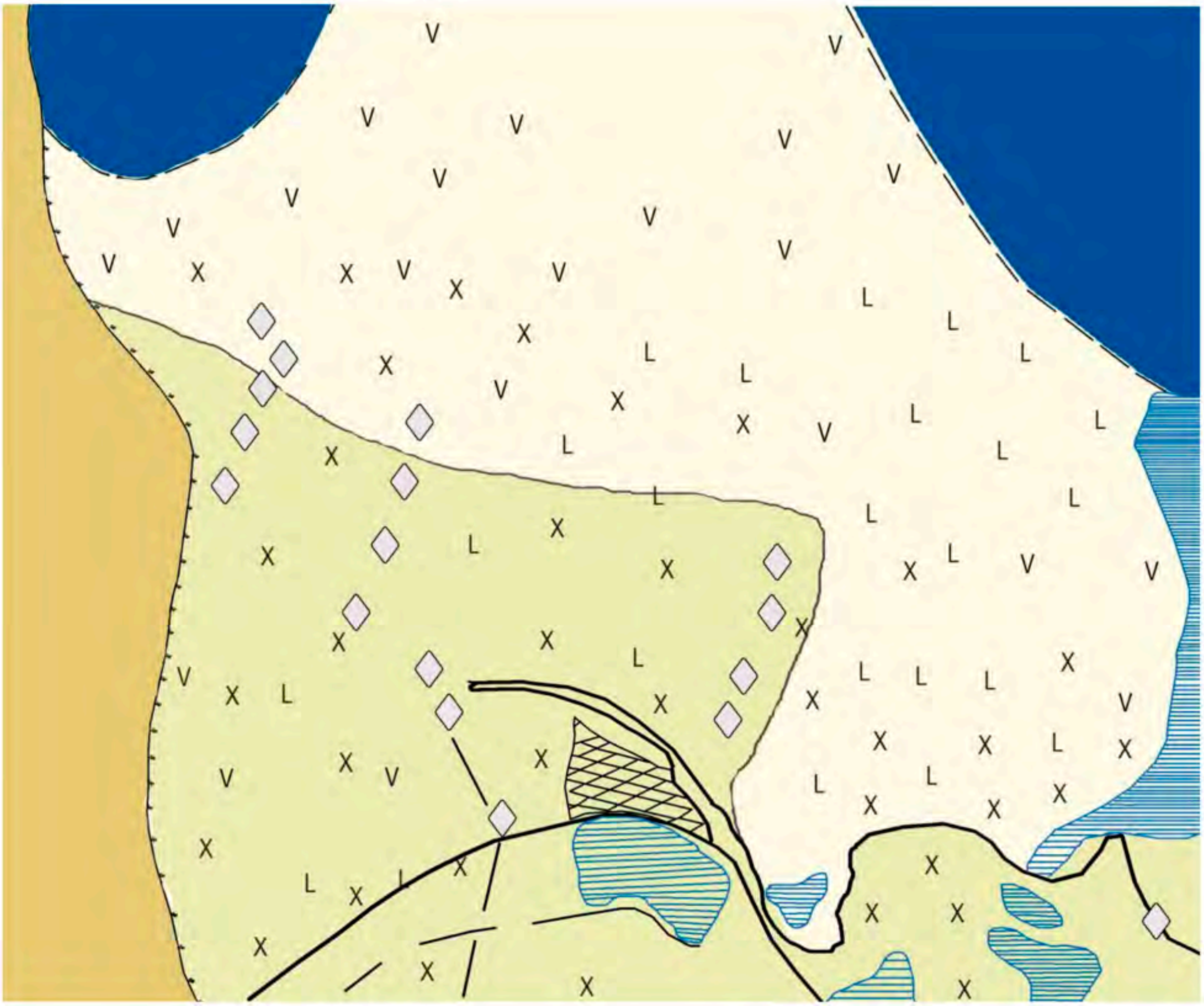


Fig. 27. Layout of hydrogeological sections located on the dried seabed



Legend

1 Groundwater depth level, October 2006

0,0 — 3,0 m | 3,0 — 10 m

2 Mineraslization of the undeground water, October 2006

L L — 1,5 g/l | V V — 1,5-3,0 g/l | X X — over 3,0 g/l

Fig. 28. Observation hydrogeological wells at the Sudochie-Adjibay and Muynak River sections – the groundwater table at the Muynak part of the dried seabed, as of the year

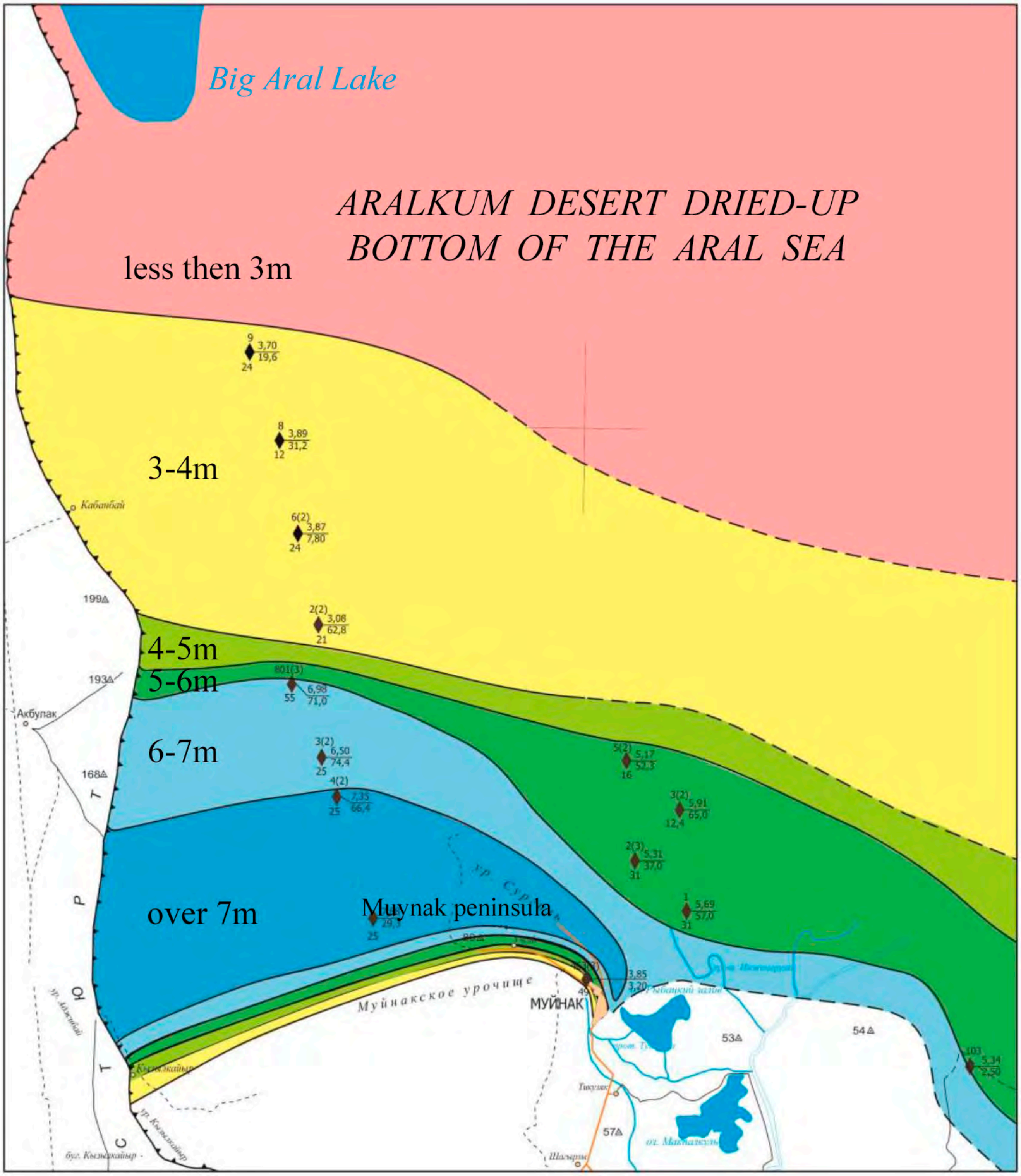


Fig. 29. Observation hydrogeological wells at the Sudochie-Adjibay and Muynak River sections – the groundwater table at the Muynak part of the dried seabed, as of the year 2019

Characteristics of the level and hydrochemical status of the groundwater of the Muynak part, the first from the surface aquifer systems, are given for two hydrogeological sections (Fig. 27). These include Sudochie-Adjibay and Muynak in both the first and second expeditions, and the Djiltyrbas part and Akkala section in the second expedition. Due to the draining of the sea and the drop in the groundwater table, the Muynak and Akkala sections have been closed since 2010, and no observations are currently conducted.

The Sudochie-Adjibay section

This section is located in the western part of the dried seabed between the Ustyurt cliff and the Aral-Kyzylkum swell and consists of 10 hydrochemical clusters (GHK) of wells (Figs. 28 and 29). The wells characterise the groundwater status, Holocene, Pleistocene and partially Upper Cretaceous (Turonian, Coniacian and Santonian stages).

The hydrogeological conditions of the station location are characterised by the distribution of aquiferous complexes of marine New Aral (ma) and underlying alluvial-lake Amudarya (al) and marine (m1) Holocene deposits, and they have ubiquitous distribution within the western part.

Changes in level depth over a multi-year period (2004-2017), depending on the location of hydrogeological observation wells, are shown based on multi-year groundwater level observations.

The section GKH-5 is located at the greatest distance from the sea (Fig. 30). The groundwater level was at a depth of 7.9 metres in 2017. This level occurred to be equal to 1.33 metres, and had changed insignificantly over 13 years, at a rate of 0.1 metres per year. The small by-year changes in groundwater level and salinity (in 70 g/l) can be explained by the influence of the Adjibay Bay.

Changes in the depth of the groundwater table and groundwater salinity in well GHK-7, located in the south of the section, are due to the influence of the Sudochie-Karadjar polder system. If one considers the trend in dynamics of the groundwater table, it should be noted that the changes were insignificant, from 5.5 metres in 2004 to 5.04 metres in 2011. At the same time there were sharp changes in the period of 2011-2017 from the groundwater table at 5.04 metres, to the groundwater table of 1.7 metres in 2017, with the average amplitude of fluctuations in this period being 0.48 metres per year. There is a level rise of 0.6-0.9 metres in 2013 and 2016. Groundwater salinity varies within a wide range of values from 54.7 to 29.1 g/l. Groundwater table and salinity change dynamics in the wells of the Sudochie-Adjibay section for a given period of time is shown in Fig. 31. Discharges from the Sudochie Lake influence the groundwater table regime, which is manifested in the rise in level and a salinity decrease.

The wells of GHK-3, located in the middle part of the section (Fig. 32), saw the depth of the groundwater table over a multi-year period from 2004 to 2006 change from 1.18 to 0.3 metres. The decrease in the groundwater table from 2006 to 2017 from 0.3 to 4.22 metres is associated with a decrease in the level of the Rybatsky reservoir, which directly affects the groundwater regime of the observation points of this section. Changes in salinity have varied from 25 g/l to 100 g/l.

The closest to the shoreline as of 2017 is the GHK-801 cluster of wells (Fig. 33), where the groundwater table is more dependent on the sea level. Between 2009 and 2017, the groundwater table decreased by 1 metre and practically settled at 7 metres with salinity of 30 g/l. For instance the decrease was at a rate of 0.1 metres per year.

As one can see from Fig. 34, a level decrease is observed in the wells located on the periphery of the Amudarya River delta outside the dried seabed and in the wells located in the north of the section.

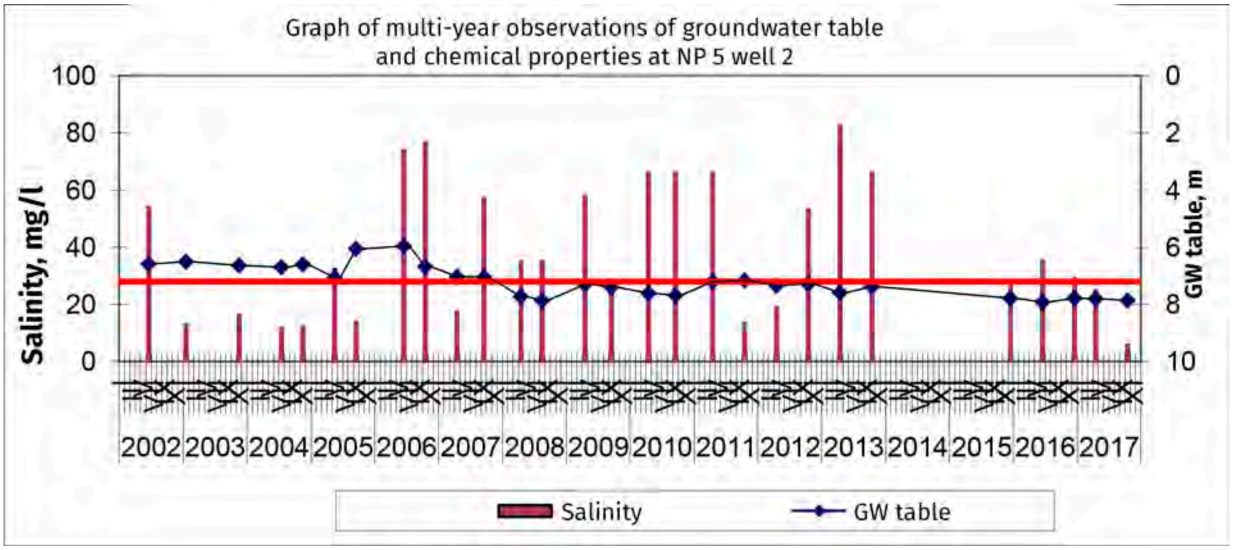


Fig. 30. Dynamics of the groundwater (GW) table and salinity of the Sudochie-Adjibay section at the cluster of wells GHK-5

The study indicated that the groundwater level regime changes from south to north. In the wells located in the southern part of GHK-6-7, the level rose by 0.37 metres until the fall of 2015, and in 2017, the level decreased to the initial marks.

In the northern direction, the influence of discharges from the delta reservoirs decreases as the modern sea level is approached (Figs. 28 and 29), and the regime of changes in the groundwater table of the northern wells is determined by the natural decrease in the sea level.

The problem of interaction between the sea and groundwater and its influence on the groundwater has been studied for many years. The search for an answer was complicated by the fact that this influence was very weak and could not be detected by existing techniques

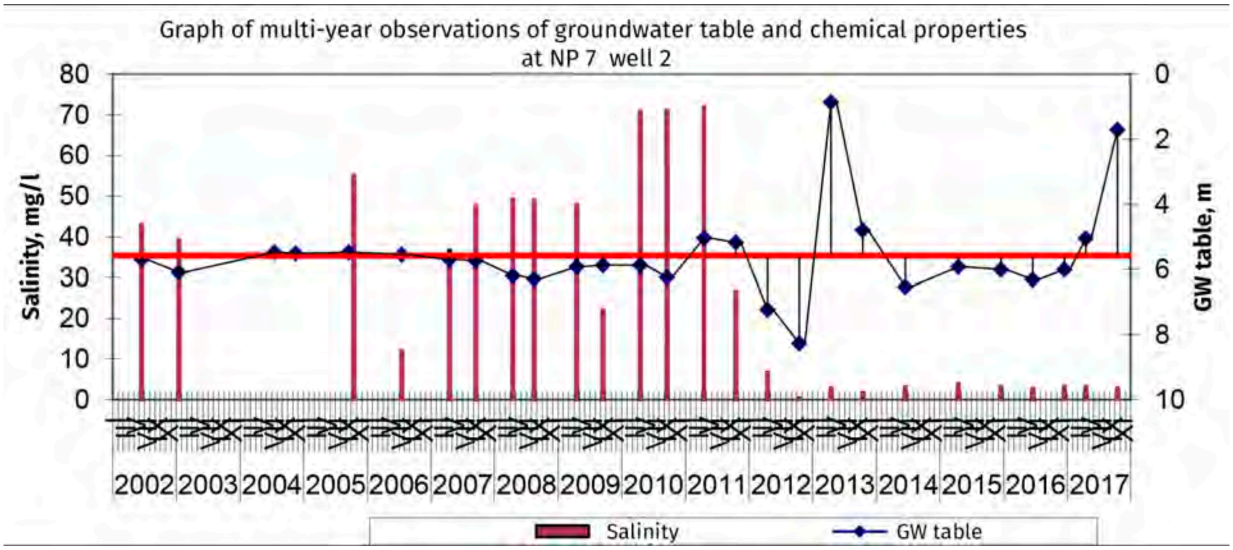


Fig. 31. Dynamics of the groundwater level and salinity of the Sudochie-Adjibay section at the GHK-7 hydrochemical cluster of wells

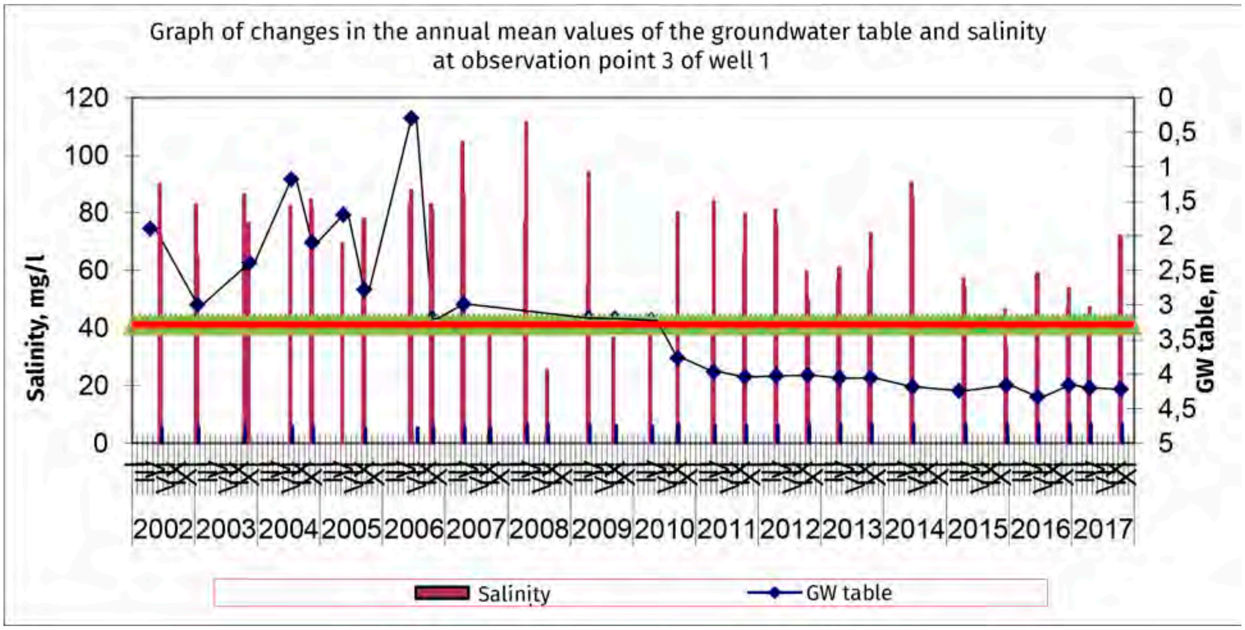


Fig. 32. Dynamics of the groundwater level and salinity in the Sudochie-Adjibay section at GHK-3

and research methods. Some groundwater back-up from the sea existed, but the flow was so negligible that it was impossible to measure this back-up.

The data obtained earlier (by the ARAL-KUM project) proved that groundwater moves towards the sea, but discharges in the backwater zone, represented by a strip which is 250 metres wide

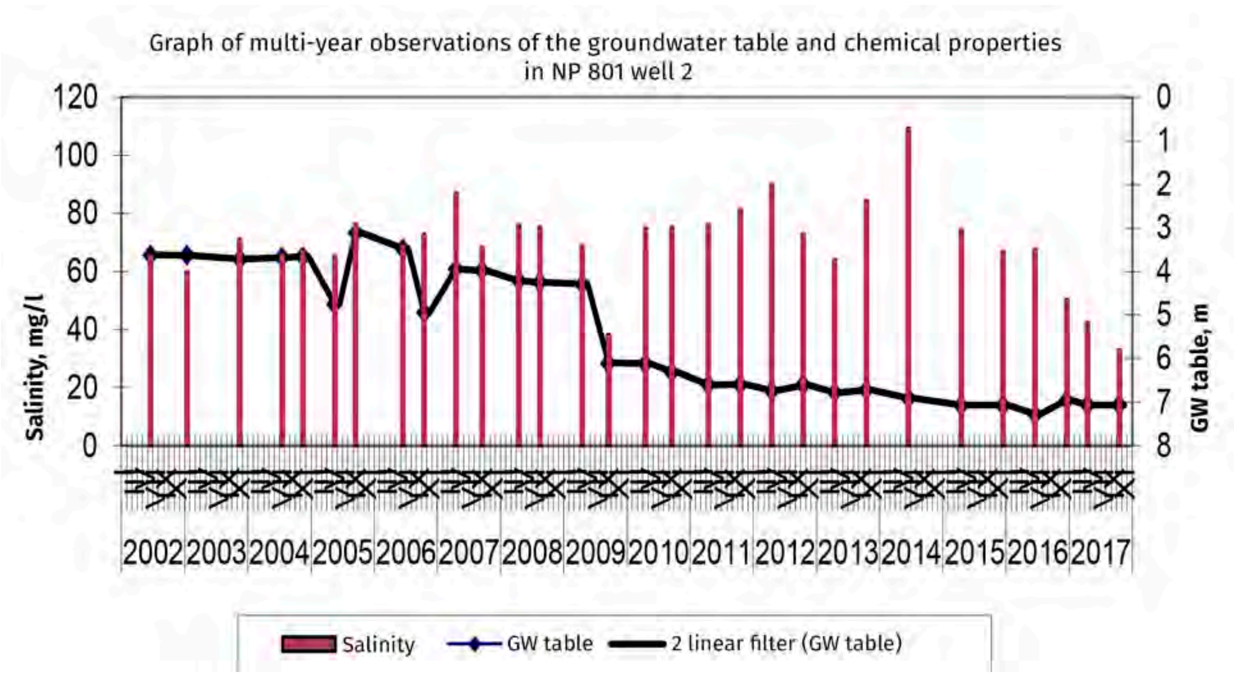


Fig. 33. Dynamics of the groundwater level and salinity of the Sudochie-Adjibay section by GHK-801(2)

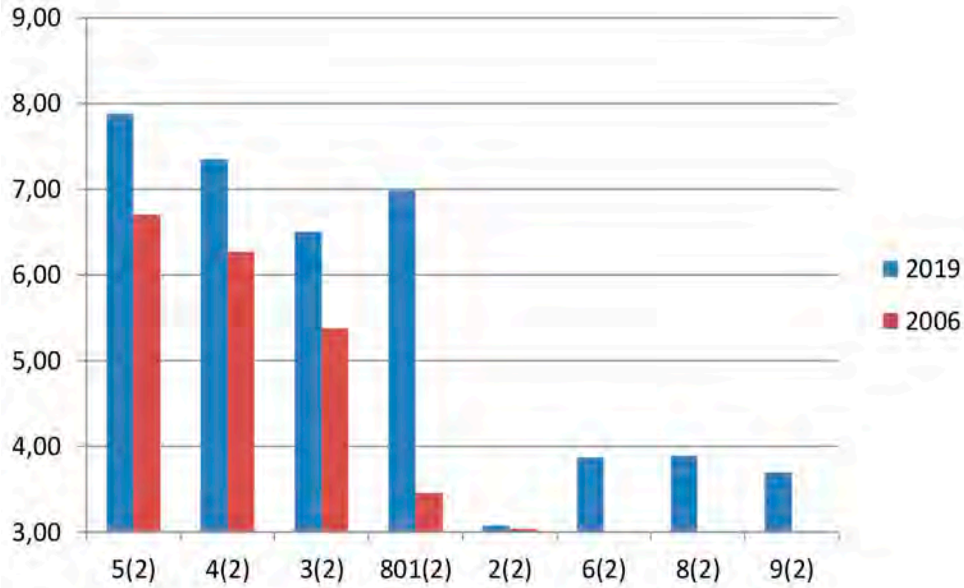


Fig. 34. Groundwater tables in the sections of the GHK located relative to the shoreline

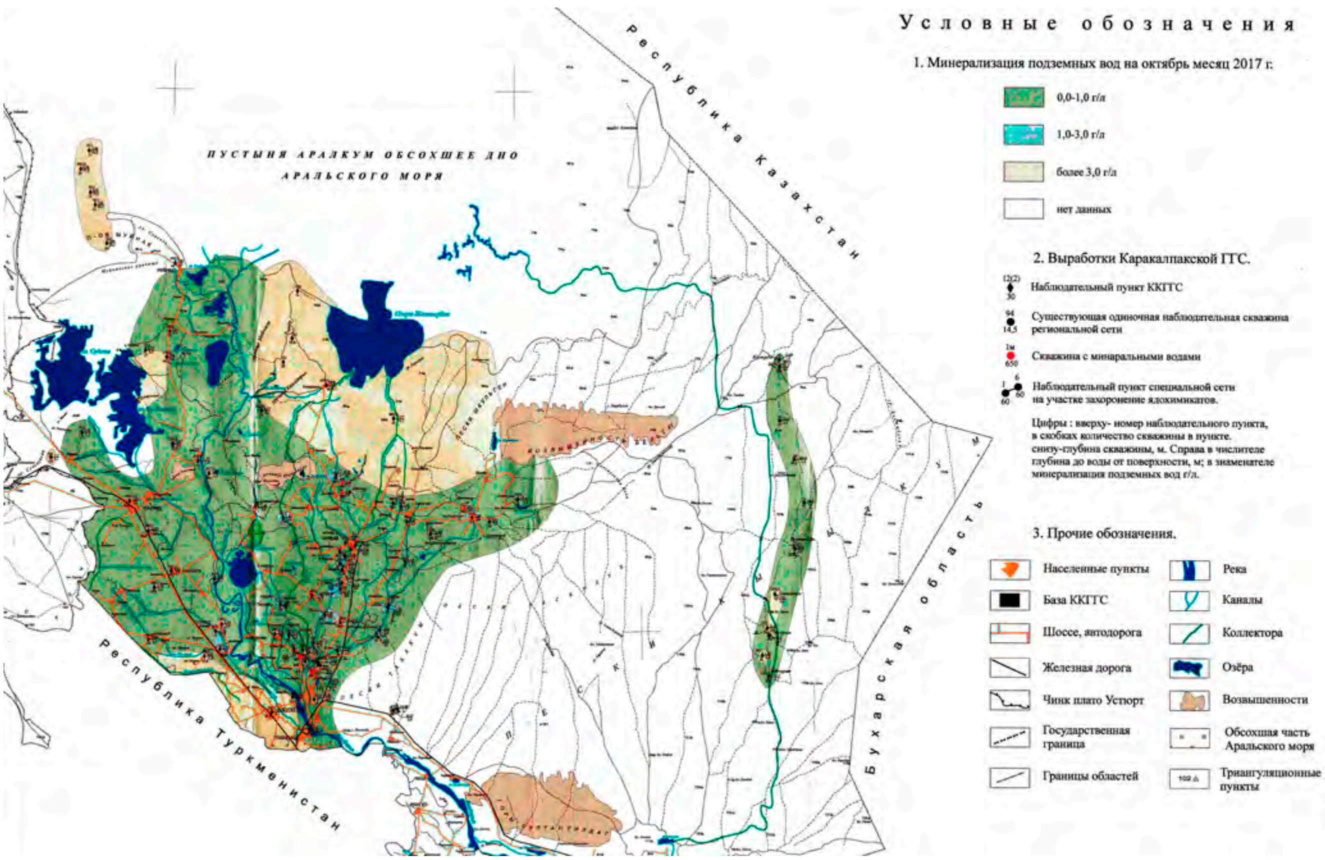


Fig. 35. Map of groundwater salinity

on average, adjacent to the sea level at the time of studies. Groundwater outflow does not participate in the Aral Sea balance. The observed outflow along the dried seabed almost completely evaporates into the atmosphere. Discharge of groundwater from the Cretaceous sediments through vertical filtration into the Aral Sea increased from 1.23 m^3/sec (0.04 km^3/year) in 1960 to 1.8 m^3/sec (0.06 km^3/year) in 1990. The total value of groundwater and confined groundwater discharge was 4.67 m^3/sec or 0.14 km^3/year from the area under consideration, in other words increasing two times compared with 1960.

According to the latest data, groundwater discharge into the Aral Sea hollow is 0.12 km^3/year.

In general, the magnitude of underground flow into the Aral Sea is too small compared to surface flow and in no way affects the position of the Aral Sea level.

Long-term observations show that the influence of the Aral Sea on the groundwater table position extends up to 15-25 kilometres from the initial shoreline. The stabilisation of groundwater tables in recent years indicates that there is practically no relation between the present sea and groundwater in the delta.

Nevertheless, the question of the groundwater role in the overall Aral Sea water balance cannot yet be considered completely solved, because the answer is associated with numerous factors that are difficult to study and take into account.

Due to further dewatering of the sea and the loss of groundwater and sea level contact, three new hydrogeological monitoring clusters of wells were installed in July 2019 at the new dewatered area of GHK-6, GHK-8 and GHK-9 (Figs. 29 and 36).

Fig. 36. Groundwater table monitoring wells, GKH-6, installed in July 2019, Sudochie-Adjibay section

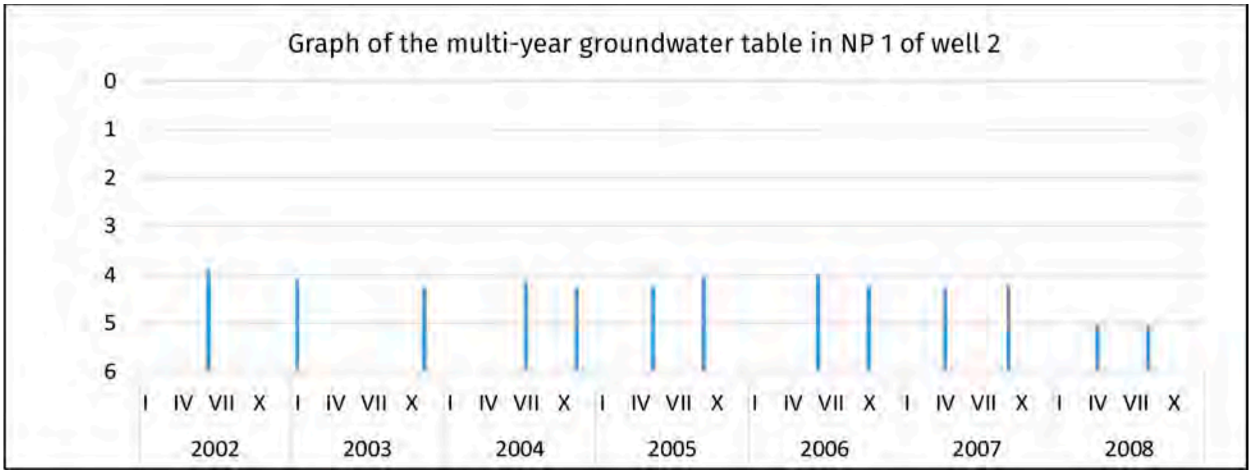


Fig. 37. Groundwater tables , metres, Muynak section, NP 1

Fig. 38. Self-discharging wells on the road to Vozrojdenie (Ascension)

This section is located to the east of the Muynak peninsula and includes three hydrochemical clusters of wells. The long-term observations at this site show that within the Muynak part covering the dried seabed, dynamics of the level and hydrochemical regimes of groundwater in the GHK-3-5 wells located to the north of the site depends only partly on the groundwater flow coming from the Rybatsky polder and the Amudarya riverbed, and is mainly directly determined by the Aral Sea shoreline retreat. Due to the retreat of the sea and the lowering of the groundwater level (Fig. 37) in the observation wells, observations were suspended at the Muynak site in 2010. At present there are two abandoned wells and the last measurements have resulted in the following information: Well 2 - 1.97 metres, x - 43°54’00”, y - 58°59’22.6” and in Well 3 - 2.13 metres, x - 44°01’09”, y - 59°05’26”.

Three self-discharging wells were drilled on the dried seabed of the Eastern Sea (Fig. 38). Their characteristics are shown in Table 15.

Table 15

Information about the Aralkum GGP wells for the year 2019

№	Number of well	Filter installed interval	Depth of the well, m	Salinity, g/l	Hardness, eq/mlg	GW table	Note for orientation
1	46	185-195 210-220 218-295	350	40.3	168	Self-discharge +7l/sec.	14,0(10,0 km)
2	44	240-270	350	62.5	158	Self-discharge +5 l/sec	25,0(7,0 km)
3	3	170-190 300-320	350	45.1	288	2.9	
4	42	185-205 290-310	345	54.5	280	3.39	
5	1	247-275	344	47	300	3.14	
6	38	245-275 305-315	322	28.1	190	1.3	82(1,2k m)
7	36	200-225 255-270	350	34	198	0	84(12 km)
8	35	190-200 220-250	334	45.5	210	8.74	98(2 km)
Muynak cleaning							
1	1 profile (Shagal site)	196-206 216-236	300	3	2.5	Self-discharge +7 l/sec	On the NE side of the Vozroj-denie island.
2	2 profile (Umid site)		110	32.1	201	1.3	
3	3 profile (0km)		170	-	-	5.2	15 reverse calculation from 0 to the left

The Akkala section

Is located in the central part of the first section between the Aral-Kyzylkum swell and the Djiltyrbas Lake. At present, out of five observation points, we have found only four clusters of wells consisting of two and three wells in each cluster. The first cluster, 437 (Fig. 39), consists of three wells (234, 235 and 236) with depths of 40, 21 and 10 metres, respectively, and is located on the northern outskirts of the Kazakhdarya settlement. Groundwater tables produced through the survey were within the ranges of 2.37 metres in well 234, 3.77 metres in well 235 (Fig. 40) and 9 metres in well 236. Water samples were taken from each well for laboratory chemical properties analysis. Groundwater salinity in the wells was within 5.2, 2.7 and 8.4 g/l at water hardness of 50.2, 14 and 46 mg-eq/l, respectively.

The second cluster 111 consists of three wells (1, 2 and 3) with depths of 31, 18 and 11 metres, respectively, and is located 16 kilometres northwest of the Kazakhdarya settlement (NP 437). At present, only one well exists out of the three. The groundwater table during the survey was within 7.12 metres. Salinity of groundwater sampled from the well was 6.4 g/l with a water hardness of 57.1 mg-eq/l.

The third cluster 112, consisting of four wells (1, 2, 3 and 4) with depths of 68, 31, 18 and 10.7 metres, respectively, is located 11 kilometres north of observation point 111. All four wells were available at the time of the survey. The fourth well turned out to be drained. Groundwater tables in those wells were between 9.05-10.79 metres. Salinity of groundwater sampled from the wells was 24.1 g/l with a hardness of 132.0 mg-eq/l.

The fourth and last cluster of the Akkala section is located on the former sea shoreline with an absolute marker of 46 metres. The section consists of 4 wells (1, 2, 3 and 4) with high elevations, up to 2.5 millimetres. The reason for such high elevations cannot be explained. The depths of the wells are 92, 51, 28 and 6.5 metres, respectively. During the survey, the fourth well turned out to be drained. In the second and third wells it was impossible to measure levels and take water samples due to the welded cover. Groundwater tables in them were within 5.79

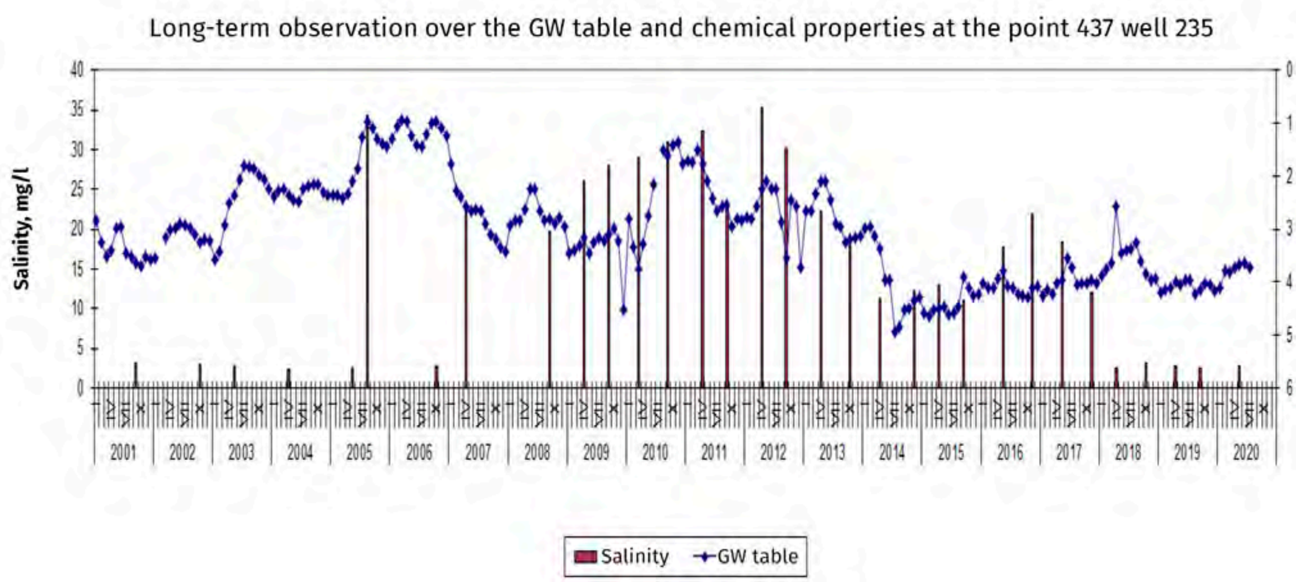


Fig. 39. Groundwater table regime, from 2001 until 2020

Fig. 40. The Akkala section for groundwater observations

Fig. 41. Farm well near the Voroshilovskaya breakthrough (the Mailyozek channel)

metres, and in the last well, it was dry at a depth of 11.7 metres. Salinity of groundwater sampled from the well was 33.6 g/l with a water hardness of 134.0 mg-eq/l.

The length of the section is more than 40 kilometres of off-road terrain with very difficult conditions, with alternate routes around loose sands and sand-dunes. In addition, on this first section we surveyed four deep self-discharging wells installed on a Cretaceous aquifer aimed to provide a water supply to livestock farms, forestry farms and small-oasis irrigation. When surveying all of the deep self-discharging wells encountered along the way, water flow rates were measured whenever possible and water samples were taken for chemical analyses. Flow rates of self-discharging wells were up to 2-3 l/sec, while water temperature was 40-45°C. Salinity of groundwater sampled from these four wells was within 1.7-2.5 g/l with a water hardness of 3.4-7.0 mg-eq/l.

In addition, one well (Fig. 41) (Tn 28) with a depth of 7 metres was found in the lowland (at a shepherd location near the farm, at the edge of the old Mailyozek channel of the central part of the site). The water level in the well was 1.97 metres from the ground. The salinity of underground water sampled from the well was within 2.6 g/l, at a water hardness of 16.0 mg-eq/l.

The groundwater table level regime both throughout the Aral Sea water area and the studied area changes from south to north. In the wells located in the southern part, near watercourses and lakes, the level elevation was observed to be 0.2-0.5 metres, which continued until autumn (during the vegetation period), while during the non-growing period the level decreased to the initial marks.

Discharges from the Djiltyrbas Lake, collectors KS-1 and KS-3, as well as from the Kazakhdarya channel, influenced the groundwater level regime through a level elevation and salinity decrease.

In the northern direction, as we approached the present-day sea level, the influence of discharges decreased and in the northern wells the regime of changes in the groundwater table was determined by a natural decrease in the sea level.

The second site, as noted above, is located between the Djiltyrbas Lake and Kokdarya on the eastern border, and to the south the KS-3 and Karauzyak collectors. This section is very poorly studied in terms of hydrogeology. The length of

Fig. 42. The Daryabay hydrant

this section is longer than 70 kilometres along off-road terrain with very difficult driving conditions, with bypass routes around loose sands, swamps, sand-dunes and wet solonchaks.

On the second site there are no observation points of the state groundwater monitoring equipped for unconfined groundwater (upper horizon), and also confined groundwater. We surveyed four deep (up to 500 metres) self-discharging wells installed on the Cretaceous aquifer, intended to provide water supply for livestock farming, forestry farms and small-oasis irrigation.

Flow rates of self-discharging wells are within 0.8-4.0 l/sec (wells: Aral 2-4 l/sec, Aral 2 - 3 l/sec, the Nemis hydrant - 1 l/sec, and the Daryabay hydrant – 0.8 l/sec) (Fig. 42). Water temperature is 37-41°C. The salinity of the groundwater sampled from these four self-discharging wells is within 1.6-1.8 g/l with a water hardness of 2.6-5.2 mg-eq/l.

6.1.2. Conclusions

Due to the drying of the Aral Sea and its surrounding region, several complex environmental, socio-economic and demographic problems have emerged, having a global origin and consequences, and are manifested through the following matters:

- Degradation of the Amudarya River delta;
- Intensification of desertification of a vast territory;
- Salt and dust transfer from the dried Aral Sea bed;
- Pollution and salinisation of water and land resources;
- Shortage of drinking water;
- Depletion of the gene pool of flora and fauna;

- Changes in the climate and landscape of the Aral Sea region;
- Deterioration of the health of the population and its gene pool;
- Disappearance of traditional livelihoods, such as fish and livestock farming, as well as hunting.

Land degradation and desertification processes occurred as vast areas of salt appeared on the dried part of the sea, which transformed into the new Aralkum Desert with an area of more than 5.7 million hectares, in the territories of Uzbekistan, Kazakhstan and Turkmenistan.

The retreat of the Aral Sea has exposed huge underwater areas that are now occupied, as a rule, by solonchaks and brine lakes with extremely high salinity.

High evaporation creates additional conditions for even greater salinisation of waters and soils. Widespread deflation processes and desertification of the territory create conditions for carrying sand and salts to oases of Karakalpakstan and Khorezm.

The most important issue for this area is to solve the migration of salt masses contained in brines and the salt of Neogene-Anthropogenic water-bearing formations.

In the period of 1989-1995, researchers of the Aral Sea region performed the ecological-hydrogeological and engineering-geological survey of the dried part of the Aral Sea bed at a scale of 1:200,000 within sheets L-41-XXI. Geochemical, hydrogeological, engineering-geological and ecological-geological maps were drawn.

However, the period from 1995 to 2020 saw changes in the geological environment under the influence of man-made factors, and it is obligatory to assess changes in the geological environment of the studied area since that time.

Further studies of groundwater, confined to the upper and lower hydrogeological levels, is of particular importance in the conditions of desertification and the development of harmful exogenous-geological processes in the South Aral Sea region. The first one lies above the regional Senonian-Palaeogene water confining bed and is characterised by free water exchange with surface and atmospheric waters.

6.1.3. Recommendations

1. The Aral Sea level decrease has had a significant impact on the change in the groundwater regime of the Upper Quaternary and modern deposits of the Amudarya and Aral complexes only within the dried seabed, for instance between the shoreline marks of 53.0 metres abs. (1961) and 30.0 metres abs. and more (2010-2019).

2. To improve the ecological situation of the dried part of the Aral Sea it is necessary to arrange:

- Phytomeliorative protection (forestry farms) – basic.
- Rational use of water from existing self-discharging wells for free-range livestock farming, forestry farms, and other purposes.
- Increasing the polder zone areas (moistening to prevent salt and dust transfer), in case of surface water shortage, by drilling new water wells.
- Increasing the number of free-range livestock farms with a water supply from groundwater by drilling new wells in the Cretaceous aquifer with a salinity of 2-3 g/l.
- A connection with the intensive shoreline variation and desertification of the Aral Sea to study the groundwater table level and hydrochemical regimes. It would be advisable to lay a hydro-well between the Djiltyrbas Lake and the Arkhangelsk swell, equipped with coupled observation wells located at every 7-10 kilometres to the upper and lower aquifers, extended to the impassable area towards the Aral Sea.

6.2. Soil cover of the studied area

The Aral Sea drying out processes led to the formation of a new soil structure on the dried seabed.

The parent rock of modern soil formation on the dried bed has a marine, lacustrine, alluvial and aeolian genesis.

Initially the seabed is changing due to the processes taking place, including the outcrop of the avandelta, the drying of residual lakes with the formation of brine, oversanding, the movement of sand masses, and the movement of sand-dunes.

The initial stage of soil cover formation is connected with the intensive salinisation of soils, which have offlapped from below the water level and are a formation of marsh and coastal solonchaks. As a result, in the process of drainage, the change of hydrogeological conditions and the further transformation of soil cover takes place and varieties of solonchaks are formed. At the last stages of soil development, the salinisation processes caused by hydromorphic conditions fade, but the role of arid-zonal factor increases many times causing the further development of typically desert type soils.

When studying the soil cover on the dried bed of the Aral Sea, we identified and described the following types of coastal soils: semi-hydromorphic solonchaks, hydromorphic solonchaks, semi-automorphic solonchaks, automorphic solonchaks, desert sandy soils, deserted alluvial-meadow soils, and sands fixed to different degrees. When carrying out forest-reclamation measures, a differentiated approach to the choice of soil conditions will be required.

The field studies included routes and descriptions of landscape points, vegetation, and soil cover. Fifty-six soil profiles were laid in the typical selected sites. The depth of embedding was 1.5 metres. When necessary, soil profile sections were made. A morphological description of the profile according to the required format was carried out, genetic horizons were selected, soil samples were taken from the middle of them, and soil description by genetic horizons and photographs of the soil profiles were given. Soil samples were analysed to determine their chemical and physical properties, including the content of organic matter, humus, qualitative and quantitative composition of water-soluble salts, as well as gypsum and carbonates. The laboratory analyses were performed by the laboratory of the Analytical Center of Soil Quality, Composition and Repository under the Committee for Land Resources, Geodesy, Cartography and State Cadastre.

6.2.1. Soil cover of the western part of the Aral Sea dried bottom

The first expedition included a study of the soil cover at the Muynak part of the dried seabed. This area is mostly flat, with a general slope to the west and north. In the middle of the massif there is a sand spit with sand-dunes, currently connected to Lazarevo Island.

Coastal hydromorphic solonchaks and their varieties

Hydromorphic solonchaks, including solonchaks created during the soil formation process with the participation of groundwater located, were at the depth of 0-3 metres in the soil. Hydromorphic solonchaks include marsh solonchaks, hydromorphic and moderately hydromorphic ones with a groundwater depth of 0-2 metres, and semi-hydromorphic ones

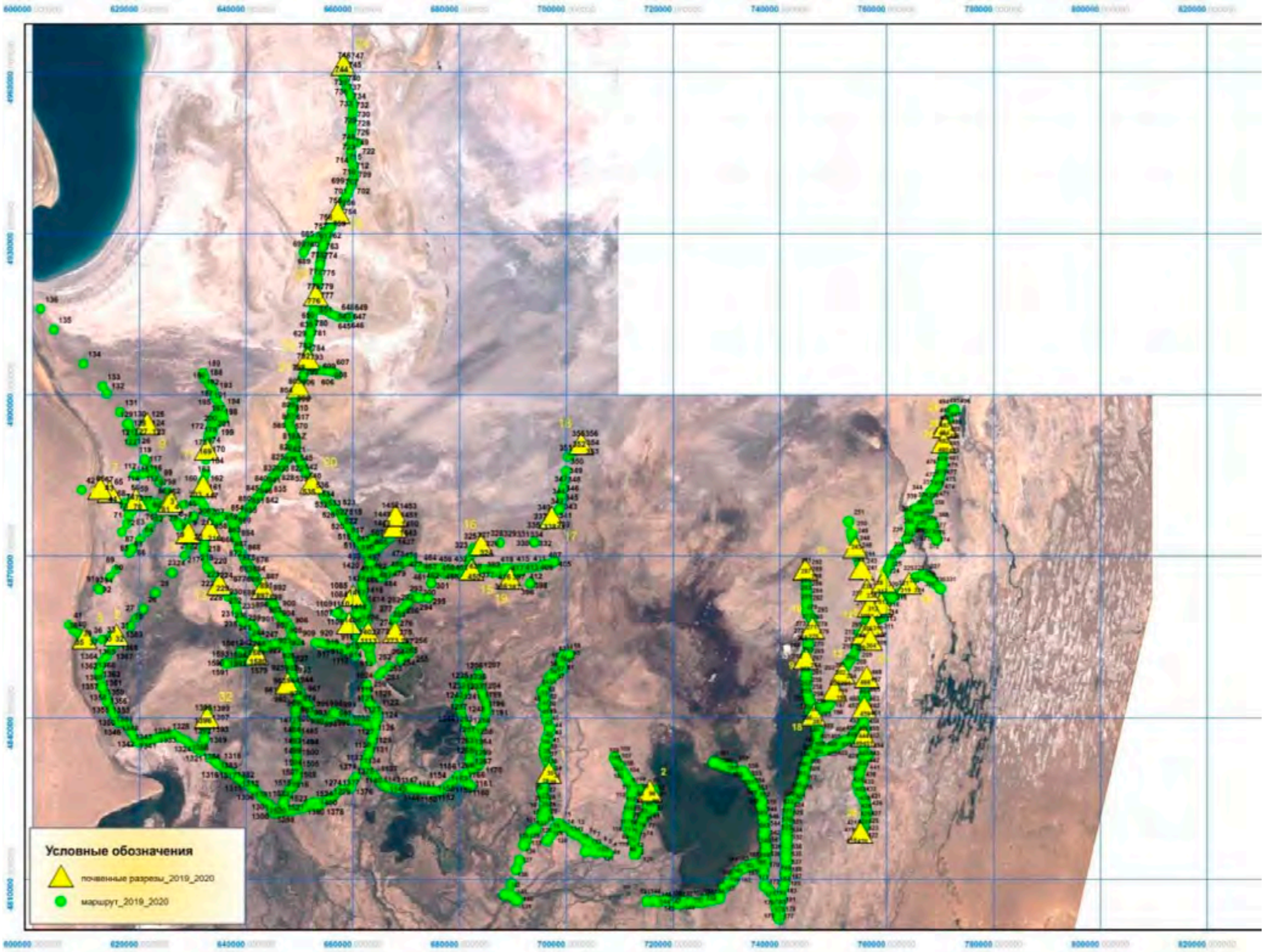


Fig. 43. Location of soil profile sections

with a groundwater depth of 2-3 metres. This division is conditional, as groundwater participation is also determined by soil parameters, for instance granulometric composition. When classifying soils, important attention is also paid to soil condition in its morphological description.

Marsh solonchaks (Fig. 44) are a strip fringing the sea periodically flooded by sea water. The marsh solonchaks have a leaching regime and uniform salt distribution along the profile, while the salinity type of the solonchak is chloride. Their granulometric composition widely varies, ranging from clay to sand.

The formation of marsh solonchaks has its own features caused by the Aral Sea drainage.

Fig. 44 shows an example of the West Sea's marsh solonchaks, which have been formed as a result of periodic inflow of water into the sea and their subsequent drainage in dry years. On the West Sea coast, the marsh solonchaks are distinguished by a narrow strip, as the inflow of water into the sea in recent years is very insignificant (Fig. 45), and the process here is mainly one-sided in the direction of draining.

Fig. 44. Narrow strip of marsh solonchak, West Sea

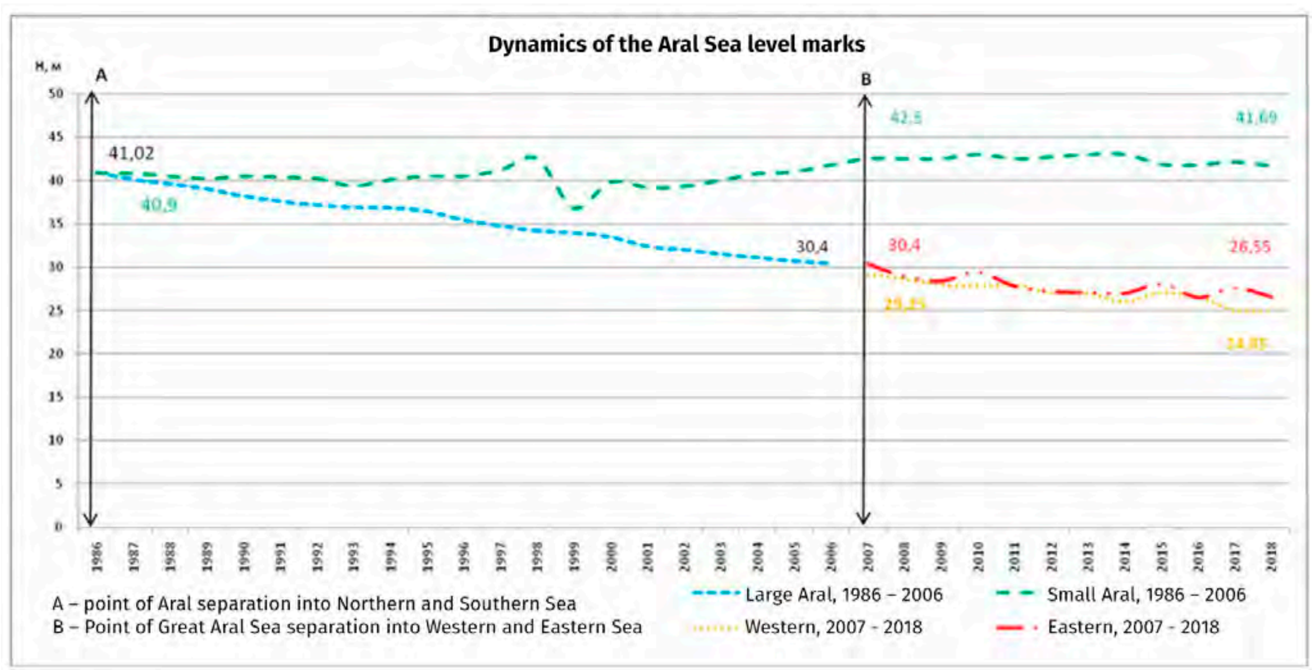


Fig. 45. Dynamics of the Aral Sea level marks

Fig. 46. Transition from marsh to hydromorphic coastal solonchak

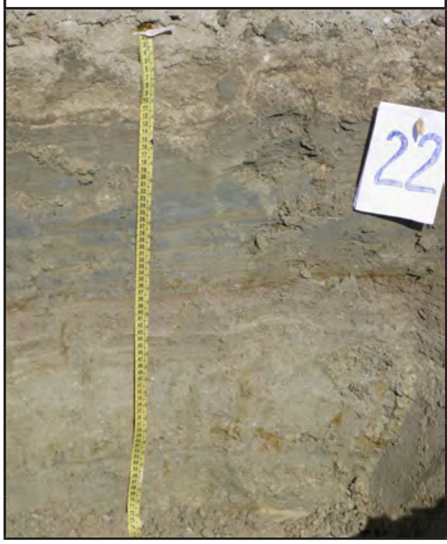
Schematic breakdown of the soil section profile P-22	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-2	Crust light grey, dry
	2-10	Sand, salt, wet, structureless, shines in the sun
	10-12	Layer of light loam, rusty coloured, large amounts of salts, loose, structureless, in some places brown structured inclusions
	12-28	Dark, grey, almost blue moist clay, layered, rusty spots on the faces of separated layers
	28-36	Blue, large amount of rust, lumpy structure 1-2 centimetres, wet, transition noticeable
	36-46	Dark grey, wet, rusty spots, more loose, scattered into small lumps, shells
	46-60	Dark grey, moist, light loam, powdery, many shells, rust spots, horizon drier than others
	60-90	Wet, bluish, rusty spots, light loam, heterogeneous

Fig. 47. Profile description, profile P-22, coastal hydromorphic (moderately hydromorphic) on the parent rock of marine genesis

Semi-hydromorphic, hydromorphic and moderately hydromorphic solonchaks

Hydromorphic coastal solonchaks occupy more than half of the area of the dried seabed. They are distributed between the semi-automorphic solonchaks and the modern seawater edge. Semi-hydromorphic soils are represented by both crustal (fragile and firmly crustal) and crust-puffed varieties. Sometimes there are salt-whitened spots of puffed soils that are easily deflated. In some places, where the surface horizons are represented by sandy loam-sandy deposits, traces of wind erosion are visible.

Due to their wide distribution, these types of solonchaks are formed on sediments of different mechanical composition, and often have a layered profile, sometimes of mixed alluvial-marine genesis.

Vegetation is represented by different associations depending on the location of the contour of the semi-hydromorphic solonchak, including karabarak-gramineous, tamarix-gramineous, saltwort, remnants of reed vegetation, and open surface without vegetation.

The typical hydromorphic (moderately hydromorphic) solonchaks observed with close groundwater are confined to the western dried part of the East Sea. Groundwater levels along the profile starting from the zero-level mark vary from 1.5 to 0.8 metres. According to granulometric composition, soils are sandy loam and sandy (P-21, P-23, P-24 and P-25) (Table 16) and stratified with loamy interlayers (P-22) (Fig. 47, Table 16). Soils have sulphate-chloride and sulphate salinity, by salinity degree strongly and medium saline by ECe, and weakly and medium saline by Cl and Na (Fig. 48).

The ECe dS/m values range from a maximum in the upper part of the loamy profile of 161.6 dS/m in profile P-22 and up to 329.6 dS/m in profile P-18, heavy loamy and clayey soil, while the remaining profiles with loamy and sandy composition do not have a clear differentiation of salts in the profile.

The profile P-18 was laid in moderately hydromorphic conditions and has a heavy granulometric composition throughout the profile (Table 16). The soil is coastal solonchak, formed on layered alluvial-marine sediments of the avandelta and seabed (Figs. 48 and 49).

Similar to deltas, avandeltae are formed from hydrosuspended material. Here, too, a lithologically layered profile is formed, but whereas deltas have alternate layers of alluvial genesis, avandelta are interspersed with layers of marine sediments, which can clearly be observed in the profile of soils on alluvial-marine material.

Semi-hydromorphic coastal solonchaks are formed when saline groundwater lies within 2-3 metres. Groundwater salinity reaches 20-80 g/l. Salinity type is predominantly magnesium-sodium chloride.

Semi-hydromorphic coastal solonchak and fragile crust soils are characterised by transects P-9 and -.11 (Figs. 50 and 51). The soils are very strongly saline throughout the profile in classifications estimates by ECe m (24-69 dS/m), TDS (2-9 percent), by Na and Cl (Table 16). The salinity type is chloride (Fig. 51).

In terms of granulometric composition, soils are classified as clays sanded from the surface and underlain by bluish wet clay.

In all soil horizons, rusty oxide colours, stains and white coating and crushed shells are observed. All are indications of the rock's marine genesis.

Rusty-coloured oxide deposits indicate that the soil periodically dries out and moistens again.

Fig. 48. Coastal solonchak moderately hydromorphic P-18

Schematic breakdown of the soil section profile P-18	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-1	Crust, salt
	1-8	Brown, greyish, puffy, loose, light loam
	8-22	Grey, moist, dense, whitish due to the large amount of salts, 7-18 layers of white
	22-38	Blue, moist, heavy loam, lumpy-nutty-like structure, rare white spots (salt) 37-40 layers
	38-45	Almost white, moist, clay, fine, lumpy-nutty layer, transition noticeable
	45-70	Blue clay, plastic, wet

Fig. 49. Profile description, profile P-18, coastal solonchak (moderately hydromorphic) semi-hydromorphic on the parent rock of alluvial-marine genesis

At present, the natural cover is disturbed everywhere by furrows created in preparation for forest plantations.

Hydromorphic coastal solonchaks are found near inflowing water bodies, in depressions of the bottom, and around numerous residual lakes. This type includes soils of the drying depression, lakes along the "Tigroviy Hvost" (Tiger's Tail), lacustrine-brine type soils, and the soil of profile 31 on the wet solonchak (shora solonchak).

Groundwater salinity of magnesium chloride-sodium composition here reaches 65 g/l. From the soil surface, dark grey crust is very dense, 2-3 centimetres thick, medium-loamy, strongly saline, and a chloride-sulphate salinity type. The rest of the profile is strongly and very strongly saline compacted sand, while the salinity type is sulphate-chloride (Table 16).

In coastal semi-hydromorphic solonchaks, the leaching regime is replaced by the evapotranspiration regime.

The most susceptible to wind erosion among semi-hydromorphic solonchaks are puffed solonchaks, the surface of which is represented by a powdery earthy-salt layer, as well as solonchaks formed on sandy loam-sandy sediments.

On the surface of the latter, a very weak sandy-salt crust is formed that can be easily destroyed by wind. The soil surface is covered by flat (stratum) deflation centres. These solonchaks are active producers of salts transported by wind outside the basin of the former water area. The vegetation is represented by different associations, depending on the location of the semi-hydromorphic solonchak contour, including karabarak-gramineous, tamarix-gramineous, saltwort, remnants of reed vegetation and open surface without vegetation.

Fig. 50. Semi-hydromorphic coastal solonchak, fragile crusted

Schematic breakdown of the soil section profile P-9	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-2	Crust, fragile, loamy sand
	2-15	Light grey, moist, large number of shells, very loose, medium loam with heterogeneous sand
	15-32	Dark grey, brownish, wet, dense, lumpy-nutty structure, easily scattered into pieces in the hand, a lot of rust spots and white plaque, the inclusion of crushed shells, heavy loam
	32-42	Dark grey, brown tint, rusty all over, well-defined prismatic structure, covered with rusty patina on the edges, heavy loam, the transition is noticeable
	42-55	Dark grey with brown spots, moist, with white shells, powdery inclusion of carbonates, very plastic, clay, noticeable transition
	55-73	Wet clay with rusty spots
	73-100	Blue clay

Fig. 51. Profile description, profile P-9, coastal semi-hydromorphic solonchakon parent rock of marine genesis

Fig. 52. Hydromorphic solonchak P-31, wet solonchak

Automorphic and semi-automorphic coastal solonchaks

Automorphic (profiles P-2, P-7, P-13, P-14, P-15, P-16, P-19, P-20, P-27, P-28, P-29, P-30 and P-35) (Table 16) and related semi-automorphic (profiles P-1, P-3, P-4, P-5, P-6, P-8, P-10, P-26, P-33 and P-34) (Table 16) coastal solonchaks are spread in the southern part of the dried seabed. Automorphic solonchaks are formed in conditions with groundwater occurring deeper than 5 metres. They can be most often found together with sands. Automorphic solonchaks are mainly represented by crust and crust-puffed varieties. The earthy-salt crust strongly armours the soil surface and protects the underlying powdery-puffy horizon from wind erosion. Such contribution is also made by the dried vegetation cover, which sometimes covers the land surface very densely. Destruction of the earthy-salt crust and destruction of the vegetation residues leads to the activation of aeolian-erosion processes.

A large body of automorphic solonchaks is located in the middle part of the studied area, confined to a sandy spit extending from south to north, as seen in profiles P-12 and P-13.

Below one can find a description of profile P-13, laid in an old saxaul bush, with soil that is a crust-puffed solonchak and automorphic (Figs. 54 and 55).

The eastern part of the territory adjacent to the avandelta and the river avandelta contains automorphic solonchaks and desert-sandy soils, of profiles P-15, P-16, P-19 and P-20 (Table 16) (Fishenko Bay). The layered nature of soils formed by river sediments leads to the formation of thick desiccation cracks in the profile when the soils dry out. Atmospheric and surface water enters these cracks and causes erosion. Karst-suffosion sinkholes are formed, sometimes of a very large size (Fig. 56).

Schematic breakdown of the soil section profile P-31	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-2.5	Crust is dense, dark, grey, with a dark spot
	2.5-6	Salted sand, light brown, layered
	6-25	Light brown, layered, 0.5 centimetre thin, small plant roots
	25-37	Grey with rusty spots, white salt noticeable
	37-53	Red sand with seashells
	53-90	Shallow, light loam, with the whole profile being damp

Fig. 53. Profile description, profile P-31, coastal hydromorphic solonchak on parent rock of lake-marine genesis

In the peripheral parts of the avandelta, desiccation cracks are also formed when drying out, but they are hidden under the sandy-sandy loam marine sediments.

Automorphic solonchaks are a transitional stage to desert-sandy soils, so the soil assessment should indicate that such a process takes place, including profiles P-13 and P-15.

Salinity varies by ECe from 9 to 60 dS/m, and by TDS from 1 to 9 percent.

Automorphic solonchaks located in the western and southern parts of the studied area along the cliff (profiles P-2, P-35 and P-27) (Table 16) are also found together with hilly sands, with sand dunes, overgrown with vegetation and weakly overgrown with vegetation.

Automorphic soils are crusty and crusty-sandy, but when unfortified artificially or naturally they are a hazard and a source of salt and dust transfer.

In a coastal solonchak (semi-automorphic) (Fig. 59) the evapotranspiration regime takes place. Capillary fringe in especially heavy soils rises to the soil's surface and on its borders intensive evaporation and deposition of salts in the upper horizon occurs, which is demonstrated by the results of water extraction of profile samples (profile P-10) (Fig. 60).

In a 0-20 centimetre layer of profile P_10 soil salinity is 120-180 Ds/m, TDS 13.7-16.7 percent. Other horizons have values of salinity of ECe 20-25, TDS 1.7-2.3.

In the profile of P-5, respectively, the values of salinity are ECe 165, TDS 12.2 percent and ECe 11-70, TDS 0.8-9.6 percent.

Fig. 54. Crust-puffed solonchak, automorphic P-13

Schematic breakdown of the soil section profile P-13	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-1	Crust light grey, dry, dense in an undisturbed state, a large number of small roots, sandy loam
	1-6	Subcrust, light grey sandy loam, dusty, dry, large number of roots, small, residual shells, whole and fragmented
	6-16	Light grey, dry, loose, unstructured, dusty, small plant roots, brown tinge in profile, transition noticeable in density
	16-37	Grey with a brown tint, dense, heterogeneous in composition, nutty structure, between parts of the pores are filled with fine-grained sand of the upper horizon
	37-58	Grey with a brown tint, almost dry, lumpy structure, light loam, 0-10 centimetre lenses of sand in the middle of the horizon, sparkles in the sun, a large number of shells
	58-85	Almost dry, grey with a brown tint, layered, lumpy structure, medium loam, sand layers along the profile, pale stains, carbonates, remains of shells are present
	85-90	Very dense, dark grey, cool to the hand, light loam, coarse and crumbly

Fig. 55. Profile description, profile P-13, automorphic crusty-puffy coastal solonchak

Fig. 56. Karst-suffosion sinkholes (ukpans)

Fig. 57. Fragile crust automorphic solonchak, profile P-15

Schematic breakdown of the soil section profile P-15	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-1	Crust, loose
	1-6	Light grey, with a paler tint, dry, dusty, loose, unstructured, shiny in the sun, many shell rocks, transition noticeable, sand, loamy sand
	6-10	Raw, brown with bluish interlayers, fine lumpy structure, loose, separate inclusion, red spots in some places, light loam
	10-30	Raw, dense, well-defined nut-like structure that measures 0.5-1.5 centimetres in undisturbed compounding, looks layered, inclusions white and floury, inclusions in the form of stones similar to glass (gypsum) 0.5-1.5 centimetres, cracks filled with pale melkozem, brown
	30-39	Raw, brown with bluish spots, inclusion in the form of small pebbles of 0.5 cm, a large number of rusty spots, heavy loam
	39-44	Homogeneous brown in colour, coarsely nutty lumpy, inclusion in the form of stones like glass, 0.5-2 centimetres gypsum, heavy loam, clay, rusty spots
	44-77	Sand, light brown with red spots, thinly porous sand

Fig. 58. Profile description, profile P-15, automorphic coastal solonchakon a marine mother rock, periodically moistened from the Engineer-Uzyak

Fig. 59. Strong-crusted semi-automorphic solonchak, profile P-10

Fig. 61. Crusty semi-automorphic solonchak with shell rock in some places, profile P-1

Schematic breakdown of the soil section profile P-10	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-1	Crust
	1-22	Loose, light loam, brown, almost dry, dusty, unstructured, lamellar, noticeable transition
	22-30	Dark grey with a paler shade of heavy loam, many small roots, well-defined nutty structure, moist, transition noticeable in moisture content
	30-65	Wet, dark grey, heavy loam, very plastic, lumpy structure weakly expressed, rare white spots, gradual transition
The profile is fractured, with cracks up to 20 centimetres filled with soil, and 22 centimetres of loose, brown, unstructured material	65-90	Wet (almost wet), lamellar, unstructured, rare white dots (shell rock), viscous clay

Fig. 60. Profile description, profile P-10, coastal solonchak semi-automorphic solid-crustal on the parent rock of marine genesis

Like the previous example, the semi-automorphic soil (profile P-1) (Figs. 61 and 62) is characterised by salt accumulation in the upper ECe horizon of 247.2 Ds/m and TDS 16.284 percent.

According to the groundwater table data, all given examples demonstrate that although the profiles are located in conditions of deep groundwater (>5 metres) because of their locations they should be referred to as automorphic solonchak. However, the heavy granulometric composition of these soils provides good capillary recharge from groundwater and evaporation moisture regime. Therefore they are referred to as semi-automorphic soils, and within the morphological description of soils it has been noted that the soil profile is very damp in the lower part, even wet.

Desert-sandy soils

Two types of desert-sandy soils are found in the studied area.

The first type is genetically formed, old soils that are in a long-term soil-forming process. These soils are confined to island landscapes. As a result of aeolian activity, they are often overlain by sand.

The second type is the ethmolode primitive desert-sandy soils (Fig. 63). In their profile, the humus horizon is already clearly defined, but they still retain signs of salinity inherent in solonchaks, on which desert-sandy soils are formed.

To demonstrate the initial process of soil formation, transition to desert type and formation of desert-sandy soils, two profiles were laid at some distance from each other. One was under an old saxaul, and the other in an empty ungrown area (profiles P-30 and P-29) (Figs. 63 and 65), to the north of Rybatsky Bay.

To characterise the morphological profile of desert-sandy soils, we described profile P-30, laid in the territory of ten-year old artificial plantations of saxaul.

As follows from the morphological description, soil profiles here are practically identical and have the same granulometric composition, but the processes of change are already traced in two directions of transition to desert-sandy soil. For example the coastal solonchak (profile P-29) has a chloride type of salinity, while the desert-sandy soil (profile P-30) has a chloride-sulphate type of salinity. Humus content in the upper part of the profile is 0.42 and 0.60 percent, respectively.

Schematic breakdown of the soil section profile P-1	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-1	Crust, rather dense, white, finely porous, with salted shell rock on top
	1-10	Brown, almost dryish, moist, unstructured, dusty, inclusion of large amounts of shell rock, the transition noticeable in salt
	10-26	Dark grey, heavy loam (slightly sandy), damp, dense, layered, lamellar-nutty structure, small white spots
	26-43	Noticeable difference from other horizons, heavy loam, dark grey moist, well-defined nutty structure in undisturbed folding, layered, sparse white spots, transition noticeable in colour
	43-57	Clay, moist, well-defined, medium-lumpy structure, scattered into faceted clumps, light-coloured underbrush along the edges, rare small spots of up to 1 centimetre, gradual transition
	57-73	Heavy loam, dark grey, moist, dense, pronounced lumpy-lamellar structure, rusty, sandy loam, light grey, sparse, small white spots
	73-100	Clay, plastic moist, homogeneous, rather dense, weakly expressed

Fig. 62. Description of the profile, profile P-1, coastal semi-automorphic solonchak, crusty on the parent rock of marine genesis

Fig. 63. Desert-sandy soil under an old saxaul, profile P-30

Schematic breakdown of the soil section profile P-30	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-1	Crust dry, loamy sand, on the surface a large number of plant residues
	1-5	Dry, loamy sand, weakly expressed lumpy structure, a lot of small roots, dusty, noticeable transition
	5-20	Raw, light loam, light brown in colour, crumbles in the hand, rare white spots 1-2 mm, more compact than the previous, transition is noticeable
	20-47	Very dense, brown, lumpy structure, rusty spots on structural faces, heavy loam, layered in profile
	42-45	Grey sand
	47-56	Whitish, dense, damp, shell layer, sand
	56-85	Brown, damp, unstable structure, crumbles in the hand, layered, light loam, at a depth of 65 centimetres to the bottom of the cut, and a powerful root of 6 centimetres

Fig. 64. Profile description, profile P-30, desert-sandy soil

Fig. 65. Coastal semi-automorphic crustal solonchak, profile P-29, at a distance of 10 metres from the forming desert-sandy soil, profile P-30

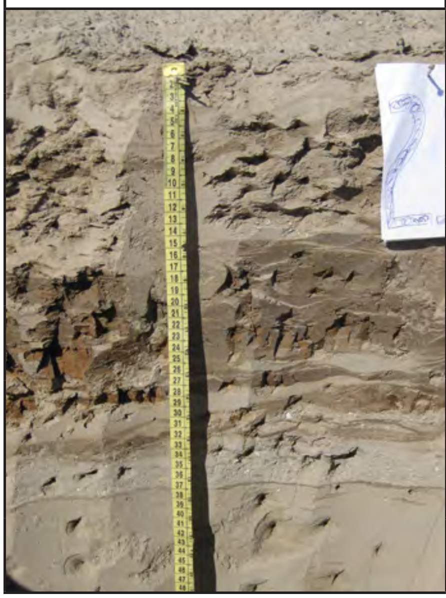
Schematic breakdown of the soil section profile P-29	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-1,5	The crust is dry, dense, on the surface there is shell
	1,5-4	Dry, dusty, loamy sand, shiny in the sun, rare shells
	4-18	Dry, grey, light loam with occasional rust spots, glistening in the sun, lots of shells, no plant roots
	18-33	Dense, damp, brown, coarse-lumpy structure, almost all rust-coloured, medium loam (heavy loam), remains of shells and sand interlayers (30-33 centimetres) in the lower part of the profile – the transition is noticeable
	33-38	Shell rocks, shiny in the sun, sandy loam, almost white (whitish), light grey, very rare brown spots
	38-69	Light brown, damp, sand, light loam, shiny in the sun, brown layer at a depth of 52-54 centimetres, in the profile a lot of shells, no plant roots, transition is noticeable
	69-95	Yellow, with red interlayers, damp, not strong lumpy structure, dense

Fig. 66. Profile description, profile P-29, coastal solonchak, automorphic, crustal

Sandy formations with aeolian erosion-accumulative landscape

The drying of the sea has led to the redistribution of sandy material and the formation of aeolian-accumulative landscape (Fig. 67).

To date, several sand bodies have formed and are currently in different degrees of stability.

These two bodies are in contact with the alluvial delta plain of the Amudarya River and the Adjibay Bay. The eastern part of the studied area of the dried seabed has a ridge-sand dune character in some places.

As one moves westwards towards the water channel, the accumulative landscape changes to shallow hilly with unfixed mobile sands. The northern half of these bodies often have a landscape characteristic of deflationary surfaces, specifically undisturbed sandy bottom surfaces alternating with numerous deep pockets of deflation. The southern part, despite active deflation, is covered with relatively good grass vegetation in some places. Here desert sandy soils are formed under the automorphic regime of moisture. The upper horizons of the soil cover are similar to loose turf.

In the area of Adjibay Bay, west of Muynak Bay, the sand body acquires a bumpy landscape. Here quite a diverse population of shrubs and herbaceous vegetation can be found. Primitive desert sandy soils are formed on the surfaces fixed by herbaceous vegetation.

A chain of medium to high semi-fixed knolls and sand dunes stretches along the “Tigroviy Hvost” (Tiger’s Tail) peninsula, where in some places one can find desert-sandy soils.

The western coast of the peninsula is composed of marine sediments and fragments of Tertiary deposits. It stretches from south to north along the coast. At present, the Tertiary debris is exposed or partially interbedded with coarse gravel-sandy material with an admixture of shells. Part of the area is buried under separate low knolls of overblown sands. Ridge sand dunes oriented from north-east to south-west, up to 5-7 metres high, unvegetated, stretch along almost the entire strip of the cone of sand transfer, sand spit, in the middle part of the sand body. The eastern part of this regional elevation is occupied by plain unfixed sands with bedrock deposits.

The general landscape of the territory is a plain with a slope towards the modern water level and a slope from the cliff to the Adjibay Bay. The drying of the sea here was observed in two directions. The sea departed from the Ustyurt’s steep shore to the east and simultaneously moved to the north. The steep shore of Ustyurt is layered with Quaternary sediments (Fig. 68).

As a result of the analysis of the obtained field and laboratory data on the typical soil profiles, a classification of soils was made (Table 15). The results of this work are given below.

Fig. 67. Aeolian erosion-accumulative landscape

Fig. 68. Cliff of Ustyurt

Table 16.

Soil Classification 2019

№	Number of the GPS point	Brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	Soil type	Granulometric composition	Salinity type
1	9	1	Coastal solonchak, crusty, takyr-like semi-automorphic	Medium and heavy loam by profile	Chloride/ sulphate-chloride
2		2	Coastal solonchak, automorphic (semi-automorphic)	Medium heavy loam along the profile	Ch/Ch
3	37	3	Coastal solonchak, crusty, semi-automorphic, washed periodically	Heavy loam	
4	45	4	Coastal solonchak, fragile crusty, semi-automorphic, periodically washed takyr-like surface	Clay loam and heavy loam, loamy sand in the lower part of the profile	Ch-S / S-Ch
5	51	5	Coastal solonchak, crusty, wet from surface, semi-automorphic	Loam and clay, loamy sand in the lower part of the profile	Ch / S-Ch
6	65	6	Sandy solonchak, non-sandy-crusty, semi-automorphic	Loam and clay	S-Ch / S-Ch
7	66 (43 old)	7	Sand with large amounts of shell rock, underlain by clay	Layered complex of sandy loam and light loam, clay in lower part of profile	S / Ch-S
8	112	8	Solonchak, takyr-like, semi-automorphic, furrows	Loam	S / Ch / S-Ch
9	124	9	Solonchak, fragile crustal, semi-hydromorphic, furrows	Clay sanded from the surface	Ch / Ch
10	148	10	Strong-crust solonchak, semi-automorphic	Clay, loam from the surface	Ch / Ch
11	166	11	Solonchak fragile crustal, semi-hydromorphic, furrows	Clay, sandy loam from the surface	Ch / Ch (S-Ch)
12	211	12	Sandy solonchak	Light loam, sandy loam from the surface	S / Ch-S
13	233	13	Solonchak crust-puffed, sandy automorphic, closer to desert-sandy soil (under saxaul)	Heavy loam, sandy loam from the surface	Ch-S / S-Ch

№	Number of the GPS point	Brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	Soil type	Granulometric composition	Salinity type
14	274	14	Solonchak automorphic, washed out, compacted from a depth closer to the desert-sandy soil	Light loam, clay at the bottom of the profile	S / S-Ch
15	317	15	Solonchak crust-puffed from the surface, automorphic gypsiferous	Clay with sandy loam at the top and bottom of the profile	S / S-Ch
16	326	16	Saltwort, crusty (salt layer at a depth of 20-26 centimetres), automorphic (semi-automorphic)	Layered, loam, loamy sand	S / Ch
17	337	17 (soil profile section)	Solonchak with shell rock	Light loam	S / Ch - S
18	353	18	Solonchak, crusty, moderately hydromorphic, strongly saline from the surface, furrows (Andijan region)	Layered complex, heavy loam, clay	Ch-S | S-Ch S-Ch | Ch-S
19	383	19 (soil profile section)	Solonchak strong-crust, in some places overlain by sand, automorphic (semi-automorphic)	Layered complex, light loam, loam, loamy sand	Ch / S-Ch
20	535	20	Solonchak, non-solid crustal, automorphic (semi-automorphic), gypsified, sandy loam in some places, weakly saline, furrows	Layered complex with a predominance of sandy loam from the surface and in the lower part	S / Ch-S
21	583	21	Solonchak moderately hydromorphic, furrows	Bound sand	S / Ch-S
22	614	22	Hydromorphic solonchak, crusty, furrows	Loam, loamy sand in the upper part of the profile	S-Ch / S-Ch
23	656	23	Solonchak, saline sand, loose crust, moderately hydromorphic	Sandy loam, sand at the bottom	Ch-S / S-Ch
24	742 3 artesian wells	24	Solonchak fragile crustal, saline sand, near bush, hydromorphic	Sandy loam, sand	Ch-S / S-Ch
25	745	25	Sandy-sandy, non-crustal, hydromorphic solonchak	Sand porous	S / Ch-S

№	Number of the GPS point	Brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	Soil type	Granulometric composition	Salinity type
26	888	26	Solonchak, strong-crust, semi-automorphic on lake-alluvial sediments (GW table, 2.5-3 metres)	Layered complex, light loam and heavy loam	S-Ch / S-Ch
27	954	27	Desert-sandy, reclaimed soil, automorphic	Loam, loamy sand in the upper part of the profile	(S-Ch) S / S
28	1036	28	Solonchak (closer to desert-sandy soil) periodically washed	Sandy loam, sand	
29	1082	29	Solonchak strong-crusted, automorphic, shells on the surface	Layered, heterogeneous, light loam, sandy loam, compacted sand	Ch / Ch
30	1082	30	Desert-sandy soil (near a tree), automorphic	Layered, heterogeneous, light loam, sandy loam, compacted sand	Ch-S / S-Ch
31	1096	31	Shora, black, hydromorphic (0-1.5 m) Solonchak on lake-marine sediments	Loam from the surface, sand along the profile	Ch (Ch-S) / S-Ch
32	1398	32	Solonchak on lake-alluvial deposits, crusty. Shell rock from the surface, near sand dunes	Layered, heavy loam, loam in the lower part, light loam and loam in the upper part	(S-Ch) Ch / S-Ch
33	1442	33	Crustal solonchak, semi-automorphic, periodically washed	Light and heavy loam	S-Ch / S-Ch
34	1448	34	Crust solonchak, (upturned crust) semi-automorphic	Light and heavy loam	Ch / Ch-S (Ch)
35	1564	35	Crustal solonchak, automorphic, periodically washed	Light and heavy loam, clay in the lower part	Ch/S / S-Ch

6.2.2 Soil cover of the eastern part of the dried bottom of the Aral Sea

Undoubtedly, the entire territory of the dried seabed has the same characteristics, but in the geomorphological, geological and soil sense, apart from the general one, each part of the dried seabed has its own characteristics. Thus, at present, the Muynak part of the drainage area adjoins both the West Sea and the East Sea. The Djiltyrbas part is adjacent to the East Sea after the division of the Large Aral Sea. This imposes peculiarities on the soil-forming process taking place. Peculiarities of drying have also led to a different ratio of soil varieties.

Solonchak semi-hydromorphic, hydromorphic and moderately hydromorphic

The level of the East Sea is more dependent on the influx of water sources and does not depend on the natural sea level regime, but on anthropogenic factors that determine its regime.

In this regard, there is a difficulty in identifying marsh solonchak, the formation of which by nature is associated with natural fluctuations in sea level, which forms a strip periodically wetted and washed along the sea.

The influx of water into the East Sea varies depending on the water content of the year, but part of the sea irreversibly passes into the land. Thus, the drainage of the sea leads to the formation of a considerable area of coastal hydromorphic and semi-hydromorphic solonchaks (Fig. 69) on marine sediments, separated from the entire drainage body by a ridge of sand dunes and coastal dunes, impassable unfixed and movable.

In 2005, profile P-22 was established on a low thickness hydromorphic solonchak underlain 15 centimetres by wet red clay, on the border of a sand dunes body.

At present, the deflating sands have significantly moved to the south-western direction, overlapping the hydromorphic soils on marine sediments. In terms of chemical composition coastal hydromorphic solonchaks have a high salinity of the chloride type, and uniform salt distribution along the profile.

Other conditions for the formation of hydromorphic and semi-hydromorphic soils are the Kokdarya spills, Djiltyrbas Bay and the Toguzarkan channel.

Hydromorphic soils formed on alluvial and marine sediments have an overlapping granulometric profile P-16 (2), (Figs. 70 and 71).

The salinity of all soil profiles is chloride. Salinity degree depends on granulometric composition. Medium and high salinity varies from 2 to 15 dS/m, ECdS/m from 0.6 to 3.2, TDS from 0.2 to 1.2 percent, while high salinity refers to being heavy on granulometric composition layers.

Hydromorphic solonchaks are characterised by a salt crust on the surface and are very highly saline P-16 (2), EU - 64 dS/m, TDS - 7.8 percent.

In light soils P-24(2) the crust is weakly thick, while in conditions of heavy and medium granulometric composition of surface the crust is strong, uplifted, and the surface is takyr-like P-25(2). There is a high degree of salinisation with values ECe - 21.5 dS/m - 123.2 dS/m, and TDS - 3-14 percent in the layer of 0-20 centimetres of the P-24(2) soil profile and ECe 25.5 dS/m - 242.0 dS/m of the P-25(2) soil profile.

The presence of chloride salts is an unfavourable condition for plant establishment.

In the Muynak part around Adjibay Bay, there are lake sediments. Alluvial lake rocks are deposited near Adjibay Bay, near Djiyltyrbas, as a result of periodic wetting and drying up.

Along the bed of the Amudarya River, sorted alluvial deposits are present.

Schematic breakdown Soil section profile P-22, 2005	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-3	Sand, grey, dry, loose, shell rock
	3-7	Light grey, bluish, dry, dense, lamellar structure (l.sug), sand
	7-14	Dark grey, wet, loose sand with inclusions of small shells, crushed shells
	14-27	Brown wet, clay with rust spots
	27-31	Layer of yellow sand
	31-47	Clay, with inclusions of sand rusty spots
	47-63 2 arr.	Sand with rust stains
	63-150	Red clay

Fig. 69. Description of the profile (profile P-22, 2005) shallow hydromorphic solonchak

Fig. 70. Hydromorphic solonchak, salt crust, profile P-16 (2)

The frequency of overflows of the Djiltyrbas and Kuat Lakes affects the soil cover of the adjacent area. The profile P-10(2) was laid in the area of bay influence in saxaul plantations. Soil cover is represented by the complex of firm-crust and crust-puffed solonchak semi-hydromorphic, and a groundwater table at 2-3 metres.

In regards to the type of salinity, this is chloride-sulphate and sulphate-chloride, respectively.

Granulometric composition is loose sand with maximum salts in upper horizons, according to ECe 30.80 dS/m and 11.8 dS/m, according to TDS 3.9-1.5 percent strongly and medium saline. The rest of the soil profile is medium-saline sulphate-chloride type.

Automorphic and semi-automorphic soils

Automorphic soils P-5(2), P-8(2), P-13(2), P-17(2), P-20(2), P-21(2) and P-22(2) are located in the central part of the sand body, where the influence of the Djiltyrbas Bay and the Kokdarya River is less.

At the same time, the presence of nearby sand dunes provides a sandy loamy surface for these soils.

In this connection, the soil in profiles P-5(2) (Figs. 72 and 73) and P-8(2) is loose sand throughout the profiles in terms of granulometric composition. They are non-saline and slightly saline with ECe values 0.4-0.9 dS/m,

Schematic breakdown of the soil section profile P-16(2)	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-2	Crust, light grey, whitish, compacted, sandy loam, saline
	2-10	Grey, dry, dusty, shiny in the sun, few shells
	10-25	Pale, raw, fine-grained, sandy, whitish
	25-40	Wet, ochre, pale, coarse sand, the lower boundary is lighter, 40-42 centimetre interlayer of shell rock
	42-50	Dark grey, wet, white spots, there are crushed shells, heavy loam
	50-60	Ochre, with white spots, wet, heterogeneous in fur, composition, light clay
	60-80	Wet sand, red, ochre, with crushed shells
	80-100	Blue wet sand

Fig. 71. Profile description, profile P-16(2), solonchak hydromorphic, crustal, salt crust from the surface

TDS 0.1-0.7 percent, and ECe 1-4.5 dS/m and TDS 0.1-0.6 percent, respectively.

Soil salinity type is chloride-sulphate.

The surface of the soil is covered with dense shell rock.

Profile P-13(2) is sandy loam and sandy throughout the profile, non-saline and slightly saline in the surface horizons.

The profiles P-20(2) and P-22(2) can be attributed to automorphic soils, according to the groundwater table of 3-5 metres. Their location on shores and near shores explains the high degree of chloride type of salinisation.

Desert-sandy soil

Desert-sandy soil is formed, as shown in previous studies (SIC ICWC, 2008) under ten-year-old saxaul.

Indicators of the transition from solonchak in the formation of desert-sandy soils are pro-

Schematic breakdown of the soil section profile P-5(2)	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-2	Light grey, dry, loose, large number of shells, small plant roots, sand is scattered, the transition is noticeable in density
	2-21	Sand, light grey, dry, shiny in the sun, very loose, loose, there are whole shells, many small roots
	21-40	Light grey, damp, cold in the hand, sand, small plant roots, glistening in the sun, small, layered shell rock
	40-54	Medium-grained sand, shiny in the sun, thin root debris, shell rock, rusty spots along the course of plants
	54-79	Raw, layered, layers of fine and medium-grained sand, inclusion in the form of shell rock in the lower part of the profile
	79-81	Light grey, coarse-grained sand, wet, there are shells
	81-120	Raw, with a bluish tint, medium-grained sand, some small crushed shells, the transition is noticeable in the fur composition
	120-150	Dark grey with a bluish tint, with an odor of hydrogen sulphide, stratified, structural, loam

Fig. 72. Profile description, profile P-5(2), solonchak fragile crustal sandy with shell rock, semi-automorphic with signs of gleying in the lower layer

files P-21(2) and P-17(2) (Fig. 73). Although organic matter is insignificantly present in the soil, in terms of organic matter content, like almost all soils of this territory, it is poor and can be explained by their mechanical composition, sandy loam-sand, and the structure is formed along the soil profile.

In the description of the soil, it is noted that it has a well-defined structure.

Sandy formations with aeolian erosion-accumulative landscape

The dried bottom of the Aral Sea between the Kokdarya, Djiltyrbas and the Toguzarkan channel, mainly has the appearance of a sloping plain which has undergone changes under the influence of desiccation and aeolian processes.

Sand dunes and dune ridges encircle the studied area and extend from north-east to south-west in the central part (Fig. 75). Sand dunes, dunes, and sands covering the soil occupy a considerable area.

In terms of organic matter content, like almost all soils in this area the profile's soils are poor, which is explained by their mechanical composition as sandy loam sand.

Fig. 73. Formation of desert-sandy soil

Deserted alluvial and lake-meadow soils

The soils are represented by profiles P-1(2) and P-2(2). Alluvial-meadow soils occupy a significant part along the old riverbed of the Amudarya (Fig. 21).

The construction of a dam in Mejdurechenskaya caused the Amudarya to change its riverbed, which in turn created a desertification zone in part of the area between the old and new riverbeds and between the new riverbed and Djiltrybas Bay.

Schematic breakdown of the soil section profile P-21(2)	**Horizon and its thickness, cm**	**Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features**
	0-2	Grey, dry, small amount of shells, annual plants
	2-6	Grey, dry, dusty, sandy loam, undisturbed, layered, finely porous, small inclusions of shells, shiny in the sun
	6-13	Light grey with a paler tint, dusty, very loose, a lot of shells, shiny in the sun
	13-15	*Dark grey, damp, well-defined finely nutty structure, many plant roots, light loam, rare inclusions in the form of shells, similar to the humus horizon (no sample was taken)*
	15-47	Grey with ochre underlain along the roots, damp, dense, weakly expressed structure, layered, sandy loam, almost no shell rocks, visible transition
	47-59	Dark grey, heterogeneous in colour, bluish tinges on the edges of the individual sections, shells occur, lumpy-lamellar structure of 1 centimetre, light loam
	59-64	*Ochre, coarse sand, wet, a lot of crushed shells (we did not take a sample)*
	64-87	Dark grey with a bluish tint, moist, heterogeneous in colour, whitish interlayers, loose nutty structure, plant roots
	87-115	Blue, dark grey, wet, weakly expressed reflection on the edges, ochreous patina, a lot of whole shells, reddish colour, clay

Fig. 74. Profile description, profile P-21(2), crust-puffed automorphic solonchak in the process of desert-sandy soil formation

The occasional fluctuations in the level of the Djiltyrbas Bay causes periodic flooding and drying of the soil profile and leads to secondary salinisation of the soil. This leads to a change of vegetation, transition of meadow and meadow-marsh soils into solonchaks. The profile P-2(2) is located near the Djiltyrbas Bay (Fig. 76).

The study of soil conditions shows that in the process of desertification, the meadow soil transformed into a crusty-large-cell (takyr-like) semi-hydromorphic solonchak. The soil retains a large amount of organic matter in the surface horizon and according to the humus content of 4.3 percent, the soil is very rich. However, the strongly saline soil profile with chloride-sulphate salinity indicates the presence of a desertification process. Similar desertification processes are observed in the Amudarya riverbeds. Preservation of organic matter with 0.7 - 5.35 percent content of humus, nutrients 16-160 mg/kg P2O5, and 337.1-467.1 mg/kg K2O surface horizon is already slightly and medium saline.

Fig. 75. Fixed sand dunes on the dried seabed of the Aral Sea

Schematic breakdown of the soil section profile P-2(2)	Horizon and its thickness, cm	Description of the section: Granulometric composition, moisture, colouring, structure, density, texture, new formation, inclusion, nature of mixing, nature of transition horizons, signs of waterlogging, salinity, alkalinity, and other features
	0-0.1	Crust, dark grey, dense, with surface salt
	0.1-16	Light grey, dry, dusty, loose, unstructured, shiny in the sun, rusty spots, large number of white inclusions of carbonates, sandy loam, transition is noticeable
	16-20	Pale with reddish spots, large number of white spots 0.1 millimetre in size, arranged vertically, (carbonates) damp, fragile structure, plant roots light loam, transition noticeable in density
	20-43	Dark grey, large number of medium and large roots, rusty spots along the roots, white spots (carbonates), less than in the previous horizon, light loam
	43-49	Light grey, moist, shiny in the sun, sandy loam, medium to large plant roots found, powdery white spotted inclusions, also red root blotches, transition noticeable by mech
	49-73	Dark grey, moist, lightly loamy, shiny in the sun, lumpy-rusty structure, large number of medium and large plant roots, rusty underbrush along the roots, rare white spots (inclusions)
	73-83	Dark grey, moist, dense in undisturbed composition, loose and crumbly structure, rusty underbrush along the roots, sandy loam, inclusion of white spots
	83-110	Light grey, wet sand, shiny in the sun, transition noticeable in density
	110-150	Dark grey, moist, dense in undisturbed, in disturbed unstructured, layered on shiny, rust-coloured faces, shiny in the sun, in the profile layered, rusty roots, there are carbonates (white spots), sandy loam

Fig. 76. Profile description, profile P-2(2), crust solonchak, coarse-cell, semi-hydromorphic, desertifying meadow

Table 17.

Soil Classification 2020

№	Number of the GPS point	A brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	**Soil type**	**Granulometric composition**	**Salinity type**
1	*33*	*1 (2)*	*Alluvial meadow*	*Medium loam in the upper horizons, underlain by sandy loam*	*Ch-S /Ch Chloride-sulphate/ chloride*
2	*93*	*2 (2)*	*Crustal solonchak, coarse-cell, semi-hydromorphic*	*Layered, light loam, sandy loam, cohesive sand*	*Ch/ S-Ch*
3	*218*	*3 (2)* *Well 3*	*Hydromorphic solonchak (semi-hydromorphic)*	*Sandy loam, loose sand*	*Ch-S / S-Ch*
4	*221*	*4 (2)*	*Sandy hydromorphic solonchak*	*Sand cohesive, loose sand in the middle part of the profile*	*Ch-S / Ch*
5	*235*	*5 (2)*	*Solonchak non-solid crustal sandy semi-automorphic with signs of gleying in the lower layer*	*Loose sand along the entire profile*	*Ch-S*
6	*243*	*6 (2)*	*Saltwort sandy semi-hydromorphic semi-automorphic with signs of gleying in the lower layers*	*Loose sand underlain by heavy loam*	*Ch-S / Ch*
7		*7 roots* *Digging No. 7*	*No description*	*Loose sand, heavy loam* *Loose sand*	*S-Ch / Ch-S*

№	Number of the GPS point	A brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	**Soil type**	**Granulometric composition**	**Salinity type**
8	*247*	*8 (2)* *Aral Sea bottom near section*	*Solonchak strongly sandy, non-structural-crustal, semi-automorphic*	*Loose sand* *Loose sand*	*Ch-S* *Ch-S*
9	*263*	*9 (2)*	*Solonchak fragile crustal semi-automorphic*	*Layered profile, cohesive sand, loose sand, light loam, medium loam*	*Ch*
10	*274*	*10 (2)*	*Solonchak combined, firm-crusty, crusty-puffy, sandy semi-hydromorphic*	*Sandy loam, from the surface, loose sand along the profile*	*Ch /Ch-S*
11	*290*	*11 (2)*	*Solonchak fragile crustal, semi-automorphic*	*Homogeneous, loose sand*	*Ch-S / Ch*
12	*294*	*12 (2)*	*Crustal solonchak, semi-hydromorphic, surface finely rippled*	*Sand cohesive, in the lower part, light loam*	*Ch*
13	*297*	*13 (2)*	*Solonchak automorphic fragile crusty, semi-automorphic (automorphic) covered with shell rocks*	*Homogeneous, loamy sand*	*Ch-S / Ch*
14	*298*	*14 (2)*	*Sandy solonchak, semi-automorphic (semi-hydromorphic)*	*Homogeneous in profile, loose sand*	*Ch-S / Ch*
15	*305*	*15 (12)*	*Solonchak strong-crust (seems to be the lowered part unsanded)*	*The sand is loose, underlain by heavy and light loam*	*Ch*
16	*323*	*16 (2)*	*Hydromorphic solonchak, crusty, surface saline*	*Homogeneous, cohesive sand, sandy loam*	*Ch*
17	*332*	*17 (2)*	*Solonchak non-strength-crust, automorphic (semi-automorphic)*	*Layered, cohesive sand, loose sand underlain by heavy loam*	*S-Ch / Ch*

№	Number of the GPS point	A brief characteristic of the soil ** (Galina Stulina, Kamalatdin Idirisov, Islom Ruziev)			
		Number of the soil profile	**Soil type**	**Granulometric composition**	**Salinity type**
18	*333*	*18 (2)*	*Strong-crust solonchak with signs of alugene*	*Layered, sandy loam, loose sand, cohesive sand, medium loam, light clay*	*Ch*
19	*381*	*19 (2)*	*Hydromorphic solonchak*	*Layered, sandy loam, loose sand, light loam*	*Ch*
20	*415*	*20 (2)*	*Crust-puffed solonchak, automorphic*	*Sandy loam on medium to light loam*	*Ch/-S*
21	*442*	*21 (2)*	*Solonchak crusty-puffy, automorphic on the way to waste soil*	*Sandy loam is underlain by light, medium, heavy loam*	*Ch*
22	*454*	*22 (2)*	*Solonchak fragile crustal, sanded automorphic*	*Homogeneous layer, sandy loam, cohesive sand*	*Ch*
23	*106*	*T. 106*	*Solonchak strong-crust, crust*	*Light loam*	*Ch*
24	*340*	*T. 340*	*Strong-crust cellular, crusty*	*Sandy loam*	*X*
25	*499*	*26(2)*	*Solonchak fragile crustal, semi-hydromorphic*	*Cohesive sand* *Cohesive sand*	*Ch* *X*
26			*Furrows*		*X*
27			*Aral*		*X-C*
28	*491*	*24 (2)*	*Strong-crust solonchak*	*Sandy clay* *Sand cohesive* *Loose sand*	*Ch*
29	*498*	*25 (2)*	*Solonchak strong-crustal cellular, semi-hydromorphic*	*Medium surface loam, profile Sand cohesive, loose, loamy sand*	*Ch*

6.2.3. Soil map

As a result of the performed field and laboratory works and the analysis of the obtained results, a soil map (Fig. 77) of the dried Aral Sea bed territory as of 2020 was constructed. Fifty soil differences were identified, which are shown as contours on the map. The explanation to the soil map is given in Table 18.

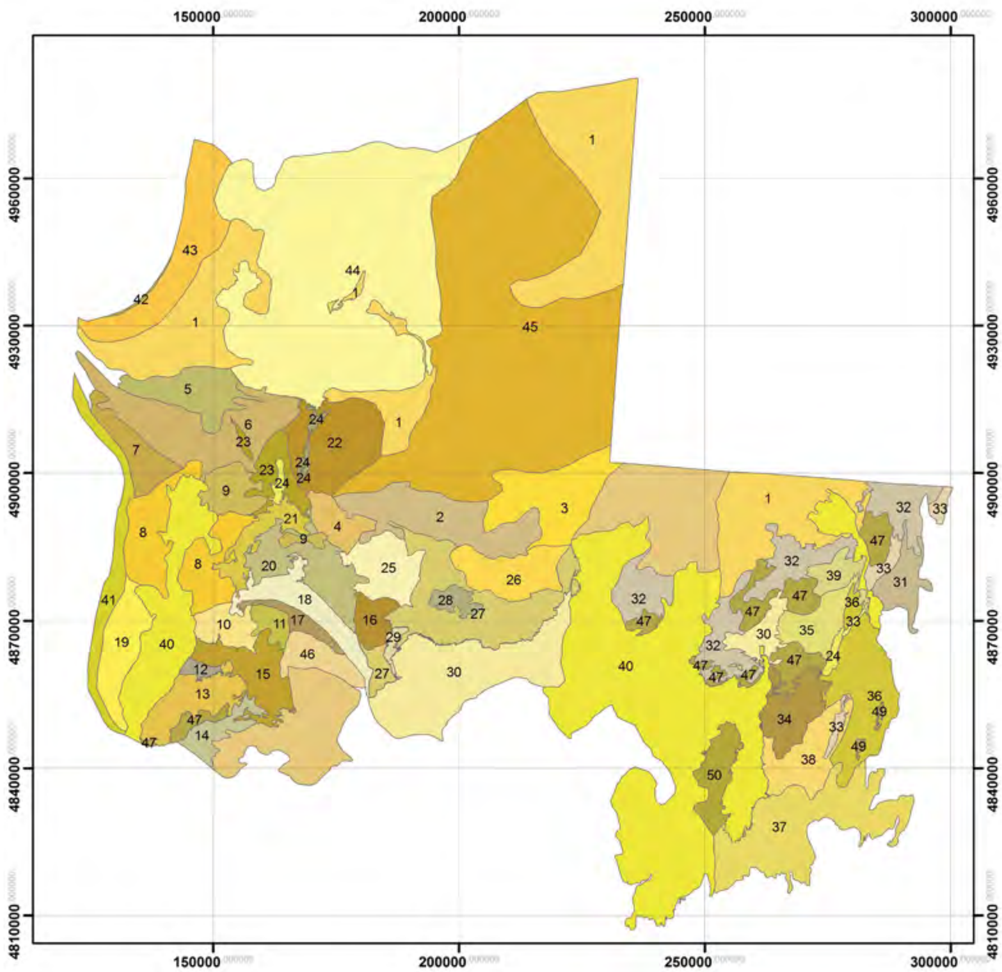


Fig. 77. Soil map of the dried Aral Sea bed, 2020

Table 18.

Explanation of the soil map as of 2020

Number of contour	Soil name	Granulometric composition
1	Solonchak coastal excessively moistened salt crust	Layered complex of loam, sandy loam, sand
2	Coastal solonchak semi-hydromorphic strong-crusty in some places with salt bodies	Layered complex of loams, sandy loams
3	Solonchak, crusty, moderately hydromorphic, strongly saline from the surface, furrows (Andijan region) on alluvial-marine sediments	Layered complex of loam, sandy loam, sand, with a predominance of loam

Number of contour	Soil name	Granulometric composition
4	Solonchak, non-solid crustal, semi-automorphic, gypsified, sanded in some places, slightly saline, furrows	Layered complex of loam, sandy loam, sand
5	Coastal solonchak moderately hydromorphic crusty, sandy-sandy in some places, furrows	Layered complex of loam, sandy loam, sand
6	Coastal semi-hydromorphic solonchak, weakly crustal, sandy in some places	Layered complex of loams, sandy loams
7	Coastal solonchak hydromorphic, non-crustal, sandy	Layered complex of loams, sandy loams
8	Coastal solonchak, crusty, wet from the surface, semi-automorphic, periodically washed, takyr-like in some places	Layered complex of loam, sandy loam, sand, underlain by heavy and medium loam
9	Coastal solonchak moderately hydromorphic crusty-puffy, sandy, saline crust in some places	Layered complex of loam, sandy loam, sand, underlain by heavy and medium loam
10	Solonchak crust-puffed, sandy automorphic, semi-automorphic closer to desert-sandy soil (under saxaul)	Sandy loam, with pronounced sinks
11	Coastal solonchak moderately hydromorphic crusty, sandy-loam sandy in some places	Heavy- and medium-loam (in some places weakly sandy) on layered loams with interlayers of sandy loam and sand
12	Coastal solonchak, automorphic crusty, mossy	Clay and heavy loam (sandy on top)
13	Solonchaks are automorphic with overhanging weakly overgrown hilly sands and high sand dunes	Sandy loam and sandy loam with thick interlayers of clay and heavy loam in the lower part of the profile
14	Solonchak on lake-alluvial deposits, crusty, shell rock from the surface, near the sand dunes	Sandy loam and sandy loam with thick interlayers of clay and heavy loam in the lower part of the profile
15	Desert-sandy soil	Light loamy, bottom-heavy
16	Desert-sandy soil	Layered complex of sandy loam, sand. Loam.
17	Combination of solonchak of coastal hydromorphic and excessively hydromorphic (lacustrine-brine) and plains-mildly hilly sands	Sandy, light loamy and sandy loam in lake-like depressions
18	Coastal solonchak moderately hydromorphic overlain by sand	Sandy-sandy
19	Coastal solonchak, crusty, semi-automorphic, periodically washed	Sandy-sandy

Number of contour	Soil name	Granulometric composition
20 20[a]	Solonchak strong-crust, automorphic, shells on the surface with sandy masses (ongoing formation to desert-sandy soil)	Layered complex with a predominance of sandy loams and sands over loams and clays
21	Coastal semi-automorphic solonchak with sandy bodies	Clay and loam with interlayers of sandy loam and sand in the lower part of the profile
22	Unfixed sand in the complex with solonchak furrows	Layered complex with a predominance of sandy loam and sand
23	Coastal solonchak semi-hydromorphic fragile crustal, overlain by loose sand, with outcrops of bedrock in the form of boulders	Layered complex with a predominance of sandy loam and sand
24	Sand with shell rock	Sand
25	Crustal solonchak, semi-automorphic, periodically washed, in a complex with sand dunes	Layered complex of loam, sandy loam, sand
26	Coastal solonchak semi-hydromorphic weakly crustal, sandy in some places, with isolated patches of shell rock	Layered complex of loam, sandy loam, sand
27	Solonchak semi-automorphic and automorphic crust-puffed and non-crusted gypsumized	Clay and loam in the lower part of the profile
28	Solonchak semi-automorphic and automorphic crust-puffed and non-crusted gypsumized	Clay and loam in the lower part of the profile
29	Sand fixed	Sand
30	Automorphic solonchak in a complex with unfixed sands	Layered complex of sandy loam, sand. Loam.
31	Solonchak excessively moistened	Layered complex of sandy loam, sand. Loam.
32	Hydromorphic solonchak overlain by sands	Predominantly sandy loam and sandy loam with interlayers of loam and clay
33	Dunes	Sand
34	Solonchak semi-hydromorphic, semi-automorphic with weakly consolidated sands	Predominantly sandy loam and sandy loam with interlayers of loam and clay
35	Solonchak strongly silted, imperfectly crusted, semi-automorphic, semi-hydromorphic	Loamy-sandy
36	Solonchak moderately hydromorphic in some places overlain by mobile sands	On heavy-loam and medium-loam sediments

Number of contour	Soil name	Granulometric composition
37	Complex of semi-automorphic and semi-hydromorphic solonchak with sand hillocks and sand dunes	Layered complex of different mech. Composition
38	Automorphic solonchak overlain by sand in some places (plantings)	Sandy and sandy loam on layered sediments of different mechanical composition (from clay to sand)
39	Coastal semi-hydromorphic solonchak overlain by a thick cover of mobile loose sands	Sandy and sandy loam
40	Complex of solonchak of lacustrine-brine (shora solonchak) with desert-sandy soils of relict islands	Sandy and sandy loam
41	Sand with a large amount of shell rock. Underlain by clay.	Layered, sandy loam and light loam complex, clay in the lower part of the profile
42	Marsh solonchak	Layered complex of loams, sandy loams
43	Wet solonchak	Layered complex of loams, sandy loams
44	Sand body	Sand
45	Coastal solonchak excessively humidified	Layered complex of loams, sandy loams
46	Mainland	
47	Sand dunes	Sand
48	Meadow desertifying	Clayey, heavy- and medium-loamy (sand-laden) on low-layered sediments of different mechanical composition
49	Wet solonchak (shora solonchak)	Layered complex of sand, loam, clay
50	Lakeside-brine solonchak, hydromorphic, semi-hydromorphic, silty, periodically flooded	Sandy and sandy loam on layered sediments, in some places with the presence of clay and loam

6.2.4. Conclusions

As a result of the conducted monitoring of the Aral Sea dried seabed cover, a large volume of field and laboratory data were obtained. This data collected during the expeditions will serve as a basis for further studies of genetic features of unique soils formed on the seabed. The transient nature of the processes occurring on the Aral Sea requires fixing the current status, otherwise the opportunity to study the process of the formation of zonal desert soils will be missed.

At present, in our opinion, the coastal solonchaks of the dried bed of the Aral Sea should be considered as intrazonal soils. However, they have a clear local zonality. The genetic types of soils, according to the classical notion of soil formation, have horizontal and vertical zonality. In the studied area, the zonality is clearly traced. The Akpetki island system is characterised by the change of soil cover in the direction from the drying lakes to the continental part protruding above them. For the plain part, the change of soil cover occurs in connection with drainage and the increase in the horizontal strip of the dried area. Since the dried area was formerly the bottom of the sea and was at different depths, there is also a vertical zonation associated with the character of the bottom sediments. The temporal factor of soil formation is especially expressive in these conditions, more than anywhere else.

As we know, according to the classical Dokuchaev soil science, there are five main factors of soil formation including climate, landscape, parent rock, vegetation and age. In this case, age is particularly important.

6.3. Vegetation cover

The dried seabed of the Aral Sea is an open, deserted and unique "laboratory" in the Central Asia region. The dried surface contains mainly different levels of soil, salts, and sands. The reason for such a chemical composition of the soil is the annual increase in the content of minerals, including sulphates, chlorides, sodium and magnesium.

It is important to note that the process of soil formation in the area is still ongoing. The current ecological state of the dried Aral Sea bottom emphasises the importance of a comprehensive study of the biological objects of the Aral Sea region, which are of great scientific and practical importance not only for science and technology, but also for the industry of the country.

At the present time, one of the problematic issues of Aralkum biodiversity formation is the natural formation of vegetation cover, which is of great scientific and practical interest to botanists, ecology scientists and forestry specialists.

From the start of the Aral Sea's drying out until now, a large part of the dried area has been revived by sand, dust and salt-binding plants.

Not all of the dried area has been revived by forest plants, as much of this area still remains unvegetated with shell residues and a white saline surface (Fig. 78).

The need for a thorough study of the seabed is the result of the formation of new natural complexes of plant communities, by structure, by development and vital activity of plants, and by succession and changes in the landscape. The formed land and the processes occurring on it predetermine 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.

Global resources of halophytes are characterised by a great diversity of genera, species and

Fig. 78. The dried bottom of the Aral Sea

populations of ecotypes. The global gene pool of halophytes includes 2,000-2,500 species. 700 of these species have been identified in Central Asia (Akjigitova, 1982).

Modern processes of changing the natural environment of the Amudarya delta by the cessation of flooding, the expansion of irrigated lands, and the drying of the Aral Sea bed, have all contributed to the activation of salt accumulation and the expansion of halophilic vegetation positions.

Increased salt content in soil has a favourable effect on the development and accumulation of the biomass of halophytes. Halophilic properties have mainly the salt accumulating representatives of the goosefoot (Chenopodiaceae) family and less so of the salt-extracting ones.

The halophytic type of vegetation (Halophyta) is widespread throughout the dried part of the Aral Sea, and is formed on various saline soils of the Aralkum Desert. In the southern part of the dried bed of the Aral Sea, almost all species of halophytic community groups are present. This was once again theoretically and practically confirmed during vegetation studies in recent years.

The chemical and physical characteristics of the biosphere are determined by the relatively constant formed environments that ensure the existence of living matter in an ecosystem. An ecosystem consists of a community of all living organisms in a given area and has a balanced cycle of chemical elements and energy flow. There is a homeostatic relationship between the non-living (abiotic) environment and living organisms (biotic environment).

The purpose of this study is to determine the composition of vegetation species of the southern Aralkum, to study the current state of the vegetation cover and to identify the dynamics of plant migrations across the dried seabed.

During the first expedition in 2019, the vegetation cover with the following large bodies of the south-western part of the dried bed of the Aral Sea was studied: Tigrovy Hvost, Akhantai, Uchsai, Muynak Bay, the vicinity of Sarybas Lake, Lazarev Island along the perimeter of the Eastern Cliff of Ustyurt, around the “zero” area, and other points. During the second expedition in 2020, the following bodies of the dried south-eastern bottom of the Aral Sea were studied: The vicinity of the Kazakhdarya settlements, from Djiltyrbas to Kokdarya, covering the Karateren and Kokdarya lands.

All field work at the above-mentioned sites was carried out by mutual agreement between expedition members and within a set period of time.

The purpose of these expeditions was 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.

The object of the study is the flora and vegetation of the dried bottom of the Aral Sea’s southern part, with plant materials (more than 300 herbarium specimens) having been collected during the expedition. Taxonomic identification was performed at the Institute of Bioorganic Chemistry of the Academy of Sciences of the RUz and the Central Herbarium Laboratory (TASH) of the Institute of Botany of the Academy of Sciences of the RUz.

Classical morphological-geographical, traditional geobotanical and other field methods were used in the research. The route-geobotanical methods (Bykov B.A., 1953; Lavrenko E.M., 1959; Yaroshenko P.D., 1961; Nitsenko A.A., 1971; Shelyag-Sosonko Y.R. et al., 1991, ‘Vegetation cover of Uzbekistan’, 1972, and Zakirov K.Z. and Zakirov P.K. classification, 1978) were used when studying the plant cover.

For registration of plant formation and association we used the classical generally accepted form #1 (according to the Drude scale) (habitat, number of plant species, life forms, etc.), according to which herbaceous plants of 10 m^2, trees and shrubs of 100 m2, rare plant communities of 250 m^2 were examined by using a 7-point system: cop3 - 7 points; cop2 - 6 points; cop1 - 5 points; sp1 - 4 points; sp2 - 3 points; sp3 - 2 points; and sol - 1 point. The obtained geobotanical materials were generalised and systematized according to the classification scheme of Zakirov K.Z. and Zakirov P.K., 1978.

As a result of the identification of herbarium samples collected during the second expedition and research work, 74 species of higher plants belonging to 51 genera and 21 families over 2,060 (2019 – 1,500, 2020 - 560) points of the dried Aral Sea bed and plant communities determined by most formations of the vegetation cover were identified (Tables 19 and 20, Figs. 78-104).

Table 19.

List of species composition of higher plants of the dried seabed of the Southern Aralkum

№	Families	Types of plants	Role in vegetation cover
1	*Chenopodiaceae*	1. *Haloxylon aphyllum (Minkw.)* Iljin.	Dominant
		2. *Haloxylon persicum* Bunge ex Boiss.	Dominant
		3. *Halostachys belangeriana (Moq.)* Botsch.	Dominant
		4. *Salsola richteri* Kar.	Dominant
		5. *Salsola paletzkiana* Litv.	Dominant
		6. *Salsola dendroides* Pall.	Dominant
		7. *Salsola micranthera* Botsch.	
		8. *Salsola paulsenii Litv.*	
		9. *Corispermum aralo-caspicum* Iljin	
		10. *Climacoptera crassa* Botsch.	Temporary dominant
		11. *Climacoptera aralensis (Iljin)* Botsch.	Temporary dominant
		12. *Climacoptera lanata* Pall.Botsch.	Temporary dominant
		13. *Salicornia europaea* L.	Temporary dominant
		14. *Atriplex pratovii* Sukhor.	Temporary dominant
		15. *Bassia hyssopifolia (Pall.)* Kuntze.	Temporary dominant
		16. *Suaeda crassifolia* Pall.	
		17. *Suaeda cuminate* Moq.	
		18. *Ceratocarpus arenarius* L.	
		19. *Agriophyllum lateriflorum (Lam.)* Moq.	
		20. *Halocnemum strobilaceum (J.Pall.)* M.Bieb.	
		21. *Halimocnemis karelinii* Moq.	
		22. *Horaninovia ulicina* B.Fisch. et C.A. Mey.	
		23. *Chenopodium album* L.	
		24. *Halogeton glomeratus* C.A. Mey.	
2	Tamaricaceae	25. *Tamarix hispida* Willd.	Dominant
		26. *Tamarix ramosissima* Ledeb.	Dominant
		27. *Tamarix florida* Bunge	*Subdominant*
		28. *Tamarix laxa* Willd.	*Subdominant*
3	*Capparaceae*	29. *Capparis spinosa* L.	
4	*Nitrariaceae*	30. *Nitraria schoberi* L.	Dominant
5	*Solanaceae*	31. *Lycium ruthenicum* Murr.	Dominant
6	*Peganaceae*	32. *Peganum harmala* L.	*Subdominant*
7	*Zygophyllaceae*	33. *Zygophyllum oxianum* Boriss.	
8	*Elaeagnales*	34. *Elaeagnus turcomanica* Kozlowsk.	

№	Families	Types of plants	Role in vegetation cover
9	*Asteraceae*	*35. Karelinia caspia (Pall.) Less.*	*Subdominant*
		36. Lactuca undulate Ledeb.	
		37. Acroptilon repens (L.) DC.	
		38. Artemisia terrae-albae Krasch.	Dominant
		39. Artemisia diffusa Krasch.	Dominant
10	*Apocynaceae*	*40. Cynanchum sibiricum* Willd.	
11	*Convolvulaceae*	*41. Convolvulus erinaceum* Ledeb.	
12	*Boraginaceae*	*42. Heliotropium arguzioides* Kar. et Kir.	
		43. Heterocaryum rigidum DC.	
13	*Orobanchaceae*	*44. Orobanche cernua* Loefl.	
14	*Fabaceae*	*45. Alhagi pseudalhagi* (Bieb.) Desv.	Dominant
		45. Ammodendron conollyi Bunge ex Boiss.	Dominant
		47. Astragalus ammodendron Bunge	Dominant
		48. Astragalus villosissimus Bunge	Dominant
		49. Halimodendron halodendron (J.Pall.) Voss	
		50. Glycyrrihiza glabra L.	
		51. Eremosparton aphyllum (Pall.) Fisch. et Mey.	*Dominant*
15	*Plumbaginaceae*	*52. Limonium gmelini* (Willd.) Kuntze	*Subdominant*
		53. Limonium otolepis (H.Schrenk) Kuntze	
16	*Polygonaceae*	*54. Calligonum acanthopterum* Borszcz.	
		55. Calligonum aphyllum (J.Pall.) W. R. Guerke	*Dominant*
		56. Calligonum aralense Borszcz.	*Dominant*
		57. Calligonum caput-medusae H.Schrenk	*Dominant*
		58. Calligonum macrocarpum Borszcz.	*Dominant*
		59. Calligonum microcarpum Borszcz.	*Dominant*
		60. Calligonum eriopodum Bunge	*Subdominant*
		61. Calligonum junceum (Fisch. et Mey.) Litv.	*Subdominant*
17	*Brassicaceae*	*62. Descurainia sophia (L.) C. J. Webb et Silipr.*	
		63. Strigosella africana (L.) Botsch.	
		64. Strigosella scorpioides (Bunge) Botsch.	
		65. Tetracme quadricornis (Steph.) Bunge	
		66. Octoceras lehmannianum Bunge	
18	*Cyperaceae*	*67. Carex physodes* M.Bieb.	

№	Families	Types of plants	Role in vegetation cover
19	*Poaceae*	*68. Stipagrostis karelinii* (Trin. et Rupr.) Tzvelev	*Dominant*
		69. Stipagrostis pennata (Trin.) De Winter	*Dominant*
		70. Phragmites australis (Cav.) Trin. ex Steud.	*Dominant*
		71. Aeluropus littoralis (Gouan) Parl.	
		72. Eremopyrum orientale (L.) Jaub. et Spach	
21	*Typhaceae*	*73. Typha angustifolia* L.	*Subdominant*
22	*Salicaceae*	*74. Populus diversifolia* Schrenk.	*Dominant*

Analysis of the distribution of genera and species into families shows that six large families (Chenopodiaceae, Tamaricaceae, Fabaceae, Polygonaceae, Poaceae and Brassicaceae) have 58 species, while other families have 16 species. The largest family Chenopodiaceae includes 16 genera and 24 species, while 12 families have only one genus and species each.

During the study (2019-2020), the following dominant and subdominant plant species were identified in the Halophyta, Psammophyta, Gypsophyta, and Potamophyta vegetation of the Southern Aralkum.

Dominants and subdominants of halophilic vegetation – Halophyta

Black saxaul – Haloxylon aphyllum (Minkw.) Iljin. Dominant. Halo xerophilous tree, reaching (3) 4-5 metres in height.

Salsola dendroides Pall. Dominant. Halo xerophilous shrub up to 1-1.5 metres in height.

Halo stachys belangeriana (Moq.) Botsch. Dominant. Halo mexerophilous shrub up to 1.5-2.5 metres in height.

Tamarix hispida – Tamarixhispida Willd. Dominant. Halomexerophilous shrub, reaching 2-3 metres in height.

Schober'sselittiferousshrub–Nitrariaschoberi L. Dominant. Haloxeromesophilous shrub up to 1-1.5(3) metres in height.

Dereza russica – Lyciumruthenicum Murr. Dominant. Halomexerophilous shrub up to 1-1.5(3) metres in height.

Karelinia caspica – Kareliniacaspia (Pall.) Less. Subdominant. Halomezophilous perennial up to 1-1.5 metres in height.

Kermek Gmelina – Limoniumgmelini (Willd.) Kuntze. Subdominant. Halomezophilous perennial up to 0.5-1 metres in height.

Climacopteracrassa Botsch. Temporary dominant. Halomesophilous annual up to 15-30 centimetres in height.

Climacoptera aralensis (Iljin) Botsch. Temporary dominant. Halomesophilous annual up to 15-40 centimetres in height.

Climacoptera woolly – Climacopteralanata (Pall.) Botsch. Temporary dominant. Halomesophilous annual up to 20-40 centimetres in height.

Glasswort – Salicornia europaaea L. Temporary dominant. Halomezophilous annual up to 15-30 centimetres in height.

Pratov's goosefoot – Atriplexpratovii Sukhor. Temporary subdominant. Halomezophilous annual up to 15-20 centimetres in height.

Bassiahyssopifolia (Pall.) Kuntze. Temporary subdominant. Halomesophilous annual up to 20-30 centimetres in height.

Dominants and subdominants of psammophilous vegetation – Psammophyta

Saxaul-white – Haloxylonpersicum Bungeex Boiss. Dominant. A psammose-xerophilous tree, reaching 4-5 metres in height.

Ammodendron conollyi Bunge ex Boiss. Dominant. Psammose-xerophilous shrub up to 2-3 metres in height.

Sandy-tree astragalus – Astragalus ammodendron Bunge. Dominant. Psammose-xerophilous shrub up to 1-2 metres in height.

Salsolarichteri Kar. Dominant. Psammome-xerophilous shrub up to 2-3 metres in height.

Salsola paletzkiana Litv. Dominant. Halome-xerophilous shrub up to 2-2.5 metres in height.

Medusa head candymere – Calligonum Caput-medusa Schrenk. Dominant. Psammome-xerophilous shrub up to 2.5-3 metres in height.

Calligonum aralense Borszcz. Dominant. Psammose-xerophilous shrub 2 metres in height.

Calligonum aphyllum (J.Pall.) W.R. Guerke. Dominant. Psammose-xerophilous shrub 2 metres in height.

Calligonum macrocarpum Borszcz. Dominant. Psammose-xerophilous shrub 2 metres in height.

Calligonum microcarpum Borszcz. Dominant. Psammose-xerophilic shrub 2 metres in height.

Calligonum eriopodum Bunge. Subdominant. Psammome-xerophilous shrub 2 metres in height.

Calligonum junceum (Fisch. et Mey.) Litv. Subdominant. Psammose-xerophilous shrub, 2 metres in height.

Artemisiaterrae-albae Krasch. Dominant. Xerophilous (psammospermophilous) semi-shrub up to 30 centimetres in height.

Sprawling wormwood – Artemisia diffusa Krasch. Dominant.Xerophilic semi-shrub up to 40 centimetres in height.

Camelthorn – Alhagi pseudalhagi (Bieb.) Desv. Dominant. Haloxeromesophilous perennial up to 1-1.5 metres in height.

Aristidaperia – Stipagrostis pennata Trin. Dominant. Psammose-xerophilous perennial 1 metre in height.

Aristida Karelinii – Stipagrostis karelinii Roshev. Dominant. Psammos-exerophilous perennial 1.5 metres in height.

Dominants and subdominants of hypsophilous vegetation – Gypsophyta

Eremosparton leafless – Eremosparton aphyllum (Pall.) Fisch. Et Mey. Dominant. Psammose-xerophilous shrub up to 1.5-2 metres in height.

Astragalus oblongata – Astragalus villosissimus Bunge. Dominant. Psammose-xerophilous semi-shrub up to 1 metre in height.

Peganum harmala Subdominant. Psammome-xerophilous perennial up to 25-40 centimetres in height.

Dominants and subdominants of riparian vegetation – Potamophyta

Turanga diversifolia – Populus diversifolia Schrenk. Dominant. Mesophilous tree up to 5-8 metres in height.

Tamarix ramosissima – Ledeb. Dominant. Halomexerophilous shrub up to 1.5-3 metres in height.

Tamarix florida – Tamarix florida Bunge. Subdominant. Halomexerophilous shrub up to 1.5-2 metres in height.

Tamarix laxa Willd. Subdominant. Halomesoxerophilous shrub, up to 1.5-2 metres in height.

Phragmites australis (Cav.) Trin. ExSteud. Dominant. Hygroesophilous perennial up to 2-3 metres in height.

Table 20.

The main dominant vegetation species of the Southern Aralkum Desert and their habitats (soil)

Associations	Dominants and subdominants	Abun-dance	Soil		
			Solon-chak	Clay	Sand
Formation black saxaul – *Haloxyletaaphylli*					
Black saxaul	*Haloxylonaphyllum* (Minkw.) Iljin	cop^3	+	+	+
Djingilov and black saxaul	*Haloxylonaphyllum* (Minkw.) Iljin	cop^2	+	+	-
	Tamarixramosissima Ledeb	cop^1	+	+	-
	T. hispida Willd.	cop^1	+	+	-
Cherkezovo - black saxaul	*Haloxylonaphyllum* (Minkw.) Iljin	cop^2	+	+	-
	Salsolarichteri Kar.	cop^1	+	+	-
Karabarakovo - black saxaul	*Haloxylonaphyllum* (Minkw.) Iljin	cop^2	+	+	-
	Halostachysbelangeriana (Moq.) Botsch.	cop^1	+	+	-
Formation Kuyansuyak – *Ammodendretaconollyi*					
Djingilov-kuyansuyak	*Ammodendronconollyi* Bunge ex Boiss.	cop^2	-	-	+
	Tamarixramosissima Ledeb	cop^1	-	-	+
Cherkezovo kuyansuyak	*Ammodendronconollyi* Bunge ex Boiss.	cop^2			+
	Salsolarichteri Kar.	cop^1	-	-	+
Selinovo kuyansuyak	*Ammodendronconollyi* Bunge ex Boiss.	cop^2	-	-	+
	Aristida pennata Trin.	cop^1	-	-	+
Formation Cherkez – Salsoletarichteri					
Djuzgunovo- djigilovo cherkezovaya	*Salsolarichteri* Kar.	cop^2	**-**	**-**	**+**
	Tamarixramosissima Ledeb	sp^2	**-**	**-**	**+**
	Calligonum sp. sp.	cop^2	**-**	**-**	**+**
Black saxaul-cherkezovye*	*Salsolarichteri* Kar.	cop^1	-	-	+
	Haloxylonaphyllum (Minkw.) Iljin	sp^1	-	-	+
Kuyansuyk-cherkezovye	*Salsolarichteri* Kar.	cop^2	-	-	+
	Ammodendronconollyi Bunge ex Boiss.	cop^1	-	-	+
Formation Kyzyljingilov – *Tamaricetaramosissimae*					
Kyzyljingilov	*Tamarixramosissima* Ledeb	cop^3	+	+	-

Associations	Dominants and subdominants	Abun-dance	Soil		
			Solon-chak	Clay	Sand
Jingyla	*Tamarixramosissima* Ledeb	cop2	-	+	-
	T. hispida Willd.	cop1	-	+	-
Cane and kyzyljyngyl	*Tamarixramosissima* Ledeb	cop2	-	+	-
	Phragmites australis (Cav.) Trin. Ex Steud.	cop1	-	+	-
Solerosovo kyzyljingilov	*Tamarixramosissima* Ledeb	cop2	+	-	-
	Salicornia europaea L.	cop2	+	-	-
Balykkuzovo kyzyljingilov	*Tamarixramosissima* Ledeb	cop2	+	-	-
	Climacopteralanata (Pall.) Botsch.	cop2	+	-	-
Chernosaxaulo - kyzyljingilov *	*Tamarixramosissima* Ledeb	cop1	+	+	-
	Haloxylonaphyllum (Minkw.) Iljin	sp2	+	+	-
Formation Yermanyjingil – Tamaricetahispida					
Akbashevo - yermanyjingilov	*Tamarixhispida* Willd.	cop2	-	+	-
	Kareliniacaspia (Pall.) Less.	sp3	-	+	-
Karabarakovo - hermangilov	*Tamarixhispida* Willd.	cop2	+	+	-
	Halostachysbelangeriana (Moq.) Botsch.	cop1	+	+	-
Reed - hermangiland	*Tamarixhispida* Willd.	cop2	-	+	-
	Phragmites australis (Cav.) Trin. Ex Steud.	cop1	-	+	-
Formation Reed – *Phragmitetaaustralis*					
Cane	*Phragmites australis (Cav.) Trin. Ex Steud.*	cop3	-	-	+
Rogozovo reed	*Phragmites australis (Cav.) Trin. Ex Steud.*	cop2	-	-	+
	Typha angustifolia L.	cop1			
Yermanyjingilo - vo - trostnicheskaia	*Phragmites australis (Cav.) Trin. Ex Steud.*	cop2	-	-	+
	Tamarixhispida Willd.	sp3			
Formation Selinum – *Aristidetapennata*					
Selinum	Aristida pennata Trin.	cop2	-	-	+
Calligonum-selinum	Aristida pennata Trin.	cop2	-	-	+
	Calligonum caput- medusa Schrenk	cop1	-	-	+
Formation Karabarak – *Halostachetabelangeriana*					
Karabarakova	*Halostachysbelangeriana (Moq.) Botsch.*	cop3	+	+	-

Associations	Dominants and subdominants	Abundance	Soil		
			Solonchak	Clay	Sand
Akbashevo - karabarakova	*Halostachysbelangeriana* (Moq.) Botsch.	cop^{2}	+	+	-
	Kareliniacaspia (Pall.) Less.	cop^{1}	+	+	-
Chernosaksaulovo karabarakova	*Halostachysbelangeriana* (Moq.) Botsch.	cop^{2}	+	+	-
	Haloxylonaphyllum (Minkw.) Iljin	sp^{1}	+	+	-
Yermanyjingilovo karabarakova	Halostachysbelangeriana (Moq.) Botsch.	cop^{2}	+	+	-
	Tamarixhispida Willd.	sp^{3}	+	+	-
Formation Cumulus – *Nitrarietaschoberi*					
Karabarakovo-kumuzumovaya	*Nitrariaschoberi* L.	cop^{2}	+	+	-
	Halostachysbelangeriana (Moq.) Botsch.	cop^{1}	+	+	-
Amber karachingyl - cumusum	*Nitrariaschoberi* L.	cop^{2}	-	+	-
	Lyciumruthenicum Murr.	cop^{1}	-	+	-
	Alhagipseudalhagi (Bieb.) Desv.	sp^{2}	-	+	-
Formation Balikkuzovaya – *Climacopteretalanata*					
Mixed-balancourt *	*Climacopteralanata* (Pall.)Botsch.	cop^{3}	+	-	-
	C. aralensis (Iljin) Botsch.	cop^{1}	+	-	-
Alabutavo balikkuzovaya	*Climacopteralanata* (Pall.)Botsch.	cop^{2}	+	+	-
	Atriplexfominii Iljin	sp^{2}	+	+	-
Bassievo balikkuzovaya	*Climacopteralanata* (Pall.)Botsch.	cop^{2}	+	-	-
	Bassiahyssopifolia (Pall.) Kuntze	cop^{1}	+	-	-

N o t e: * - associations cited by the author for the first time

Typha angustifolia L. Subdominant. Hygroesophilous perennial up to 2-3 metres in height.

To reduce the removal of toxic substances, it is necessary to fix mobile sands and solonchak, and the dominant and subdominant vegetation species undoubtedly play a major role.

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 the families Chenopodiaceae, Tamaricaceae, Fabaceae, Polygonaceae and others, as they create formations, associations and occupy a certain part of the dried area (Tables 21-23).

Table 21.

Species (floristic) composition of some psammophilous communities of the Southern Aralkum

Types of plants	**Types of vegetation**			
	Psammophile	**Psammophile**	**Psammophile**	**Psammophile**
	Associations			
	Selinum	**Akbashevo - blacksaxaulovaya**	**Black saxaul**	**Calligonum**
Coordinates	60° 14’ 8.556» E 43° 51’ 47.639» N	60° 14’ 44.725» E 43° 51’ 57.229» N	60° 19’ 32.930» E 43° 54’ 10.444» N	60° 21’ 21.992» E 43° 58’ 8.807» N
Description date	9.06.2020	9.06.2020	9.06.2020	11.06.2020
No. of site(s)	317	318	327	371
Projective coverage, %	55-60	35-40	50-60	35-40
Site size	100 m^2	100 m^2	100 m^2	100 m^2
Trees				
Haloxylon aphyllum	sol	sp_1	cop_1	-
Shrubs				
Astragalus villosissimus	-	-	sp_2	sp_2
Calligonum sp.	sol	sol	sp_2	cop_1
Tamarix hispida	sol	sol	-	-
Salsola sp.	-	-	-	sol
Herbs				
Stipagrostis pennata	cop_3	-	cop_1	-
Stipagrostis karelinii	-	-	-	sp_2
Karelinia caspia	sol	cop_2	-	-
Atriplex pratovii	sol	-	-	-
Euphorbia seguieriana	-	sol	-	sol
Phragmites australis	-	-	sol	-
Horaninovia ulicina	-	-	-	sp_2
Alhagi pseudalhagi	-	-	-	sol
Total	**6**	**5**	**5**	**7**

Table 22.

Species (floristic) composition of some halophilic communities of the Southern Aralkum

Types of plants	Types of vegetation			
	Halophilic	**Halophilic**	**Halophilic**	**Halophilic**
	Associations			
	Djuzgunovo - chernosaxaulovo - cherkezova	**Djuzgunovo - chernosaxaulovo - cherkezova**	**Djuzgunovo - chernosaxaulovo - cherkezova**	**Chernosaxaulovo - cherkezova**
Coordinates	60° 10’ 39.943» E 43° 55’ 4.066» N	60° 10’ 30.533» E 43° 55’ 41.041» N	60° 10’ 10.981» E 43° 56’ 55.378» N	60° 10’ 1.225» E 43° 57’ 16.852» N
Description Date	5.06.2020	5.06.2020	5.06.2020	5.06.2020
No. of site(s)	242	244	246	247
Projective coverage, %	70-80	60-70	50-60	45-50
Site size	100 m^2	100 m^2	100 m^2	100 m^2
Trees				
Haloxylon aphyllum	cop_1	cop_1	cop_1	cop_1
Shrubs				
Salsola richteri	sp_1	sp_1	sp_1	cop_2
Calligonum macrocarpum	cop_3	cop_3	cop_3	-
Tamarix hispida	sp_1	-	-	-
Herbs				
Horaninovia ulicina	sp_2	sp_2	sp_2	sp_2
Atriplex pratovii	sol	-	-	-
Total	**6**	**4**	**4**	**3**

Table 23.

Species (floristic) composition of some riparian communities of the Southern Aralkum

Types of plants	Types of vegetation			
	Umbrella	**Umbrella**	**Umbrella**	**Umbrella**
	Associations			
	Yulgunova	**Yulgunova**	**Turanga**	**Reed**
Coordinates	59° 26’ 14.626» E 43° 35’ 44.023» N	59° 37’ 46.286» E 43° 28’ 22.030» N	59° 19’ 37.600» E 43° 23’ 38.594» N	60° 10’ 15.395» E 43° 38’ 45.917» N
Description Date	31.05.2020	1.06.2020	2.06.2020	12.06.2020

Types of plants	Types of vegetation			
	Umbrella	Umbrella	Umbrella	Umbrella
	Associations			
	Yulgunova	Yulgunova	Turanga	Reed
No. of site(s)	32	68	142	452
Projective coverage, %	90	40-50	50-60	65-70
Site size	50 m^2	50 m^2	50 m^2	50 m^2
Trees				
Populus diversifolia	-	sol	cop_1	sol
Elaeagnus orientalis	-	-	sol	-
Shrubs				
Tamarix hispida	cop_1	cop_1	-	sp_1
Tamarix florida	-	cop_1	-	-
Tamarix sp.	-	-	sp_2	-
Halostachys belangeriana	-	sp_2	-	-
Ziziphus jujuba	-	-	sol	-
Herbs				
Climacoptera aralensis	sp_2	-	-	-
Zygophyllum fabago	sol	sol	sol	-
Euphorbia seguieriana	sol	-	sp_2	-
Alhagi pseudalhagi	sp_2	-	sol	cop_2
Phragmites australis	sp_2	sp_2	-	-
Karelinia caspia	-	sp_2	sp_2	sp_2
Taraxacum officinale	sol	-	-	-
Corispermum aralo-caspicum	sol	-	-	-
Limonium otolepis	sp_2	-	-	-

Types of plants	Types of vegetation			
	Umbrella	Umbrella	Umbrella	Umbrella
	Associations			
	Yulgunova	Yulgunova	Turanga	Reed
Aeluropus littoralis	cop_1	sp_2	-	-
Chenopodium album	sol	-	-	-
Atriplex tatarica	-	sol	sol	-
Carex sp.	-	sol	-	-
Agriophyllum lateriflorum	-	-	sol	-
Итого	**11**	**10**	**10**	**4**

Note: the species composition of all points (2062) is attached as a separate table.

Some species are dominant and subdominant in several associations. For example: Haloxylon aphyllum (Minkw.) Iljin., Tamarix hispida Willd., Salsolarichteri kar., Ammodendron conollyi Bunge ex Boiss., Halostachys belangeriana (Moq.) Botsch, Phragmites australis (Cav.) Trin. Ex Steud., Stipagrostis pennata Trin., Climacoptera lanata (Pall.) Botsch., Artemisiaterrae-albae Krasch., Artemisia diffusa Krasch.

Based on the results of the study of phytocenoses of the southern part of the dried bottom of the Aral Sea, the following halophilic plant groups were identified. Below are the results of the study of halophilic vegetation, which plays a major role in the composition of biological diversity of the dried seabed of the Aral Sea.

I. Haloxyletaaphylly – Black Saxaul Formation

The Black Saxaul Formation is widespread throughout the dried Aral Sea bed, especially in large bodies in the southern part. With the lowering of the Aral Sea level (since the 1960s), saxaul communities gradually appeared on sandy shores and sandy bodies (after a series of successions of plant groups).

The edificator of this formation is Haloxylonaphyllum (Minkw.) Iljin, a haloxerophilous tree of the Chenopodiaceae family, reaching (3) 4-5 metres in height. As a representative of this formation, it is the dominant plant in the upper layer of plant cover on various saline soils of the dried bed (Fig. 82 and 83). In our study of the Black Saxaul Formation, we identified six associations:

a) Black saxaul (Haloxylon aphyllum);

b) One-year saltwort-black saxaul (Haloxylon aphyllum, Atriplex pratovii, Suaeda crassifolia, Climacoptera lanata). Spread on wet, puffy solonchak;

c) Solanaceous-carabarachian-black saxaul (Haloxylon aphyllum, Halostachys belangeriana, Salsola nitraria). Widespread on highly saline soils and crusty, crusty-puffed solonchak;

d) Cerkez-yulgun-black saxaul (Haloxylon aphyllum, Tamarix hispida, Salsola richteri). Widespread on medium saline soils and crust-puffed solonchak;

e) Adraspanic-cherkezov-chernosaxaulic (Haloxylon aphyllum, Salsola richteri, Peganum harmala). Distributed on moderately saline soils and sands;

f) Grass-black saxaul (Haloxylon aphyllum, Eremopyrum orientale, Descurainia sophia, Salsola paulsenii). Widespread on saline soils and sands.

II. Halostachydetabelangerianae – Karabarak Formation

The Karabarak Formation is distributed on saline habitats of the dried Aral Sea bed. We first recorded this formation in the south-western part of the Aralkum Desert in 2007. Long-term observations have shown that associations of the Karabarak Formation are well developed and formed year after year throughout the dried sea area and play a significant role in the composition of vegetation cover and biodiversity.

The edificator of this formation is Belyanger's Saltwort – Halostachys belangeriana (Moq.) Botsch., Haloxerophilous shrub, family of the Marecchiaceae (Chenopodiaceae), reaching 2-3.5 metres, strongly branched with articulate stems and opposite branches (Fig. 99). Annual shoots are succulent, cylindrical, segmented, glaucous-dark green, and blackening in autumn. Leaves are reduced to filmy, short-triangular scales, which, clustered in pairs, form a slightly lagging two-lobed belt around the stem. During our studies, we identified three associations:

a) Saline-black saxaul-karabarak (Halostachys belangeriana, Haloxylon aphyllum, Salsola micranthera);

b) Cherkezov-karabarak (Halostachys belangeriana, Salsola richteri);

c) One-year saltwort-sulphur-karabarak (Halostachys belangeriana, Tamarix hispida, Climacoptera lanata, Salicornia europaea).

III. Tamaricetahispidae – Yulgun Formation

The Yulgun Formation is widely distributed on saline soils and solonchak throughout the south-western part of the dried bed. Other species and hybrids of the genus Tamarix are often found as part of this formation, which form mixed communities inhabiting several tens of hectares in different areas. The formation is considered one of the leading communities forming in the area. The role of the formation in the composition of biodiversity of the dried Aral Sea bed is very characteristic.

The edificator of this formation is the Tamarix hispida, Tamarixhispida Willd., a halomexerophilous shrub, reaching 2-3 metres in height, of the family Tamaricaceae (Fig. 79 and 86). The crown is formed with numerous thin and small branchlets or by coarse and obtuse branches. The leaves are scale-like, with awns at the base. Young branches and leaves are puberulent with straight, short hairs. The bark is brown-red.

a) Mixed-jugular (Tamarixhispida, T. laxa, T. ramosissima, T. spp.);

b) Astragalus chernosaxaulo yulguna (Tamarixhispida, Haloxylonaphyllum, Astragalusammodendron);

c) One-year saltwort-julguna (Tamarix hispida, Bassia hyssopifolia, Climacoptera lanata, Salicornia europaea, Atriplexpratovii);

d) Bassi-desert-julgunian (Tamarixhispida, Lyciumruthenicum, Kareliniacaspia, Bassiahyssopifolia).

IV. Halocnemeta strobilacei – Sarsazan Formation

The edificator of the Sarsazan Formation is Halocnemum srtobilaceum (J.Pall.) M.Bieb., a haloxerophilous small greyish shrub of up to 70 centimetres, of the Chenopodiaceae family, strongly branched with segmented stems and opposite branches, forming circles or tubercles with prostrate, dense, in turn branched and partly rooting branches (Fig. 97). The annual shoots are cylindrical, succulent, and geniculate, with short cylindrical or almost club-shaped segments. Its leaves are undeveloped, in the form of supronate, almost shield-shaped scales. Its habitat is puffy and crusty solonchak.

a) Sarsazan (Halocnemum srtobilaceum);

b) One-year saltwort-sarsazan (Halocnemum srtobilaceum, Salicornia europaea, Climacoptera aralensis, Suaeda crassifolia);

c) Black saxaul-juzgun-sarsazan (Halocnemum srtobilaceum, Calligonumaphyllum, Haloxylonaphyllum);

d) Kermeko-wormwood and sarsazan (Halocnemum srtobilaceum, Artemisiaterrae-albae, Atraphaxisspinosa, Limonium otolepis).

V. Climacoptereta aralensis – Climacopteric Formation

The edificator of the Climacopteric Formation is Climacoptera aralis (Iljin) Botsch. A temporary dominant, halomesophilous annual of up to 15-40 centimetres in height, of the Chenopodiaceae family. Stems and branches during fruiting are covered with sparse, straight, short protruding hairs. Branches and leaves are alternate, or only the lowest suprose, descending. Forage grazing plants, especially in fall and winter.

a) Climacopter (Climacoptera aralensis, C. lanata, C. spp.);

b) Annual;

c) Saltwort-climacoptera (Climacoptera aralensis, C. lanata, Bassia hyssopifolia, Atriplex pratovii, Tamarix hispida).

VI. Mixto-Chenopodiaceta – One-year Saltwort Formation (Fig. 88).

a) Yulguno-one-year old saltwort (Suaeda crassifolia, Climacoptera spp, Salsola paulsenii, Tamarix hispida);

b) Camishevo-one-year old saltwort (Bassia hyssopifolia, Climacoptera lanata, Salicornia europaea, Phragmites australis).

Among the identified halophilic plant groups, the Black Saxaul Formation leads in terms of the number of associations and plants, as well as abundance – Haloxyleta aphylly.

Despite the Aral Sea bed’s unfavourable environmental conditions, the development of these plant communities and their wide distribution has been established.

The question of great theoretical and practical importance is which of the plant species first appeared on the bottom of the dried sea. It is known that Salicornia europaea first begins to grow in the vicinity of the dried area of each lake and sea. It is followed by halophytes, which are adapted to grow on the background with comparatively less salt in the soil.

Based on the research results, changes in the composition of flora and vegetation depending on changes in the mineral composition of soil and groundwater from the seabed to the Aral Sea (water) were revealed. On the old shorelines (on the territories) the vegetation cover is more than 40-50 percent and has a great positive impact on the formation of sustainable ecosystems. On the old shorelines the level of vegetation cover decreases towards the sea.

The vegetation of the Sarybas (Rybatsky) Lake coast is formed by plants of the Amudarya River delta. It should be noted that at this time, the vegetation cover on the shore of Sarybas Lake is still forming. Our further goal is to thoroughly study the vegetation of this area and the relationship of the vegetation cover with other lakes of the dried bottom of the Aral Sea.

More than 30 species of higher plants of the south-western Aralkum territories are the results of floristic studies for the last three years. The presented number of plants (30) and taxonomic units may necessarily change (increase) due to the continuation of further migration and flora formation.

In the first years in the waterless areas, plants were found alone or not at all. This is due to the fact that the soil level in the first year of water release is very high.

It turned out that the main mass of the studied areas had an abundance of halophyte vegetation adapted to different saline soils. Due to the high salt content and high salinity of groundwater, difficult conditions for the growth and development of plant species were observed. Despite this, relatively well-formed plant complexes were discovered in some sands and areas with relatively low salt content. At the same time, most of the dehydrated areas form a cover of halophilic vegetation adapted to growing on different saline soils.

The Aral Sea drainage vegetation cover formation is one of the main factors of arid lands development.

By economic importance, fodder plants prevail - 24 species, sand and solonchak fixers - 10 species, essential-oil and alkaloid - 9 species, medicinal - 7 species.

In order to determine which ecological group each species belongs to, scientific sources and materials collected during expeditions were analysed. According to scientific sources, as a result by plant habitats three types were identified, including halophytes, psammophytes and hypsophytes. The analysis of the distribution of ecological groups shows that halophytes make up a great number of species.

Most plant species of the southern Aralkum are represented by those that are adapted to grow on different levels of salinity of soils and saline sands. It should be particularly noted that due to strong salinity of soils, the vegetation of annual saltwort worsens. In connection with this, on sea overgrowing plots in the first year, there were few plants and these did not develop.

Observations showed the formation of phytogenic hillocks and sand dunes ranging on average from 1.5 to 2-3 metres in height and 1.5-3.7 metres in diameter. Each of such phytogenic sand dunes hold an average of 15-20 tons of salt-mixed sand (soil).

The research results can be used for writing scientific works on the flora of the dried Aral Sea bed and developing the modern system of higher plants of Uzbekistan. The research data on formations and associations can be used in highlighting the further formation of plant communities of the Aralkum. The species identified by us can be used in fixing moving sands and solonchaks in phytomelioration works, and those having fodder value as pasture lands for livestock farming.

Endangered plant species in need of protection were identified based on the analysis of herbarium data and the study of scientific sources, as well as the study of materials collected during expeditions. As a result, one species was identified as being in need of protection, specifically Atriplex pratovii Sukhor, and its habitat continues to be reduced. As a result of research, the area of its distribution is expanded.

It can be noted that about 5-6 percent of the flora of the Southern Aralkum are considered to be species in need of protection and are rare for this territory.

As a result of our research, we were able to identify dominants and subdominants that play a major role in the migration of flora and vegetation.

Table 24 shows some features of the migration of flora and vegetation.

Table 24.

Migration of flora and vegetation of the southern part of the Aral Sea bed

Migration groups	Brief description	Types of vegetation	Dominant and subdominant plants	Soils. Ratio
Migrating	The group is formed by a strip of the first years of drying, arising after the retreat of the sea. The group continues to form in progressive dynamics.	Halophilous annuals	*Salicornia europaea, Climacoptera lanata, C. aralensis, Suaeda crassifolia, Bassia hyssopifolia, Atriplex pratovii*	Solonchak (wet)
Expanding	The group is formed in the later stages of overgrowth of the dried seabed. Their spreading goes in the direction from the bedrock shore to the water's edge. The group continues to form in progressive dynamics.	Halophilous and psammophilous shrubs and semi-shrubs	*Tamarix ramosissima, T. hispida, Halostachys belangeriana, Salsola richteri, Haloxylon aphyllum, Calligonum eriopodum, C. caput-medusa и др.*	Solonchak (crusty and puffy), saline sand
Stabilising	The group forms near the coast of the native shores of the former sea, which requires a less saline soil. The group forms in progressive dynamics, but is relatively slower than the previous ones.	Psammophilous perennials and semi-shrubs	*Artemisia terrae-albae, Stipagrostis pennata, Carex physodes, Halimodendron halodendron, Astragalus ammodendron, Ammodendron conollyi, and others*	Salty sand
Declining	A group of declining species, which are characteristic of hygro- and hydrophilic plants, formerly of the shallow water and representatives of the meadow-tugue flora. A group in regression.	Herbaceous marsh, hygro- and hydrophilic annuals and perennials	*Ceratophyllum demersum, Najas marina, Zostera minor, Phragmites australis, Typha angustifolia*	Swamps

The high adaptation of plant groups and types of vegetation (halophilic, psammophilic) indicate the instability of environmental conditions.

Annual hyperhalophytes (Salicornia europaea L., Suaeda crassifolia (Pall.), Bassia hyssopifolia (Pall.) Kuntze, Climacoptera aralensis (Iljin) Botsch., and others) are adapted to grow on highly saline soils. Therefore, they develop new areas of the drying sea.

Due to the hyperhalophytes which reduce soil salinity, halomesoxerophilous, haloxeromesophilous shrubs and semi-shrubs from the families Chenopodiaceae and Tamaricaceae are formed behind them. However, these plant species (groups) are not the main representatives of the flora and vegetation cover.

Psammophilous perennials and semi-shrubs (Artemisiaterrae-albae Krasch., Stipagrostispennata Trin., S. karelinii Roshev., CarexphysodesM.Bieb.,Astragalusammodendron Bunge., Ammodendron conollyi Bungeex Boiss., Atraphaxisspinosa L., and others) occupy a much larger part of the dried area. There are plant species whose habitat is reduced due to shallow water bodies and groundwater drying out.

There is a connection between soil salinity and plant species. On strongly saline soil, there are glasswort, climacoptera and saltwort. On medium saline soil there are tamarix and some representatives of annual saltwort, and on low saline soil there is kermek, black saxaul and also vegetation of various grasses (ephemeroids).

The following conclusions can be made based on the results of studies to determine the regularities of the formation of the flora of the south-western part of the Aral Sea bed:

1. In the process of forming the flora and vegetation of the dried Aral Sea bed, the pioneers are annual hyperhalophytes: Salicornia europaea L., Suaeda crassifolia Pall., Bassia hyssopifolia (Pall.) Kuntze., Climacoptera aralensis (Iljin) Botsch., C. Lanata (Pall.) Botsch., Atriplex pratovii Sukhor., and others. They migrate at the site of the drying up of the sea.

2. The main dominant species of the flora are habitat-expanding halophytes and psammophytes: Tamarix hispida Willd., T. ramosissima Ledeb, Halostachys belangeriana (Moq.) Botsch., Haloxylon aphyllum (Minkw.) Iljin., Salsola richteri Kar., Calligonum eriopodum Bunge., C. caput-medusa Schrenk., Astragalus ammodendron Bunge., Ammodendron conollyi Bunge ex Boiss., Stipagrostis pennata Trin., and others.

3. The habitats of declining species of flora are hygro and hydrophytes: Ceratophyllum demersum L., Najas marina L., Zostera minor, Phragmites australis (Cav.) Trin. ex Steud., Typha angustifolia L., and others.

4. The migration of flora goes in the following order: migrating plants (halophytes: hyperhalophytes, halomesophytes) → habitat expanding plants (haloxeromesophytes, halomesoxerophytes) → relatively stabilized plants (psammophytes: psammoxeromesophytes, psammoxerophytes).

Starting from the base of the shore to the bottom of the dried sea, the vegetation cover and flora composition will naturally change with changes in the soil and water regime.

In subsequent years, it is noted that vegetation barely grows on the site of the dried seabed.

As a result of subsequent retreats of the lake, plant growth may not occur at all due to the onset of solonchaks, which form a white saline soil surface.

It should be noted that geobotanical data of the vegetation community of the southern Aralkum Desert are not final. Further study of the vegetation cover of this area should undoubtedly lead to clarification of the communities of the southern part of the dried bed of the Aral Sea, in connection with the continued formation of flora and vegetation.

The above-mentioned associations can be used for stabilizing sands and solonchaks, and as forage pastures in the spring and autumn periods. Further detailed study of the vegetation cover of the studied territories can undoubtedly contribute to the solution of the Aral Sea region's ecological problem (Figs. 82, 84, 85, 87, 92, 93 and 96).

Year by year, the content of sulphates and chlorides of such minerals as sodium, magnesium and potassium increases in Aralkum soils. It has been proved that the coverage of saline soils by plants takes place in accordance with natural regularities, which stipulate stage-by-stage settlement by psammophilous plants of soils developed earlier by halophytes. The landscape decreases, including the degree of vegetation cover formation (quantitative composition and diversity), in the direction from the former seashore to water (the Aral Sea).

The practical significance of this research is that the approach to phytomelioration work aimed at the dried Aral Sea bottom re-population with promising plant species (Tamarixhispida, T. ramosissima, Halostachys belangeriana, Haloxylon aphyllum, Salsoladendroides, S. orientalis, Climacoptera aralensis, Nitraria schoberi, Lycium ruthenicum, Limonium otolepis) has been developed to fix moving sands and solonchaks. Additionally, the prospects of the region's plants have been revealed as being promising resources for the development of the pharmaceutical industry of the Republic.

6.3.1. Recommendations

As a result of observations made during expeditions and laboratory research, we have made the following practical recommendations:

- The use of a number of plant species in phytomelioration works on the dried Aral Sea bottom.
- The use of the Aral Sea region's plants as a natural source for the isolation of protein-peptide components with high biological activity, and the further development of new generation medicines on their basis.

Consideration of the flora formation duration in the southern Aralkum showed that the number of plants and the composition of taxonomic units are undoubtedly increasing. Based on the observations made during the expeditions, we may assume that the flora of the southern Aralkum will become stable in a few hundred years, as in the neighbouring natural-geographical areas.

As a result of our studies, it was confirmed that plant coverage of areas with saline soils occurs in accordance with the natural regularities, which determine replacement of halophilic plants by psammophilic plant representatives.

Our results contribute to a better understanding of the fundamental mechanisms of plant adaptation to environmental stressors and to the development of a strategy for periodic sowing of promising plant forms and species in the dried Aral Sea seabed area, to fix mobile sands and solonchaks.

Some dominant plant species and their plant communities on the Southern Aralkum

Fig. 79. Tamarix ramosissima, Haloxylonaphyllum, Stipagrostis pennata

Fig. 80. Kokdarya, Phragmites australis

Fig. 81. Eremopyrum orientale and one year saltwort

Fig. 82. Haloxylon aphyllum

Fig. 83. Horaninovia ulicina, Calligonum, Haloxylon aphyllum

Fig. 84. Stipagrostis pennata, Haloxylon aphyllum

Fig. 85. Stipagrostis pennata

Fig. 86. Alhagi pseudalhagi, Tamarix hispida, Phragmites australis

Fig. 87. Calligonum caput-medusae

Fig. 88. Ammodendron conollyi

Fig. 89. Nitraria schoberi and annual saltwort with black saxaul

Fig. 90. Sand dune knolls. Annual saltwort and various shrubs

Fig. 90. Sand dune knolls. Annual saltwort and various shrubs

Fig. 91. Limonium otolepis, Tamarix hispida

Fig. 92. Natural grass pastures

Fig. 93. Reed formation. Phragmites australis, Tamarix spp

Fig. 94. Riparian vegetation. Populus diversifolia

Fig. 95. Populus diversifolia

Fig. 96. Alhagi pseudalhagi, Tamarix spp

Fig. 97. Halocnemum strobilaceum

Fig. 98. Atriplexpratovii, Climacopteraaralensis

Fig. 99. Halo stachys belangeriana

Fig. 100. Tamarix hispida Willd., Tamarix ramosissima Ledeb., Astragalus villosissimus Bunge

Fig. 101. Haloxylon aphyllum (Minkw.) Iljin., Astragalus villosissimus Bunge., Ammodendron conollyi Bunge ex Boiss

Fig. 102. Haloxylon aphyllum (Minkw.) Iljin

Fig. 103. Haloxylon aphyllum (Minkw.) Iljin., Tamarixhispida Willd., Climacoptera sp

Fig. 104. Haloxylon aphyllum (Minkw.) Iljin., Climacoptera lanata Pall. Botsch., Salsola richteri Kar., Tamarix hispida Willd

6.4. Ecological situation on the dried seabed

The expeditions of 2019 and 2020 covered approximately 1,200,000 hectares of the dried Aral Sea bed located in the Republic of Uzbekistan territories. These territories, which belong to the earliest dried seabed, revealed rather heterogeneous processes and sharp differences in the landscape.

The Aral Sea's dried bed is a unique laboratory of nature, where a new landscape is formed by the natural processes of the gradual formation of soil cover on the background of vegetation. Simultaneously, destructive processes take place under the impact of desertification and anthropogenic destruction of the emerging fragile natural cover. At the same time, the origin, development and replacement of one formation by another, or in combination, reflects the evolution of landscapes themselves and depends on several factors. These include firstly the local features of the dried bottom, secondly the composition of bottom sediments, their salinity and the depth of occurrence and groundwater salinity, thirdly, wind direction and strength, and finally, human interference. Along the expeditions' route, it was possible to observe different vegetation cover and landscape combined with various forms of meso- and micro-landscapes.

A landscape is a natural, genetically homogeneous territorial complex with vegetation cover as a main component. The natural processes of landscape formation are interconnected and are influenced by afforestation which affects its condition. The processes of vegetation overgrowth were established by such shrubs as Tamarix hispida Willd (jyngyl), Halostachys belangeriana Botsch (saltwort belanger, karabarak) or Phragmites australis (common reed), as well as dense perennial thickets of saxaul.

In the course of previous expeditions and the analysis of remote sensing data, landscapes of the dried Aral Sea bed and field survey data allowed specialists of GTZ, Terra Firma and SIC ICWC (Dukhovny V.A. et al., 2008) to reduce the number of landscape subsections and narrow down the composition of classes for creating a subject-related map with regards to the project goals and objectives. This composition of classes makes it possible to estimate the degree of erosion danger and to trace the dynamics of desertification processes. As a result of the analysis of the spectral characteristics, 17 classes were identified, which are given in Chapter 5.2.

The defined and coordinated list of classes for the dried bed area corresponds to the goals and objectives of the project identification of erosion-hazardous areas and areas for promising phytoreclamation works.

Assessment of landscapes by degree of ecological hazard

For perspective development and elaboration of nature protection measures, it is particularly important to assess the landscape of the dried and drained seabed from the position of possible changes, development of deflation processes, dust, and salt transport. Such assessments should be based on landscape classification in connection with soil cover, vegetation state and other factors.

By its nature, the landscape is a highly non-equilibrium, changeable system, which is characterised by daily, annual and multi-year rhythms. We consider the modern transformation of the Aral Sea region's natural environment, which has a regional scale, to be an anthropogenic-driven aridization process. The peculiarity of this process is that the trigger mechanism was man-made. Because this process develops against the background of desert zonal conditions, the leading factor of dynamics being the reduction of moisture, the landscapes evolve to forms corresponding to desert complexes and this process is called "desertification".

As noted above, environmental hazards are considered from the perspective of a harsh landscape that will not easily sustain life or the possibility of human economic activity. The instability of the dried seabed's landscapes is manifested not only in the momentary state, but may also occur during any economic interference in the dynamics of their formation. Thus, the assessment of the ecological hazard is carried out taking into account the dynamics of processes occurring in the area in accordance with the scheme given earlier (Dukhovny V.A. et al., 2008).

Table 25.

Environmental hazard rating scale for classification results

Degree (level) of environmental hazard	Index on the map	Distribution of classes according to the degree of territory instability
No (practically none)	1	1.3 1.4 2.1 2.2 2.5 4.1 4.3 4.5
Weak	2	1.1 1.2 3.5 4.2
Medium	3	2.3 3.4 4.4
Strong	4	2.4 3.1 3.2 3.3

Scale of environmental hazard adopted according to the assessment of the development of destructive exogenous processes:

1. Practically no environmental hazard:

2.1 Marsh solonchak without vegetation or with saltwort communities, excessively hydromorphic

2.2 Wet coastal solonchak with shell rocks, sometimes with isolated specimens of saltwort and sarsazan, hydromorphic

2.5 Saltwort solonchak 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-bog soils

4.3 Shrub thickets (halophytic: tamarix, karabarak) on alluvial-meadow soils

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

Solonchaks are not dangerous because they are hydromorphic for most of the year.

In landscapes of lake plains periodically or permanently watered by river and collector-drainage water pose no danger as they belong to the hydromorphic regime. In addition, vegetation is one of the main factors determining the dynamic state of the landscape; meadows on alluvial plains have sufficiently high projective cover and shrub thickets contribute to the fixation of moving sands.

2. Weak environmental hazard:

1.2. Shallows, sometimes with reeds

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

4.2. Deserted alluvial-meadow soils, hydromorphic, with cereal-halophytic-grass communities with shrubs

These classes are categorised as weak ecological hazard because their existence depends on water inflow to the delta, for instance on the water availability of the year. For example, in low-water years, the area of water surface decreases significantly, causing suppression of reed vegetation.

3. Medium environmental hazard

2.3 Crust-puffed and crust solonchak without vegetation, sometimes with isolated specimens of shrubs (karabarak, tamarix-grass)

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

4.4 Deserted meadow-alluvial soils covered with shrubby plants

The surfaces without vegetation, sometimes with a single specimen of shrubs (karabarak, tamarix), are one of the main suppliers of salt and dust to the atmosphere. Deserted shrublands pose a danger in terms of vegetation degradation causing intensive development of aeolian processes. Hilly and hilly-ridgy sands not fixed by vegetation occupy significant areas of the dried bed of the Aral Sea. The degree of projective coverage varies from 20 to 40 percent and contributes to the development of aeolian processes. Therefore, the inter-sand dune depressions are the main supplier of salt and dust to the atmosphere.

4. Severe environmental hazards

2.4 Solonchak with overblown sandy cover with sparse goosefoot and selinum communities

3.1 Plains (with shells) without vegetation or with sparse shrubs (saxaul, tamarix)

3.2 Dunes without vegetation

3.3 Shallow-hilly (weakly fixed) with sparse communities of wormwood, shrubs, and selinum crops

These classes represent territories with intensive development of exogenous processes and represent the highest degree of ecological hazard, being the formation of salt-dust-transfer source. A significant part of the territory develops in automorphic regime.

The ecological situation on the dried and drained seabed is under several impacts, which are two sides of the transformation of this object:

- Desertification is manifested in the form of sea retreat, up to the disappearance of some water bodies, causing the exposure of bedrock and the gradual formation of a new landscape, as well as the development of new biological processes (overgrowing, soil formation, formation of microbiological biota) and in parallel, the emerging processes of aeolian transformations.
- The watering of peripheral areas of the sea, both from the delta and other water bodies, including collectors, wells and discharge canals, and the anthropogenic impact in the form of both protective and nature-supporting measures (afforestation, stocking of residual water bodies and their biological use) and negative measures harmful to nature in the form of geological prospecting and extraction works. This should also include unregulated water inflow both to the delta and remnant reservoirs, along the river and through collectors flowing into this area.

The stochasticity of natural processes, as well as the variously directed anthropogenic impacts, indicates that the current environmental situation is extremely unstable. The main goal of environmental activities, sustainable functioning and production, is difficult to achieve and cost/effort intensive to manage, in order to maintain the natural-anthropogenic stability.

At present, it is difficult to determine which area is under the influence of purely natural inducing factors (shoreline retreat and seabed drainage, development of sand transport and overgrowth, and the reduction of area and volume of water bodies), which is predatorily used and destroyed by oil producers and will be subjected to sustained wetting. This will be possible to determine precisely after completing an expeditionary survey of all three million hectares of the Uzbek part of the seabed, as well as a multi-year analysis of satellite observations of the wetting zones. Variations of humidification zones are shown in the table below. Two remnants of the Aral Sea on the territory of Uzbekistan have, as presented in Table 26, an area of 422,000 hectares.

SIC ICWC has regularly monitored the Aral Sea and Aral Sea region for many years using Landsat 8 OLI satellite images. The images determined areas of wetlands and open water surface on the Aral Sea in dynamics since the beginning of the year (Table 1 in Chapter 2.1) and areas of wetlands and open water surface in the Aral Sea region (Fig.105, Tables 26 and 27).

Table 26.

Areas of wetlands of the Aral Sea region, by hectare

Water body	19.02.2020	22.03.2020	25.05.2020	10.06.2020	28.07.2020
Sudochie	20613,6	21799,0	29466,78	32837,28	43851,93
Mejdurechenskaya	28506,8	28295,5	31002,77	33072,59	34936,58
Rybatsky	6018,6	8271,2	8676,63	8854,92	8891,82
Muynak	11200,9	13705,1	15217,56	15274,17	15557,85
Djiltyrbas, bounded by a dam	36993,5	38807,6	41897,2	41817,8	41740,7
Djiltyrbas (together with the former right and left channels)	71151,3	77756,8	93206,6	97683,2	98829,8
Dumalak	15358,5	15604,3	15860,64	16016,07	16049,19
Makpalkol	7283,6	7655,7	7854,11	8031,14	7946,27
Mashan-Karadjar	25361,1	25861,6	26299,38	26414,4	26590,26
Water surface south of Muynak	8900,9	9536,2	9605	9605	9605
Water surface along the bed of the Kazakhdarya River	4751	4751	4751	4751	4751
Zakirkol Lake	2339,0	2253,7	2692,12	2721.6	2791,3
Total:	***238 479,8***	***254 298,6***	***286 530,4***	***297 079,8***	***311 542,3***

Table 27.

Areas of open water surface of the Aral Sea region, by hectare

Water body	19.02.2020	22.03.2020	25.05.2020	10.06.2020	28.07.2020
Sudochie	37910,3	36724,9	29057,22	25686,72	14672,07
Mejdurechenskaya	9277,1	9488,4	6781,23	4711,41	2847,42
Rybatsky	5474,3	3221,7	2816,37	2638,08	2601,18
Muynak	4963,0	2458,8	946,44	889,83	606,15
Djiltyrbas, bounded by a dam	10478,8	8664,7	5575,14	5654,52	5731,65

Djiltyrbas (together with the former right and left channels)	27799,6	21194,1	5744,34	1267,74	121,14
Dumalak	691,4	445,6	189,36	33,93	0,81
Makpalkol	1400,3	1028,2	829,89	652,86	737,73
Mashan-Karadjar	1839,8	1339,3	901,62	786,6	610,74
Water surface south of Muynak	704,0	68,7	0	0	0
Water surface along the bed of the Kazakhdarya River	0	0	0	0	0
Zakirkol Lake	452,2	537,5	99.18	69,66	0
Total:	***100 991,3***	***85 172,5***	***52 940,7***	***42 391,3***	***27 928,8***

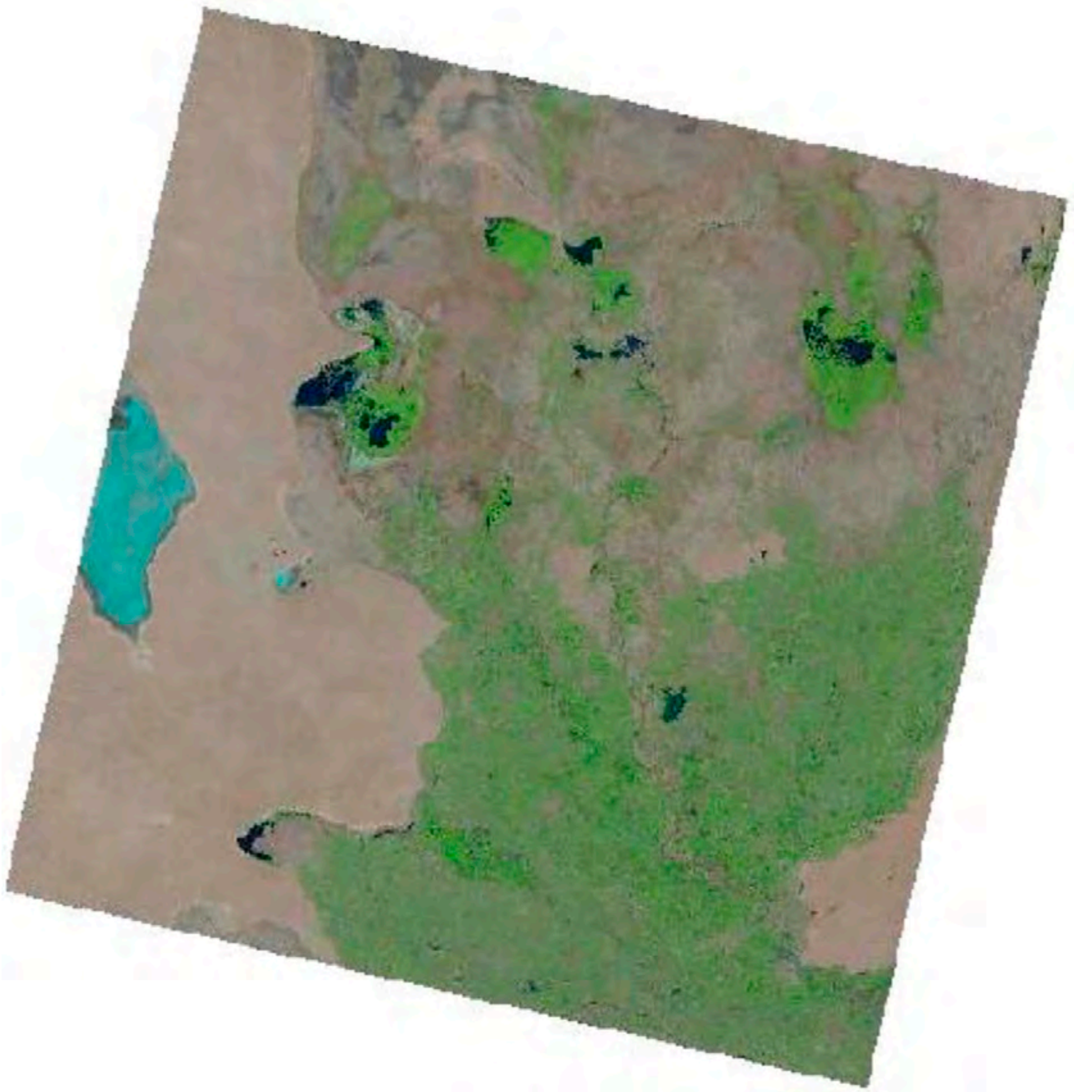


Fig. 105. Wetlands of the Aral Sea region

Water surface area reduction increased the area of wetlands. Compared to 2010, the area of wetlands in the western part of the sea increased by 114,000 hectares by 2019, and in the eastern part of the sea, the wetland area correspondingly increased to 498,000 hectares. Extremely unstable and poorly predictable watering of the Amudarya River delta and all water body remnants of the Aral Sea, formed a new Aral Sea region. This region extends to the dried bed, creating an unstable landscape and simultaneously causing difficulties to the potential of this vast area, similar to best international practice.

For example, in the first expedition, watering was observed on the territory of the former Adjibay Bay, where water was discharged from the Sudochie Lake system. Water was also discharged from Muynak and Rybatsky Reservoirs and from the Mejdurechenskaya Reservoir. In the high-water year of 2017, moistened zones formed around the Adjibay discharge channels, spreading the seeds of shrubs and other plant species contributing to the natural self-overgrowing of a large area. During the second expedition, many flooded areas were found in the Djiltyrbas Reservoir's territory of the Kokdarya

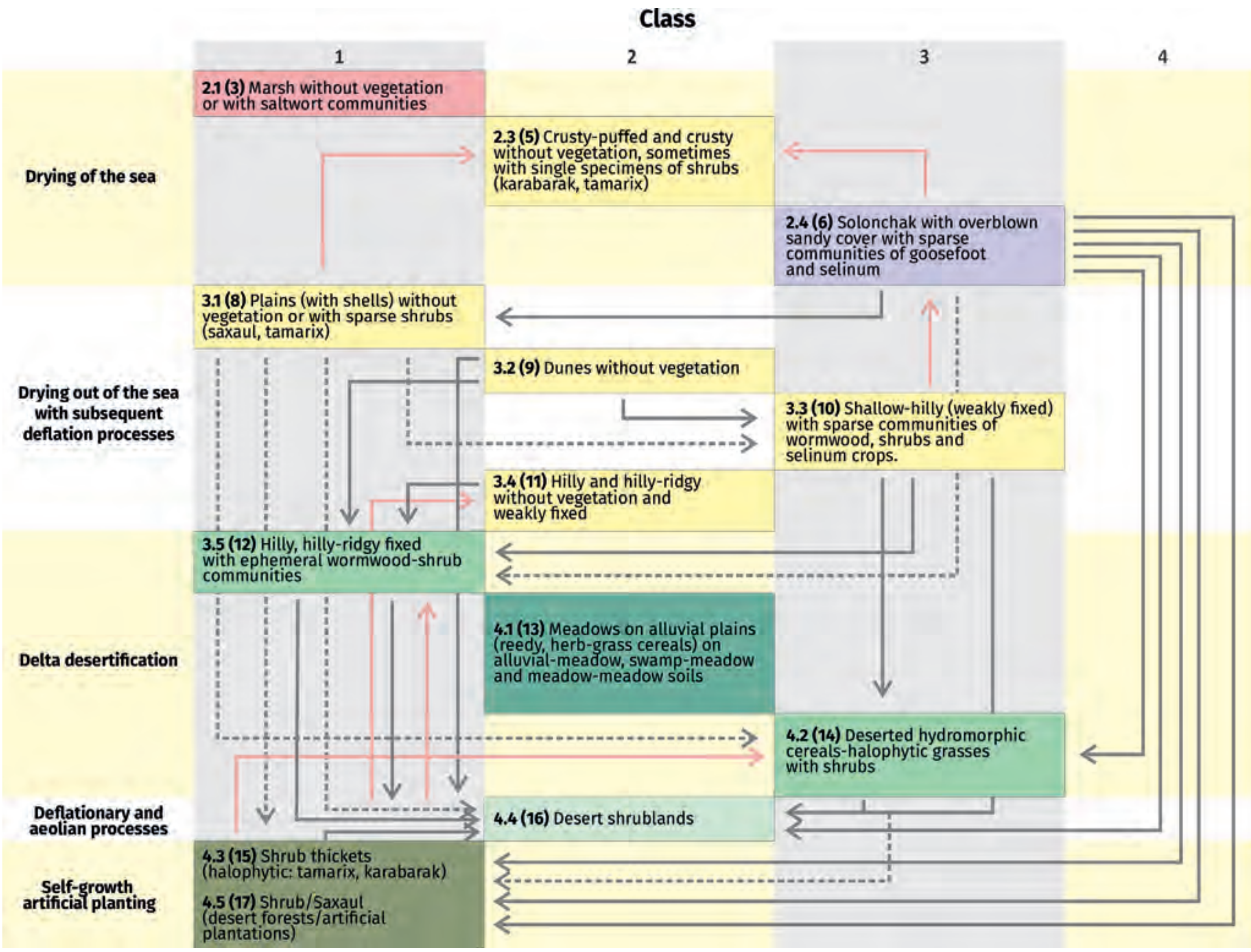


Fig. 106. Direction of drying sea surface classes transformation, regulated process development, possible process development

and Kazakhdarya Channels, where rather hydromorphic vegetation was observed. The preservation of this vegetation requires constant moistening and watering, which is unfortunately problematic as it is not consistent.

Considering the significant influence of the natural state of the bottom, natural processes and impacts, as well as anthropogenic factors, the classification of the territory is a dynamic process. Based on the comparison of the situation in 2006 and the process of the two expeditions, maintaining if possible the route of previous years, the dynamics of landscape transformation in the territory covered was obtained and is reflected in the attached matrix. The scheme and the matrix of class transformation are given below. The matrix is compiled based on the territory assessment by 17 classes (Fig. 106, Table 28).

Here, the vertical line shows classes at the level of the year 2006, and the horizontal line shows classes at the level of the year 2019. The green colour shows the most common transformations. Below are examples of these changes.

Point 147. In 2006, corresponded to Class 6: 2.4 (6). Solonchak with overlain sandy cover with sparse communities of goosefoot and selinum. Class 2019 did not change and remained to be 6. Rare saxaul in association with very rare karabarak. Flat terrain, soil with white patches and shell rocks.

Point 583. In 2006 corresponded to Class 8: 3.1 (8). Plains (with shells) without vegetation or

Table 28.

Matrix of the drying sea surface classes transformation

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1																	
2																	
3																	
4																	
5					6					1							
6					6	113		9			2	9		6	17		16
7																	
8					5	1		53		1	8	3		13	58		
9						1		2		5	2	54		8	34		4
10					2	3				2		28		17	24	14	5
11					2	1				1	3	1 20		15	44	35	9
12												11		14	20	12	5
13																	
14														10	32	6	4
15											**1**	**1**		5	28	9	
16														21	12	16	6
17														12	1	1	2
	1.1	1.2	2.1	2.2	2.3	2.4	2.5	3.1	3.2	3.3	3.4	3.5	4.1	4.2	4.3	4.4	4.5

with sparse shrubs (saxaul, tamarix). No change in Class in 2019. Terrain is flat with sliced furrows. The solonchak is moderately hydromorphic. Planting tamarix seedlings along furrows, sparse results clearly visible.

Point 27. In 2006, the terrain landscape of soil and vegetation cover was by Class 14: 4.2 (14) - desertifying hydromorphic cereal-halophytic mixed grasses with shrubs. In 2019 it became Class 15: 4.3 (15). Shrubby thickets (halophytic: tamarix, karabarak). Terrain is flat, soil is crust solonchak with shell rocks. Vegetation cover of karabarak with plant height up to 0.3 metres with vegetation cover of 60 percent.

Point 44. In 2006, it was Class 11: 3.4 (11). Hilly and hilly-ridgy with no vegetation and poorly consolidated. In 2019 changed to Class 16: 4.4 (16). Desert shrubs, soil is crusty-puffy solonchak with shell rocks, sliced sand-accumulative furrows. Rare young saxaul mixed with annual dried grasses.

Point 99. In 2006 corresponded to Class 14: 4.2 (14). Deserted hydromorphic cereal-halophytic grasses with shrubs. In 2019 became Class 15: 4.3 (15). Shrubby thickets (halophytic: tamarix, karabarak). Terrain is flat, soil is semi-hydromorphic solonchak. Where plants do not grow, the soil has white salt spots. Groundwater is close. Vegetation cover is mostly tamarix, well developed with a height of almost 2.0 metres. There is karabarak and climacoptera.

Point 866. In 2006, was Class 10: 3.3 (10). Shallow-hilly (weakly anchored) with sparse communities of wormwood, shrubs and selinum crops. In 2019 became Class 12: 3.5 (12). Hilly, hilly-ridgy fixed with ephemeral-wormwood-shrub communities. There are sand dunes of up to 1.0 metres high. Soil is sandy with shells. Perennial saxaul up to 3 metres high. Climacoptera in some places, dried up annual grasses. There is young saxaul, self-overgrowing.

Point 1107. In 2006 was Class 9: 3.2 (9). Dunes with no vegetation. In 2019, became Class 12: 3.5 (12). Hilly, hilly-ridgy fixed with ephemeral wormwood-shrub communities, dune sands of 0.5-1,0 metres. Soil is sandy with shells, stony covers. Perennial saxaul with a height of 0.5-1.5 metres, together with young saxaul, is self-overgrowing. There is also karabarak, kandym, selinum, ajrik (Aristida L.) and camelthorn (Lat. Alhági).

Point 1359. In 2006, it corresponded to Class 9: 3.2 (9). Dunes without vegetation. In 2019, became Class 17: 4.5 (17). Shrubby Saxaul (desert forests/ artificial plantations). Saxaul old planting 2-3 metres high, self-overgrowing, dried annual grasses in progress.

The whole route of both expeditions was summarised in the corresponding table with the format given below, and based on this, a breakdown by risk classes was made and is summarised in the table and compared with the data of distance classifications. As an example, an excerpt from the mentioned Table 29 is given.

After flooding, seeds of shrubs and other vegetation species came with water to a part of the dried seabed and contributed to the increase of vegetation cover on the dried seabed. This means that it is necessary to maintain some intervals at discharges to form wetted zones on the dried seabed of the Large Aral Sea.

In the absence of repeated rewetting on the dried seabed for a long period, soils degrade, the water table decreases, and the salt content of the soil increases. Biodiversity also decreases significantly. The overgrown vegetation cover begins to dry out.

During the expedition it was determined that the discharge waters cannot always flow in the former directions where it used to flood. This has been caused by artificial dams, canals and roads made by oil and gas companies working on the dried Aral Sea bed, especially on the surveyed territory of the first expedition in the Muynak part of the drainage. It should be noted that these water structures, dams, canals and engineering facilities (asphalted, gravel and un-

Table 29.

Assessment of the ecological hazard degree of soil and vegetation cover classes on the dried seabed of the Aral Sea

Route num-bers	Total number of points	The topography of the described area	Land cover data	Assessment of the degree of environmental hazard
2019				
1	44 (T.1-44)	The landscape of the area covered by the first route is variable, flat at the beginning, then with a transition of landscape with sand dune sands. In some places there are depressions and sinkholes with a diameter of 0.1-0.4 metres on the dried seabed. Then the landscape is flat, with rare dunes. In the continuation of the route, the terrain is flat.	From the beginning, the main landscape plants were karabarak with vegetation cover of 20-30 percent with dried branches. Then sparse vegetation appears, sowing seeds in the spring period of 2018 gave no results, while on sand hills the height of plants is 0.2 metres. Sand hills sometimes reach 10-20 metres. Furthermore, the described area along the route changes to rare 5-6-year-old saxaul, 1.8 metres high. There is a process of self-overgrowing, the soil is covered with annual grasses, dried after the summer period, sowing lines are visible, but there are no results. The soil is dark solonchak in some places. Vegetation cover is 10 percent, then 4-5-year-old saxaul, a lot of young saxaul, and intensive self-overgrowing is going on. Vegetation cover is almost 100 percent, and saxaul disease was found. Another described area was flooded by water, and because of this the plant cover appeared mainly to be of tamarix, with a cover of 60 percent. Furthermore the soil is compacted, with the gas prospecting drilling unit having been working, and the vegetation cover consists of annual dried grasses. In most places along the route, furrows are cut and accumulate sand. Saplings are occasionally planted in the furrows, where there is little or no overgrowth.	At the beginning of the route there is an (25%) **average environmental hazard.** Next there are (25%) **strong environmental hazards.** In the remaining points of the route there are mostly **weak** (40%) and the **rare medium** (10%) environmental hazards.

Route numbers	Total number of points	The topography of the described area	Land cover data	Assessment of the degree of environmental hazard
2	51 (T.45-94)	The terrain is mostly flat, while in some places there are very rare dunes.	At the beginning of the route, rare young saxaul mixed with dried annual grasses were observed. Then there are very rare dunes with tamarix and karabarak plants 0.4-1.0 metres high. The soil is puffed solonchak, wet on the surface, white in some places, and sandy loam-sandy furrows are cut. The landscape changes to very rare shrubs of tamarix, karabarak and Selitraria schoberi (lat. Nitraria schoberi). Dried saxaul seedlings are found. Further along the route, mixed thickets of karabarak occasionally with tamarix are observed. Due to the earthen dam, a certain area up to the dam was flooded with water. In this area there is the process of the self-overgrowing of shrubs of karabarak and tamarix. On the other side of the dam there are fields without vegetation, but with very rare small dunes, where Nitraria schoberi grows. At the end of the route the landscape changes to rare perennial saxaul of up to 3.5 metres high, and with annual dried grasses.	At the beginning of the route is a strong (43%) **environmental hazard.** Then a switch to a mixed class of **no environmental risk** and **weak environmental hazard** (33%). In the remaining points, there is an average (24%) environmental hazard.

paved roads) are constructed arbitrarily without coordination with local water management organizations, which operate the local water bodies in region.

During land expeditions, self-discharging wells for water supply, livestock farming and shallow irrigation were also studied.

It should be noted that in the area between the bed of the Amudarya and Djiltyrbas (in the area of Kazakhdarya), close to settlements, there is degradation of pastures, especially around the self-discharging well due to constant grazing of animals, mainly cattle and horses.

At this time, in the area between Djiltyrbas and Kokdarya, as well as in the area behind Kokdarya, geophysicists carried out explosion works to prospect for oil and gas.

In the Kazakhdarya area, between the bed of the Amudarya and Djiltyrbas, they found a road where asphalted sections had collapsed in several places and large steep precipices had formed and could be dangerous for vehicles of working personnel and of the population in this area.

Local water bodies in the southern Aral Sea region have a certain reserve and an appropriately designed water level. In high-water years, excess water is forcedly discharged towards the dried bed of the Large Aral Sea. The Amudarya flow is characterised by great variability, and there are short-term flood releases that pose a danger to structures.

Therefore, the construction of water management structures and engineering facilities on the seabed without coordination with local water management organizations endangers the safety of these oil and gas facilities. With such inconsistency of design data and sites of facilities, there will probably be a consequence in the form of the flooding of gas wells and facilities where drilling operations are currently carried out.

Another negative aspect of the works carried out on the dried seabed by gas and oil companies is that the construction of roads, dams and discharge channels prevent self-overgrowing processes and the preservation of vegetation.

The negative environmental impact of new infrastructure on the seabed is also related to the drilling rigs for producing natural gas, and leads to the destruction of the grass cover and vegetation on the bottom of the dried sea where the recovery processes are particularly slow. In the areas where the drilling unit is standing and where the drilling has already been completed, the vegetation cover is completely destroyed in an area of about 2-3 hectares. Even after ten years vegetation has not been restored at the drilling site.

In pursuance of the President of the Republic of Uzbekistan’s order to create a “green cover” on the dried bed signed in December 2018, large-scale works were started for the afforestation of the dried Aral Sea bed, with over 1 million hectares to be completed by the end of 2019. To accelerate the afforestation, 400 billion soums in funds were allocated from the state budget of Uzbekistan in 2019. More than 530 tractors from all regions of the country and two AN-2 aircraft were mobilised, while 1,532 tons of saxaul seeds and 73 tons of karabarak were prepared. In the period from December 2018 to March 2019, work was carried out on an area of 451,600 hectares. 323,150 hectares were sown by two AN-2 aircraft, 119,440 hectares were sown with agricultural equipment, and 3,000 hectares were sown by hang-glider.

The results of ground expeditions obtained in most of the explored areas along the route, especially in the survey area of the first expedition, showed that cut furrows for sand accumulation areas were found almost everywhere. To date seedlings are planted very seldomly on these furrows and where planting is made, only rarely do the plants take root.

According to field studies, self-overgrowing is particularly active near and at the end of the plots with artificial plantations on the territories where international projects have been implemented (for instance by GTZ), as well as on the areas afforested on the dried Aral Sea bed by the State Forestry Committee where sites are correctly selected. This proves that the choice of planting sites must be carefully studied, and their locations must be properly determined. In order to ensure good establishment, a detailed study of the ecological condition of the area, including the soil cover in parts of the selected sites, also needs to determine the boundary conditions for groundwater levels and salinity. This is a strong indication of the positive impact of mitigation works on the ecological situation in the area of the dried Aral Sea bed.

Another environmental problem of the dried Aral Sea bed is garbage pollution. During both expeditions along the route, we often saw places where there was abandoned refuse including empty glass and plastic bottles, and plastic bags. Closer to the town of Muynak, at the “Ship Graveyard” Museum, a landfill of construction waste had appeared. These examples stress the need for urgent measures to be taken by the State Committee of Ecology to prevent negative impacts on the ecology of the dried Aral Sea bed.

6.5. Study of forest vegetation cover

The Government of Uzbekistan, in pursuance of the initiative of the President Sh. Mirziyoyev, has deployed large scale works with striking dynamism that without such decisions, a natural transformation would require centuries to undertake. Monitoring the dried seabed and the processes occurring there is considered to be the main tool for undertaking such transformational and partial preservation of this unique zone, and to prevent the development of possible negative phenomena. The Aral Sea region and the dried seabed currently serve as a space for innovative methods of nature transformation. In addition, the dried seabed zone is a unique laboratory for scientists, who can observe and study within the lifespan of one generation, the processes that normally take place over centuries.

The issue of resuming monitoring of the dried seabed was raised in several government documents after German financing ceased in 2010. However, financial support reappeared through the establishment of the UN Multi-partner Trust Fund for Human Security for the Aral Sea region. In 2019-2020, comprehensive expeditions were organized by SIC ICWC with the financial support of UNDP and with the participation of the International Innovation Center of the Aral Sea Region under the President of the Republic of Uzbekistan. The expedition's tasks studied the soil cover and the state of flora on a part of the dried seabed, observed the changes of some environmental indicators in recent years, and compared the dynamics with the previous period.

As previously mentioned, the two expeditions' survey areas belong to the state forest fund of the Muynak and Kazakhdarya forestries. In these areas, the main works of artificial planting and sowing of forest crops have been carried out from the 1980s to the present day.

6.5.1. Organization of research

The surveys included routes and descriptions of landscape points, vegetation, and soil cover. The analyses determined the amount of reforestation work performed, methods of silvicultural and phytomeliorative measures, identified sources of disease and plant pests in the surveyed area to determine the survival rate of conducted reforestation work, as well as the state of the natural regeneration between rows and around older forests. Participants strictly recorded any factors that may have influenced the survival rate of plantings, including age, condition, diseases and efficiency. Such factors have included, among others, the presence of canals, lakes, streams and other sources of moisture, the presence of pastures and wells both active and abandoned, roads, and anthropogenic damage to plants.

6.5.2. Study of forest cover and recommendations made from the expeditions' results

The development of deserts in conditions of scientific and technical revolution is a difficult task and one that carries great responsibility. On the one hand significant capital investments, a special approach and the application of appropriate methods and technical means are all required, while on the other hand there must be a close connection with environmental protection, the improvement of the ecological situation, and the scientific forecasting of undesirable consequences of human interference into the existing natural balance. At the same time, it is necessary to keep in mind that the nature of deserts is especially unstable and easily irreversible. Arid biogeocenoses are fragile systems, since anthropogenic impacts can quickly destroy them, and their recovery is slow. Desert preservation under conditions of increased economic pressure requires continuous improvement of the organization and technology of rational land use, and the application of special measures.

Results of research conducted in the first expedition

The first expedition covered the south-western part of the dried seabed. It was conducted from four camps along 16 routes and recorded 1,581 observation points.

As an example, an excerpt from the dendrologist's field log is given below.

'Route 2' (T.45-T.94)

"Second route from the first camp along the road to the cliff in the south-western and western directions (T.45-T.94). The area is flat with a slope to the cliff.

The following features were noted.

The area changes considerably based on what amount of water flows downstream of the Amudarya River into the Tuyamuyun reservoir. In affluent years water spills from the Adjibay Bay, holds for a long time, and contributes to the development of tamarix and karabarak. The karabarak body has 80 percent coverage (T.45-T.47). Part of the route (T.50-T.64) passes through sliced furrows of heterogeneous appearance with rare specimens of climocoptera, karabarak, tamarix and saxaul. Wet and dry solonchak patches alternate. Point (T.65) has rare thickets of saxaul aged 3-5 years and tamarix sprouts, of a 5 percent coverage. (T.66) has coordinates of 43 points of previous expeditions, saxaul in poor condition. Open space (T.67-T.70) – dead saxaul sowing. At points (T.71-T.73) – natural bodies of saxaul of 10-12 years old and tamarix, 50 percent coverage. Karabarak and tamarix bodies in (T.74-T.81), 85 percent coverage. Tamarix massif (T.87), 70 percent coverage."

In addition, the botanist gave a detailed systematic description of the vegetation. Finally, the ecologist's log and summaries provided characteristics of the vegetation, including self-overgrowth, which was compared with the results of 2006. Particular attention in the first expedition is paid to new plantings and the preparation of furrows.

The following are conclusions of the first expedition:

- Intensive natural regeneration between and around intercropping is observed.
- Most of the area of the "Tigroviy Hvost" (Tiger's Tail) massif and along the cliff of the Ustyurt plateau is often subjected to flooding. Thanks to this, natural regeneration of tamarix, karabarak and other salt-tolerant crop species appears in this area (Fig. 107 and 108).
- Furrows were cut (Fig. 109) for the further planting of desert plants.
- Immediately after cutting sand-forage furrows, salt-tolerant species were planted.
- Due to premature silvicultural works on the cut furrows with no accumulated sand layer, the degree of rooting of the planted vegetation is not satisfactory.
- In some areas, sources of desert plant diseases such as powdery mildew and gall blight appear (Fig. 110).

Recommendations for the first expedition area

- Considering that the cutting of furrows on these territories is premature, it is necessary to wait until the sub-surface groundwater has lowered and loamy soil formation appears. These are favourable conditions for the development of desert crops' root systems.

- After the second year of cutting furrows, it is necessary to annually survey and wait until the amount of sand accumulation allows for the planting of forest crops. Aerial seeding should be carried out on those areas where tamarix-karabarak thickets dry up and the filling of sands begins.
- Take necessary measures to control diseases and pests of desert forests.
- We recommend the development of two research stations for laboratory studies for ecological assessment, and possibly the ecological risks of the Aral Sea's dried seabed.
- Conduct an annual permanent expedition with the participation of highly qualified and experienced specialists and experts, in order to obtain reliable information and create a database to conduct monitoring with appropriate comparisons of previous research analyses.

Results of research conducted in the second expedition

The second expedition (Fig. 112) covered mainly the south-eastern part of the dried seabed. The survey was conducted from three camps, 14 routes, and 561 observation points. The terrain on this expedition was hillier and with greater presence of water factors that disrupted the normal course of the desert-tolerant vegetation growing processes.

Conclusions of the second expedition

1. In some places, tamarix and karabarak begin to dry out due to the lowering of the groundwater table. In addition to shrubs, fodder crops such as camelthorn and new species such as limonium can be found in this area. Along the asphalt road, good sprouts of garmala (adrapan, isirik) are found.

2. In the coastal zone of the Amudarya River, riparian vegetation such as turanga and jida (Oleaster) grows.

3. As a result of groundwater levels elevation and flooding by discharge waters of the Kokdarya River, more than 90 percent of the 2005 GTZ-funded planting in the nearby areas had died.

4. The same situation occurred along Kuat Lake.

Recommendations for the second expedition area

- At the Aral section (northern part), at Djiltyrbas Lake, it is necessary to carry out afforestation works (saxaul, cherkez, kandym and selinum). The terrain is sandy (mobile sands). In the unfixed areas, it is advisable to supplement inter-rows with fodder plants.
- In the western part of Djiltyrbas Lake, it is necessary to supplement the inter-row saxauls with Richter's cherkez, kandym and selinum.
- In the northern part of Djiltyrbas Lake (on the border with Kazakhstan), it is advisable to carry out afforestation works on the saline parts in a expedient way by sowing and planting tamarix and karabarak. The area is not fixed.
- In the southern part of Djiltyrbas Lake, it is advisable to carry out afforestation works with the use of sowing of fodder plants, as the area has been used for a long time by livestock farming on the basis of five wells.
- On the eastern part of the collector KS-3 to Djiltyrbas Lake, it is advisable to

Fig. 107. Examples of “Tigroviy Hvost” (Tiger’s Tail) vegetation

Fig. 108. Vegetation along the cliff

Fig. 109. Sliced furrows

Fig. 110. Saxaul disease identification

Fig. 111. Photos of the first expedition

carry out afforestation works. The terrain is poorly fixed with desert plants and is exposed to wind erosion.

- In the eastern part of Kuat Lake (starting from Dariyabay wells to Chimbay wells, from Burovaya road and down to Terbenbes Island), it is advisable to supplement the inter-row planting and sowing of fodder crops.
- To the north of Kuat Lake, saxaul shrubs are prone to diseases (powdery mildew). Shrubs have stunted growth. It is necessary to carry out planting and sowing of Richter's cherkez. The results of the survey have shown that cherkez is more resistant to various diseases.
- In the north of the terrain up to the border with Kazakhstan mobile sands are weakly fixed. Considering the fact that in some places the soils are highly saline (the end of Kokdarya), it is necessary to sow and plant more salt-tolerant plants (tamarix-grass, karabarak). The use of aviation is recommended since the terrain is difficult to access.

There is no need to carry out afforestation along the banks of the Kokdarya, since the right and left banks from the 'Kabakly Ata' cemetery to the final part of the Kokdarya are overgrown with tamarix and karabarak. The terrain is impassable.

Along the banks of Togyzarkan and Kytay Kazgan, afforestation must be carried out by sowing fodder plants. The terrain is poorly fixed, and there are sporadic specimens of shrubs.

The eastern part up to the border with Kazakhstan and the whole northern part is not fixed. Large-scale afforestation with the use of various planting technologies is required.

Based on the daily review of expedition routes, the distribution of various species in the zone of each expedition was determined and a generalisation of the results of the quantitative account of the different tree crops sowing states was made.

As one can see in Table 30, the total area coverage in the zone of the first expedition is 32 percent, while for the second it is more than 60 percent. The increase in percentage is due to the greater watering of the zone of the second expedition. Meanwhile saxaul prevails in both zones.

Table 30.

Summary of quantitative analysis of rocks in dendrological survey

Expedition	Surface coverage expert evaluation, %				
	Saxaul		Hydrophilous: rushes, reeds	Tamarix, karabarak	Sliced furrows
	Total	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

6.5.3 Results of the new forest crops survey

The results of the study of new plantings showed that in the winter-spring period of 2018-2019, work was carried out on sowing forest crops and other desert plants on the area of 461,000 hectares (Fig. 113).

To date, the seeds sown out by the AN-2 aircraft on an area of 250,000 hectares resulted in unevenly dispersed sprouts. On average, their number was from 300 to 2,000 pcs per 1 hectare *(according to the rules of creation of forest plantations in the desert zone, the area is considered forested when the number of plants is 300-500 pcs).*

On an area of 3,000 hectares (in the 'Ahantai' territory) on gypsiferous and strongly saline soils, the seeds were sown by hang-glider. At present no sprouts have been detected, but there are seeds on the soil surface (according to scientists, saxaul seeds can keep their germination for 2 years).

In strongly saline soils (solonchaks), seedlings of tamarix and saltwort belanger (karabarak) were planted. The rooting ability of these 10 plants was 3-4 pcs (30-35 percent), while the upper part of some seedlings 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 medium saline soils. At the same time, on average 5-8 pcs of every 10 seedlings have taken root in some plots (5-58 percent), whereas on strongly saline acid soils, 1-2 pcs (10-20 percent) of plants have taken root.

For the crops sown by means of agricultural machinery on the area of 119,400 hectares, sprouts in 10 m2 on sandy soils were 55-60 pcs, on medium and weakly saline soils were 15-25 pcs, and on gypsiferous soils no sprouts were found.

According to the results of preliminary monitoring, scientists positively assessed the state of seed and seedling plants.

Certain works were completed to provide the disaster area with water suitable for livestock farming development, and to enable the attraction and reproduction of flora and fauna of the region.

To date, water has been obtained from 41 wells, including 16 in the Aral Sea area, 17 in Kazakdarya settlement of the Muynak region and 8 in the Takhtakupyr region. The drilling and rehabilitation processes for nine wells have been completed.

Prepared wells are equipped with a hydrant control device and devices for livestock watering.

To prevent transport of sands along 93.5 kilometres, reed protective strips were built with a total area of 1,244 m^3.

6.5.4 General recommendations

The dried part of the Aral Sea bed is characterised by typical desert vegetation types. Sandy (psammophilous) and solonchak (halophilous) types are predominant. Elements of Tugai vegetation are typical for the Amudarya River delta. Peculiar landscape reed beds are observed. They are formed in most cases during the depression of hydrophilous annual saltwort vegetation. As a rule, they are short-lived and degrade as excessive moisture reserves are depleted in soils.

Within the dried bays and the southern part of the Aral Sea bed, we recorded 64 species of higher plants, including representatives of 47 genera and 17 families. These included 1 species of tree, 18 species of bushes, 4 species of semi-shrubs, 18 species of perennial grass, and 22 species of annual grass.

All plant species growing on the dried part of the Aral Sea bed can be divided into three

Fig. 112. Conducting the second expedition

groups according to the condition of the total number of individuals in the cenopopulations, i.e., life span, number, age structure, and dispersal intensity.

1. Progressive cenopopulations
2. Regressive cenopopulations
3. Local cenopopulations

The latter are characterised by stenotopicity, narrow tolerance and, consequently, adaptability to a narrow range of environmental factors. The eugalophilous annual plant, glasswort, is confined to clay marsh coastal solonchaks. It inhabits the seabed even before it is completely dry. Its seeds grow better in an aquatic environment.

Saltwort reaches its greatest development within the 1st-2nd year of seabed drainage. Later, in the 4th-5th year of seabed drainage, it dies off due to intensive desertification of soils. It continues to renew on the newly dried seabed areas. From the point of view of phytomelioration, such species have no special importance.

Regressive cenopopulations can be represented by numerous individuals. However, they are characterised by a weak or complete absence of seed regeneration, the predominance of old-age and dead individuals. They can bear fruit normally, but they do not have ecological conditions for seed regeneration. Such are the cenopopulations of tamarix, reed and other hygro-mesophilous plants.

Progressive cenopopulations are characterised by all age groups, intensive seed regeneration and dispersal. These are black saxaul, leafless eremosparton, jujugum species, sandy astragalus and others. They are promising for phytomelioration of the dried part of the Aral Sea bed, and deserted cones of the Amudarya River.

Phytomeliorants

Eremosparton leafless – Eremosparton aphyllum Fisch et Mey of the legume family. Tall shrub 2-4 metres high, psammophyte, euxerophyte, characteristic representative of mobile, weakly fixed desalinated sands.

Eremosparton in the southern part of the Aral Sea bed was first recorded in 1989, in the Kabanbai area, on mobile sands with salinity not exceeding 0.2-0.25 percent. At present, here and in adjacent areas, such as Vozrojdeniya Island, there are fairly well-developed fruiting individuals. The number of individuals of Eremosparton varies in the range of 5-8 specimen/100m2, and bear fruit in summer.

Black saxaul – Haloxylon aphyllum / Minkw / Ijin from the family of Marecchiaceae - tree or tall shrub up to 3-4 metres high, euxerophyte, eugalophyte, phreatophyte, characteristic representative of sandy, clay and solonchak deserts.

On the dried part of the Aral Sea bed, black saxaul is a fairly widespread plant. It is represented by all age groups. On the western part of the dried Adjibay Bay, there are rather dense thickets with a height of 3-4 metres. Black saxaul tends to expand its territory, in which saxaul numbers fluctuate within a wide range of 1-20 specimen/100 m2. Seeds mature in autumn.

Calligonum (juzgun) species – Calligonum Sp.Sp., of the buckwheat family. Juzgun species are shrubs, characteristic representatives mainly of slightly saline and desalinised sands. About 15 species are characteristic to the Aral Sea region. Of these, about 8-10 species are found in the dried part of the Aral Sea bed on weakly fixed saline sand dunes. They are usually confined to slightly fixed saline sand bodies and are characterised by close ecological features. They bear fruit in summer.

Volumes of performed works 'Fall 2019 - Spring 2020'

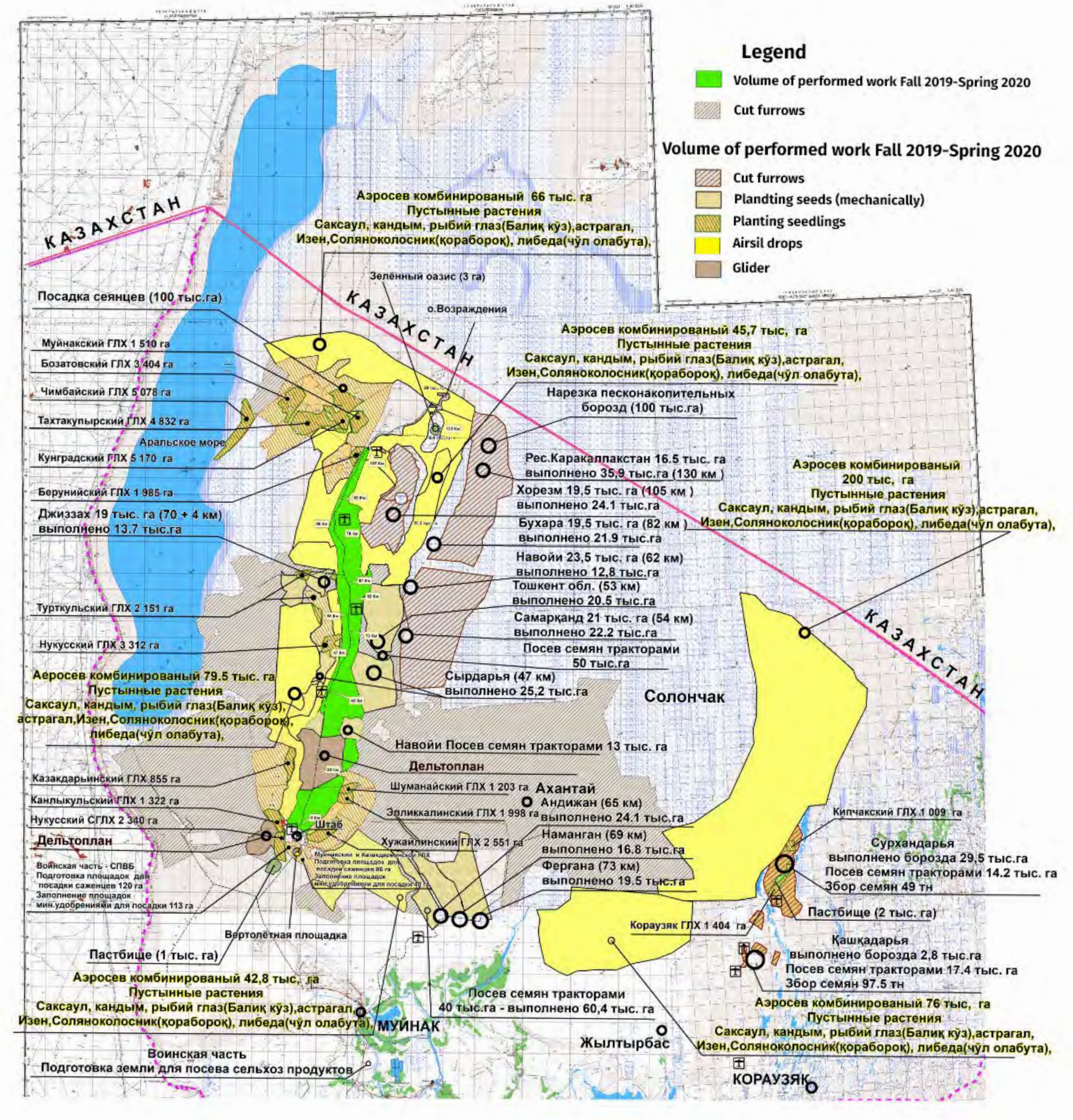


Fig. 113. Volumes of performed works 'Fall 2019 - Spring 2020'

For phytomelioration purposes, juzgun ("Head of Medusa"), a powerful shrub 2-3 metres high, is most often used. Experiments carried out by employees of SredAzNIILKh (Koksharova & Isakov, 1985) on the phytomelioration of the drained Rybatsky and Adjibay bays with the use of this species gave positive results. Other species of juzgun can be also used with the same success: leafless, Aral, flat-bristle, bristle-shaped, scale-shaped, tree-shaped and others.

Astragalus sandus – Astragalus ammodendron Bunge, from the legume family, is a shrub 50-120 centimetres high, psammophyte and euxerophyte. It is widespread on the dried part of the Aral Sea bed. This species of astragalus is more numerous in the former coastal zone of the sea, where the soil is composed of desalinised and weakly consolidated, gypsiferous sands. The number of plants is 1-2 specimen/100m2. It bears fruit in summer.

Richter's Solyanka, Cherkez – Salsolarichteri / Moq / Kar.exLitv., a shrub of 1-2 metres in height, psammophyte, euxerophyte, a characteristic representative of the vegetation of weakly fixed sandy deserts.

Cherkez is absent in natural vegetation. It was introduced on the dried part of the Rybatsky and Adjibay bays, and on the deserted cones of the Amudarya outlet by employees of SredAzNIILKh (Koksharova & Isakov, 1985) at the beginning of the 1980s. The experiments were successful. The plants reached 1.2-1.7 metres in height and bear fruits abundantly every year. They began to disperse by self-seeding. Richter's cherkez is a valuable fodder plant, fruiting in autumn.

Solyanka Palecki, Cherkez – Salsola paletzkiana Litv, from the family Marecchiaceae, shrub with a height of 1-3 metres, psammophyte, euxerophyte, one of the characteristic plants of desalinised, weakly fixed sands.

This species of cherkez in terms of biology and ecology is very similar to the preceding plant. The main difference between them is that the latter has assimilative shoots that are two or more times longer than those of the former. In addition, the Palatsky's cherkez in natural conditions is widespread in the southern regions of Karakalpakstan, whereas it is not found in the vegetation of the dried part of the Aral Sea bed and the bordering areas of the Aral Sea region.

Paletskiy's cherkez was introduced on the dried Rybatsky and Adjibay bays and deserted cones of the Amudarya outlet simultaneously with Richter's cherkez at the beginning of the 1980s by employees of SredAzNIILKh. Here the plants took root, reached a height of 1-2 metres, bear fruit annually, and disperse by self-seeding. It fruits abundantly in autumn every year. It is a valuable fodder plant.

Solyanka orientalna, Keireuk – Salsola orientalis S.GGmel is a valuable fodder plant. The shrub is 30-60 centimetres in height, and is widespread in the gypsum and clay deserts of the Aral Sea region. It is not found in the natural vegetation of the dried part of the Aral Sea bed.

Keireuk for phytomeliorative purposes was introduced on the drained Rybatsky Bay, by the sowing of seeds by the employees of the Institute of Botany of the Academy of Sciences of RUz and the Institute of Bioecology of KKO of the Academy of Sciences of Ruz, in the late 1980s (Kabulov, 1997). So far a few bushes have managed to grow. However, they bear fruit abundantly every year. It can be supposed that this species will be promising in slightly saline and desalinised loamy and clayey areas of the dried bays of the Aral Sea.

Tree saltwort, Axar – Salso ladendroides Pall., from the family Marecchiaceae is a semi-shrub 80-120 centimetres high, a mesophilic, halophilous plant, widely distributed in slightly to medium saline areas of dried coastal spills and lakes. Fruits abundantly each year. Seeds ripen in autumn.

Teresken – Geratodoideseveresmaniana / Satchegl. Ex Losinsk / Botsch.et Ikonn, is a semi-shrub of the Mare family with a height of 60-120 centimetres. It is a valuable fodder plant. In nature, it is widespread on desalinised sands and weakly-medium saline sandy loam and loam areas.

Teresken is absent in the natural vegetation of the dried part of the Aral Sea bed. For phytomelioration purposes, it was introduced on the dried Rybatsky Bay by sowing seeds in the late 1980s (Kamalov, 1995; Kamalov & Aschurmetov, 1998).

Currently there are fruiting individuals here, which, although slow, are spreading out. Fruiting in the fall.

Wormwood sandy, Kum joussan – Artemisia schernieviana Bess, of the Compositae family, characteristic representative of sandy deserts, is a semi-shrub 50-90 centimetres high.

It settled on the dried part of the Aral Sea bed in the early 1990s and we had planted it for the first time on the western part along the weakly fixed sands in the Kabanbai area. It bears fruits in autumn.

Aristida pinnate, Selinum, Urgashy Seleu – Stipagrostis Pennata / Trin / Winter, from the cereals family is a perennial bushy grass, 30-60 centimetres high, a typical representative of slightly saline and desalinised weakly fixed sand dune sands, and a fodder plant.

Selinum settled on the dried part of the seabed in the early 1980s. It is widespread on sand dunes everywhere. The number of adult individuals (families) of selinum in some cases reaches 10-12 specimens/100m2. It bears fruit in summer.

Camelthorn, Yantak, Jantak – Alhagi pseudalnagi / Bieb / Fisch, is a perennial plant of the legume family, 30-80 centimetres in height, a hemixerophyte and phreatophyte. It is widespread in desalinised and slightly saline clay and loam territories, as well as on low-powdered sands underlain by clay soils with slightly saline groundwater. Valuable forage, honey-bearing and medicinal plant. Bears fruit in summer.

For phytomelioration purposes, annual halophilous plants such as Fomin’s swan, bassia, serpentine sorrel and others, which are widespread in the dried part of the Aral Sea bed, can also be used.

The success of phytomelioration of the dried part of the Aral Sea bed and the deserted Amudarya River delta is largely determined by the right choice of seed sowing and planting technology. On clay and loamy areas, seed sowing and planting of plants can be carried out through traditional methods like harrowing, on sand and moisture accumulating furrows. Whereas with sandy soils, maximum precautions should be taken as even a small mechanical impact on the soil can cause large negative phenomena such as intensive deflation, and the aeolian export of saline dust.

Many years of experience in phytoreclamation of deserts show that the autumn months are the most favourable for sowing seeds of the above phytoreclamation agents. When sowing in spring, it is possible to obtain satisfactory results only under certain conditions with sowing seeds subjected to special treatment, such as stratification and scarification. However, the planting of seedlings and cuttings should preferably be carried out in spring, as winter drought in the Aral Sea region contributes to their mass death due to desiccation.

Seeds should preferably be harvested from plants growing on the dried bottom of the Aral Sea. Seeds of plants growing on this territory during their formation undergo the necessary adaptation to the harsh soil and climatic conditions. On the territory of the dried seabed’s areas of the Rybatsky and Adjibay bays, in areas of “French planting”, Akpetkey and Akhantay, and around Djiltyrbas Lake, the necessary amount of seeds of saxaul, cherkez, jugun and other phytomeliorants can be harvested.

6.5.5 Prospective measures to improve phyto- and forest-reclamation works

Cutting of sand furrows. During the examination of the territory, it was found that in early autumn, sand-filled furrows were cut to a depth of 40 centimetres using a furrow-cutting tool with a slotting tool designed by the Laboratory of Protective Afforestation and Forest Reclamation of the Research Institute of Silviculture and Forestry. While simultaneously cutting the furrow, a slot was also cut to a depth of 40 centimetres with the help of the slotting tool. In some places, the same sand-filled furrows were cut but without the crevice. The physical objective of the first variant was that moisture at the expense of winter-spring precipitation was collected in the furrow and penetrated into the slot, forming a reservoir of moisture which the plant could use during the whole vegetation period. Through the second variant, moisture was collected only in a furrow 40 centimetres deep. At the same depth in summer in temperatures of 50 °C, the sand completely dried out, and accordingly all the moisture evaporated, distinct from the first option wherein the main moisture was collected in the available slot. As saxaul has a deep root system, it uses moisture accumulated in the slot, while in the second variant, the saxaul experiences a serious lack of moisture which leads to the death of the plant. At the same time it should be noted that during the planting of seedlings with the help of a planting machine, the coulter strips the sand in the sand furrow to a depth of 30 centimetres, forming a planting slot where the seedling is planted. Studies have shown that in the second year after planting in a furrow with a crevice, the safety of saxaul is 85 percent (plant height of 95 centimetres and crown diameter of 110 centimetres), and in a furrow where the slot has not been made, the safety is over 50 percent (plant height 51 centimetres and crown diameter 64 centimetres). Thus, if moisture is in the upper horizons and in summer and evaporates leading to the partial death of plants, developed technology with the slotter ensures the moisture will be available to plants throughout the growing season. After five years when the plants enter the fruiting stage, the seeds spread throughout the area by wind will accordingly be protected from the deflation processes.

Harvest of forest seeds, their accounting and forecasting

Harvest of forest seeds. Forest seed yield refers to the amount of forest seed produced in a particular year per hectare of plantation.

Forestry authorities should systematically conduct rudimentary phenological observations and seed harvest records to determine the expected yield and organize the harvesting of fruits, strobiles and seeds of trees and shrubs.

Phenological observations and accounting of fruiting are conducted on trial plots, which are established in each category of forest seed plantations intended for harvesting seeds (permanent forest seed plots (PFSP), temporary forest seed plots (TFSP), forest seed plantations, forest cutting plots, and others). For this purpose, all the above categories of forest seed plantations are divided into relatively homogeneous groups of sites in terms of composition, structure, age, growing conditions, and condition, and one sample plot is established in each of them. At the same time, permanent test areas of 0.25 hectare in size are established in the PFSP and forest seed plantations, and temporary areas of 0.1- 0.5 hectare in size are established in other categories, so that each area contains at least 100 trees of the monitored species.

Counting the expected yield of seeds is carried out by determining the numbers of flowers, ovaries, and ripening fruits visible to the naked eye or through binoculars during mass flowering

(Phase I), mass ovary formation (Phase II) and before the beginning of seed ripening (Phase III).

Organization of a permanent forest seed base

A forest seed base is organized to ensure regular procurement of forest seeds with high hereditary and sowing qualities. In forestry, the seed base of highly productive natural plantations and forest crops is selected, as well as specially formed and artificially created forest seed plots and plantations designed for seed harvesting. The seed base in the state forest institutions is organized considering the current need in forest seeds, and the creation of a necessary seed reserve.

The selection inventory is carried out during forest management or special surveys of mature, ripening, deficient and middle-aged stands. Trees are divided into three categories including plus, normal, and minus.

The plus stands are the most highly productive, high quality and stable trees in the given forest and vegetation conditions and are singled out as seed reserves. They are subjected to a continuous selection inventory of plus-size trees. They are not included in the cutting area and are not subject to harvesting. Negative-growth trees are cut down as part of care. The plus-size stands are used to produce seeds of improved selection qualities.

Normal stands are stands of high and medium productivity, being good and average quality for given growing conditions. Seeds can be harvested from plus and normal trees of normal breeding value.

Minus stands are plantations of poor quality, low productivity for the given silvicultural conditions, with a large number of minus trees. It is forbidden to collect seeds from minus stands.

According to the 'Rules of attestation and accounting of selection and genetic objects in areas of the state forest fund', verification of selection and genetic objects, which include plus trees, is performed by a specialised organization which establishes a commission by the order of the management.

Attestation commissions shall determine the compliance of selected objects with the established requirements. Passports with attached schematic plans of their locations are prepared for the certified objects, and information on them is noted in forest management materials and submitted to the state register of plus and elite trees, and included in the consolidated list of plus plantations of the Republic. The certified plus trees in nature are marked on the trunk at the height of 1.3 metres with a ring, 10 centimetres wide, painted in white oil paint. Elite trees are additionally marked with a red ring. The white ring is marked with a double number, with the numerator according to the state register, and the denominator according to the farm.

Forest seed plantations

Forest seed plantations (FSP) are specially created plantations designed for mass harvesting of valuable hereditary seeds of local and introduced species over a long period of time.

A distinction is made between the first and second order of FSP. The first ones are used to breed progeny of plus trees, are selected by phenotype, and not verified by seed progeny. They are created for the evaluation of genetic qualities of the clones presented on them, and for the mass procurement of selection-improved seeds.

Plantations of the second order are created from the seeds of elite trees that have confirmed their genetic value in the test crops.

Permanent and temporary forest seed plots

Permanent forest seed plots (PFSP) are highly productive and of high quality for the corresponding forest types, natural plantations, or crops of known origin (from local seeds). They are specially formed and designed to produce selection-valuable seeds over a long period of time. For their creation, forest plots are selected in normal to more valuable plantations of 1 to 3 assigned growth classes, and in extremely severe conditions, dry and stony forest types, assigned to a 4th growth class.

6.6. Landscape assessment with remote sensing

This chapter of the book describes the assessment of spectral separability of some classes in order to recognise the landscape in the studied area (classes including water, hydromorphic, salinity, sandy soils, vegetation and others). The basic principle of the remote sensing method is the reflectance or absorbance of objects in different spectral ranges. The reflected radiation as a function of wavelength is called the spectral characteristic of the surface. The main purpose of spectral separability estimation is a visual or automatic comparison of spectral brightness curves determining the reflectivity of different groundcover objects. The test sites were selected in the most characteristic areas for the studied landscape.

Water surface, shallow water, sometimes with a cover of reeds (Classes 1 and 2)

Fig. 114 (a, b) shows the averaged values of water reflectance in different spectral bands of Landsa -8 OLI for different months of 2019-2020. As a rule, water is reflected only in the range of visible light (blue, green, red). Since water has almost no reflection in the infrared range (NIR, SWIR; Fig. 114a), water surfaces without any plants will be clearly marked as dark areas (low pixel values) in the images (Fig. 114 c, e). Consequently, in all satellite images, water appears quite different from other surfaces. However, with the appearance of aquatic plants (Phragmites australis, Chara fragilis, Lemna, Potamogéton and others) on the surface of water (Fig. 114 d, f), the reflection coefficient increases in the near infrared range (NIR; Fig. 114 b).

Solonchak (Classes 4 and 5)

The spectral reflectance characteristics of wet-coastal and crust-puffed solonchak are presented in Fig. 115 (a and b, respectively). The value of the spectral reflectance coefficient for both types of solonchak varies during the year depending on moisture content, and in all cases, was maximal in the near-infrared region (NIR). However, the reflectance decreases sharply in the two short infrared wavelengths (SWIR1 and SWIR2) in the marine solonchak class due to the absorption of solar radiation by the wet sands/ground (Fig. 115a). For crusted puffed solonchak, due to the white tint of the salts on the land surface, the coefficients in the SWIR1 and SWIR2 channels vary within the visible spectrum coefficient (Fig. 115b). Therefore, saline soils with a surface salt crust have comparatively higher values of the reflectance coefficient than wet solonchak.

Plain (with shell rocks) and dune sands without vegetation or with sparse shrubs (Classes 8 and 9)

The spectral reflectance characteristics of plain (with shells) and dune sands without vegetation or with sparse shrubs are presented in Fig. 116 (a and b) respectively. The reflection coefficient values are significantly higher in all wave spectra in the plain sand class (Fig. 116a) due to

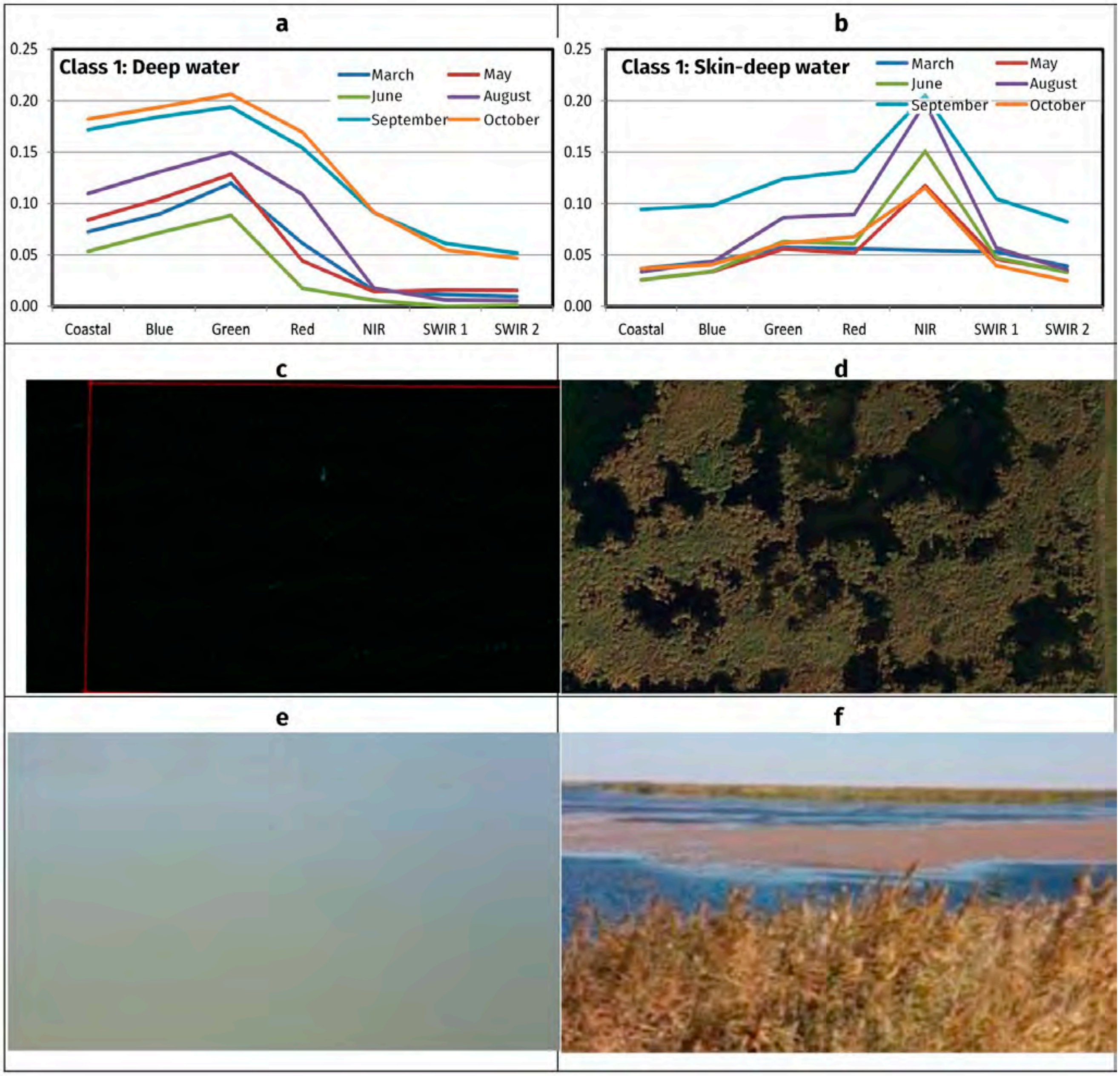


Fig. 114. Water reflectance in different Landsat 8 OLI spectral channels for March-October 2019-2020 without plant coverage (a, c, e; Class 1) and with plants (b, d, f; Class 2)

Note: Images (c, d) are from Google Earth, while photos (e, f) are from field research expeditions in 2019-2020.

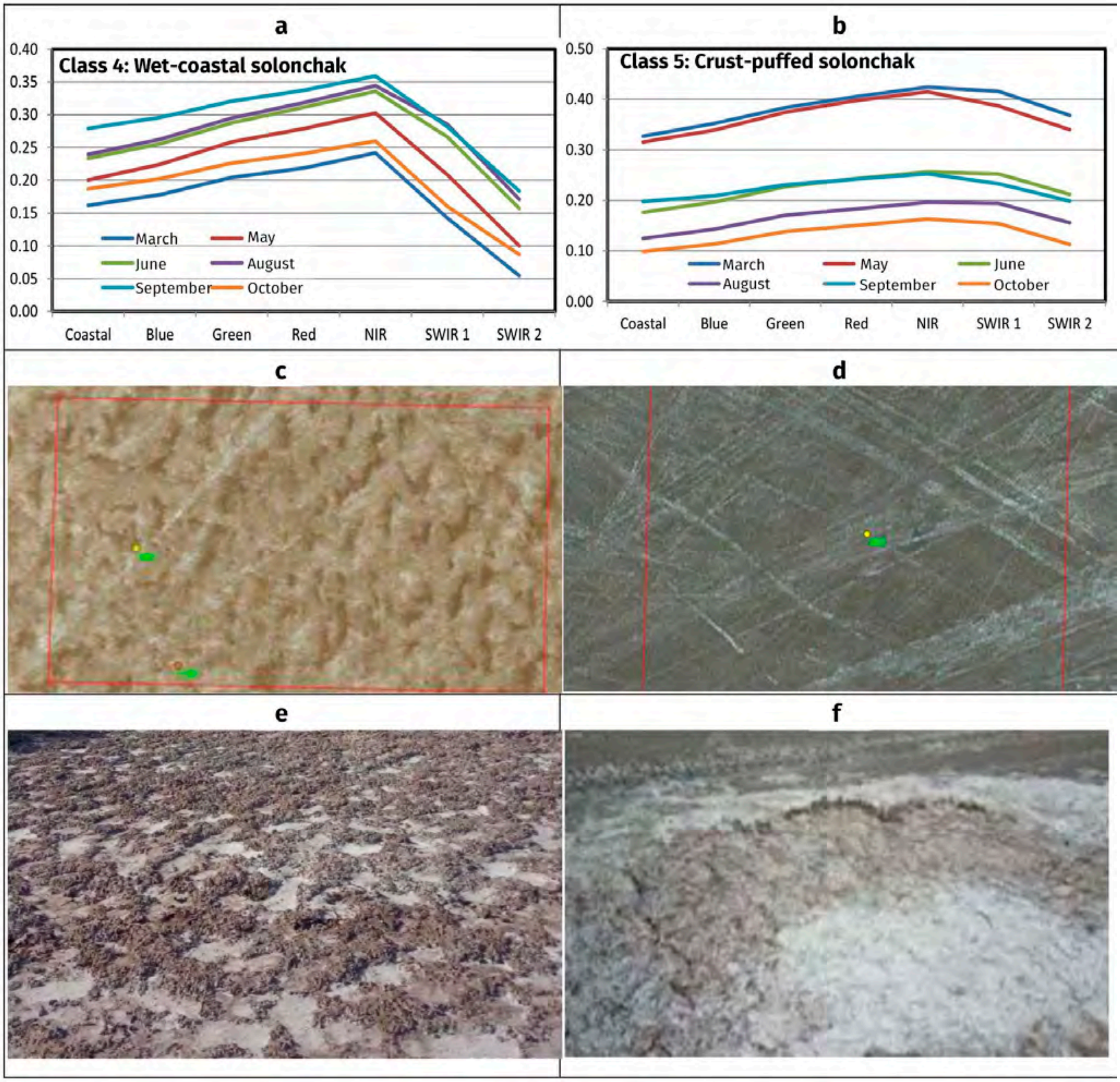


Fig. 115. Reflection coefficient of solonchaks in different Landsat 8 OLI spectral channels for March-October 2019-2020: Wet-coastal solonchak (a, c, e; Class 4) and crust-puffed without plant cover (b, d, f; Class 5)

Note: Images (c, d) are from Google Earth, while photos (e, f) are from field research expeditions in 2019-2020.

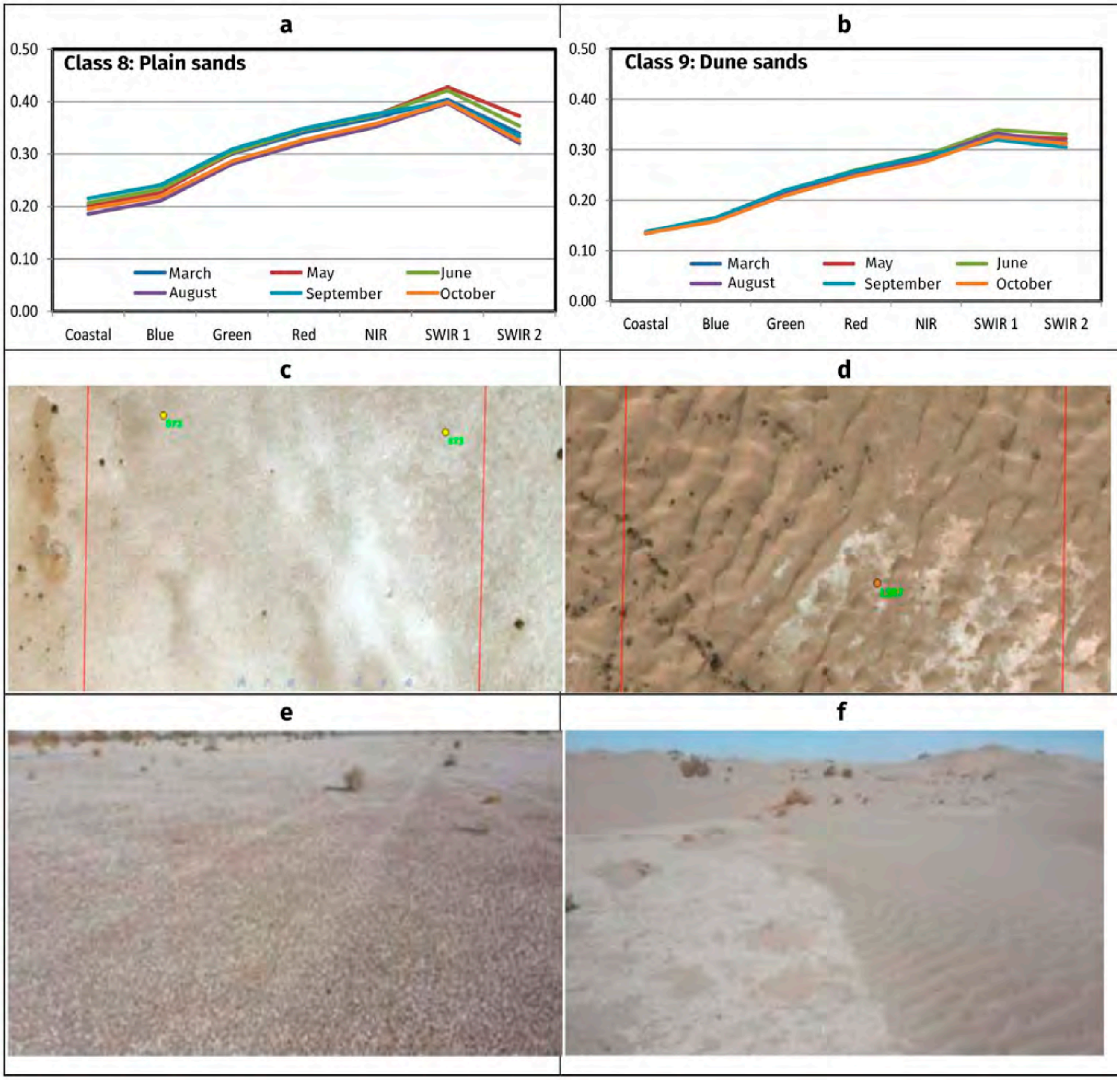


Fig. 116. Reflection coefficient of sands in different Landsat 8 OLI spectral channels for March-October 2019-2020: Plain sands (with shell) (a, c, e; Class 4) and dune sands without vegetation or with sparse shrubs(b, d, f; Class 5)

Note: Images (c, d) are from Google Earth, while photos (e, f) are from field research expeditions in 2019-2020.

the white tint of the shells on the ground surface compared to the dune sands (Fig. 116b). However, these coefficients hardly change throughout the year, especially in the case of dune sands.

Fine bumpy sands (weakly fixed) with sparse communities of wormwood, shrubs and crops (Class 10)

The reflection coefficient curves of shallow hilly sands (weakly fixed) with saxaul and shrub crops are shown in Fig. 117(a) and Fig. 117(b), respectively. The value of the spectral reflectance for the sands with saxaul crops is similar to that for the plain sands (Fig. 117a and Fig. 116a). This is due to the fact that the old French planting of black saxaul (Haloxylon aphyllum Iljin.) is at Test Polygon #33 (Expedition Points in 2019 - T. 619-620), scattered (Sr) with a design cover of 25-35 percent, damaged by powdery mildew and locusts (Fig. 118), solonchak with white calcium salt crystals (limestone) on the surface sands and small shell rocks (4-20 millimetres) in some places. The coefficients of shallow hilly sands with tamarix cover are different and have the form of a polynomial curve (Fig. 117b), which is characteristic of the green plant.

Meadows on alluvial plains (reedy, mixed grass-cereals) and desertifying hydromorphic cereals-halophytic mixed grasses with shrubs (Classes 13 and 14)

The reflection coefficient curves for meadow on alluvial plains (reedy, mixed grass-cereals) and desertifying hydromorphic cereals-halophytic mixed grasses with shrubs are shown in Fig. 119(a) and Fig. 119(b), respectively. Spectral reflectance coefficients for meadow on alluvial plains have two different values: (1) gradually increasing from Band1 (coastal) to Band6 (SWIR1), and slightly decreasing in Band7 (SWIR2). The curves have a polynomial function in March-August (Fig. 119a), associated with coverage by vegetation of low height (15-40 centimetres), at times damaged by animals - Phragmites australis (common reed), Alhagi pseudalhagi (camelthorn), Tamarix hispida Willd. (Tamarix pubescent); (2) Coefficient values change insignificantly in all channels, especially in September-October, curves show presence of moisture, as the site is occasionally flooded (during the visit of the first expedition it was covered with water - 25-30 percent, wet soil - 30-35 percent and plants - 30-40 percent) (quite abundant - Sor1) (Fig. 119d). The desertification coefficients of hydromorphic cereals-halophytic-grasses with reed cover are different and have the form of a polynomial curve (Fig. 119b). This is explained by the fact that the site is located in the southern part of the Muynak pond and is occasionally waterlogged, covered with new, post-fire Phragmites australis (common reed) with a design cover of 80-90 percent (Shora solonchak 3 Fig. 119e).

Desert shrub and shrub-saxaul (desert forests/artificial plantations) (Classes 16 and 17)

The spectral reflectance curves of the desertifying shrub and shrub-saxaul (desert forest/artificial plantations) sites are shown in Fig. 120(a) and Fig. 120(b), respectively. The coefficients for desertifying shrub plants in the near-infrared region (NIR) are significantly lower compared to well-developed shrub/saxaul plants (Fig. 120(a) and Fig. 120(b), respectively). This can be explained by the fact that the area with desertifying shrubs is located in the Takyr area along the Amudarya River, where the soil is sandy-silty and extremely dry. There is a strong drought due to the drying of the Amudarya River, with the present vegetation consisting of Tamarix hispida Willd. (Tamarix pubescent) and Haloxylon aphyllum Iljin. (Black saxaul), with the remaining green being 8-10 percent (Sol) (Fig. 120d). At the

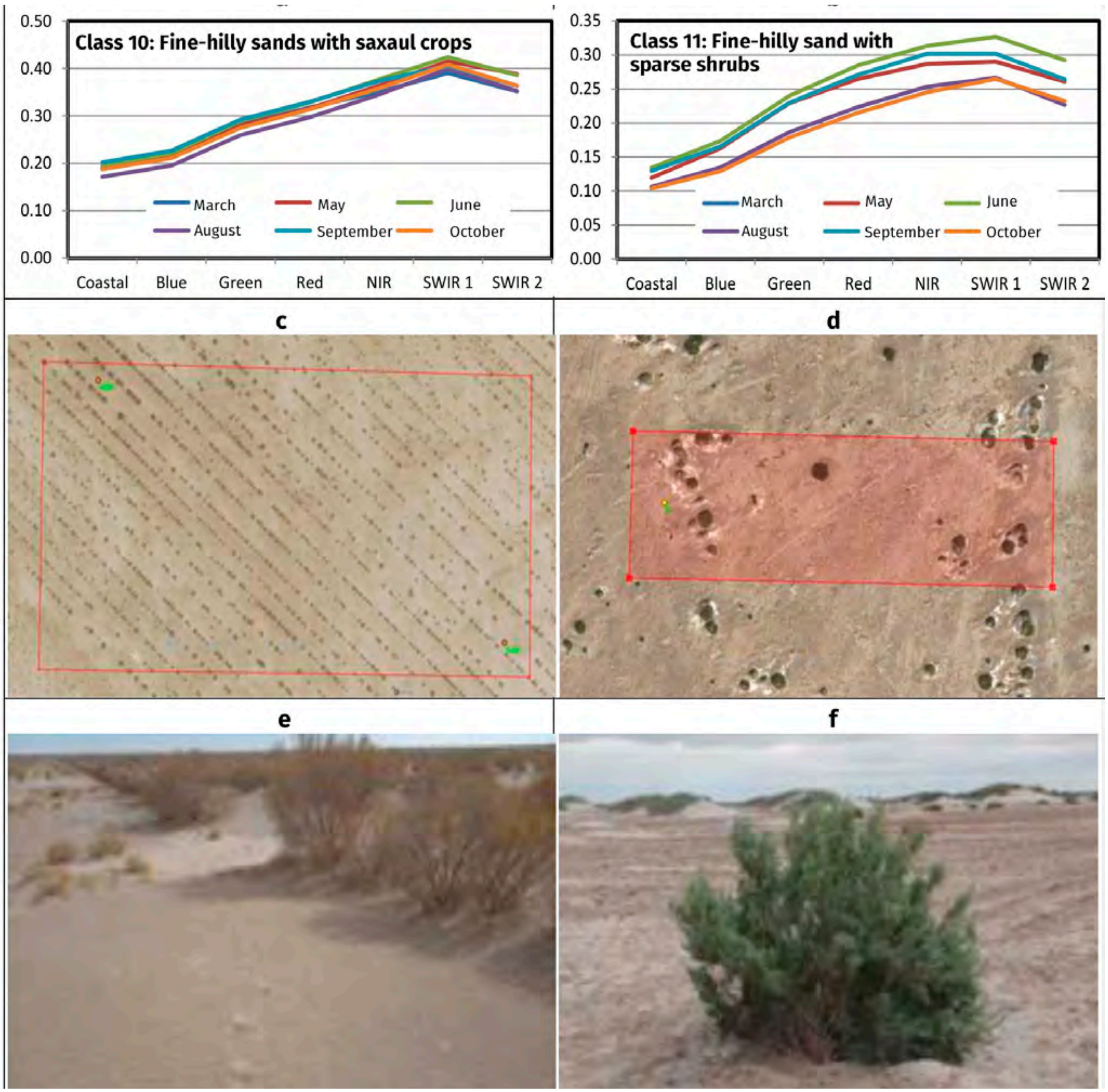


Fig. 117. Reflection coefficient of fine-hilly sands in different Landsat 8 OLI spectral channels for March-October 2019-2020: With saxaul crops (a, c, e) and with sparse shrubs – tamarix (b, d, f)

same time, the shrub-saxaul site has abundant riparian forest cover with Tamarix hispida Willd. (Tamarix pubescent) and Halostachys belangeriana Botsch. (Halostachys belangeriana Botsch.), 90-100 percent (Soc) (Fig. 120e).

Based on this assessment, the German partners from Map Tailor Geospatial Consulting were able to determine which landscapes could be classified based on the images with different spectral characteristics (water, sands, solonchaks and forest), and which objects were similar in parameters, but could be misleading (damaged saxaul, desertifying shrubs, and others). Consequently the more careful selection of reference sites and expert control of automatic interpretation (for instance supervised classification, Chapter 6.7) were carried out.

Sometimes objects with good benchmarks can often be classified falsely in automatic mode, so visual interpretation by specialists is necessary. Therefore field data, GPS points, analysis of Landsat spectral data with differences in reflection coefficients of different objects, and spectral indices were used to model the land cover of the studied area.

Fig. 118. Saxauls damaged by powdery mildew and locustsat Test Polygon # 33.
Expedition Points in 2019 - T. 619-620
(Photo as of 2 October 2019, showing 8-10 dead locustsunder the saxaul bushes)

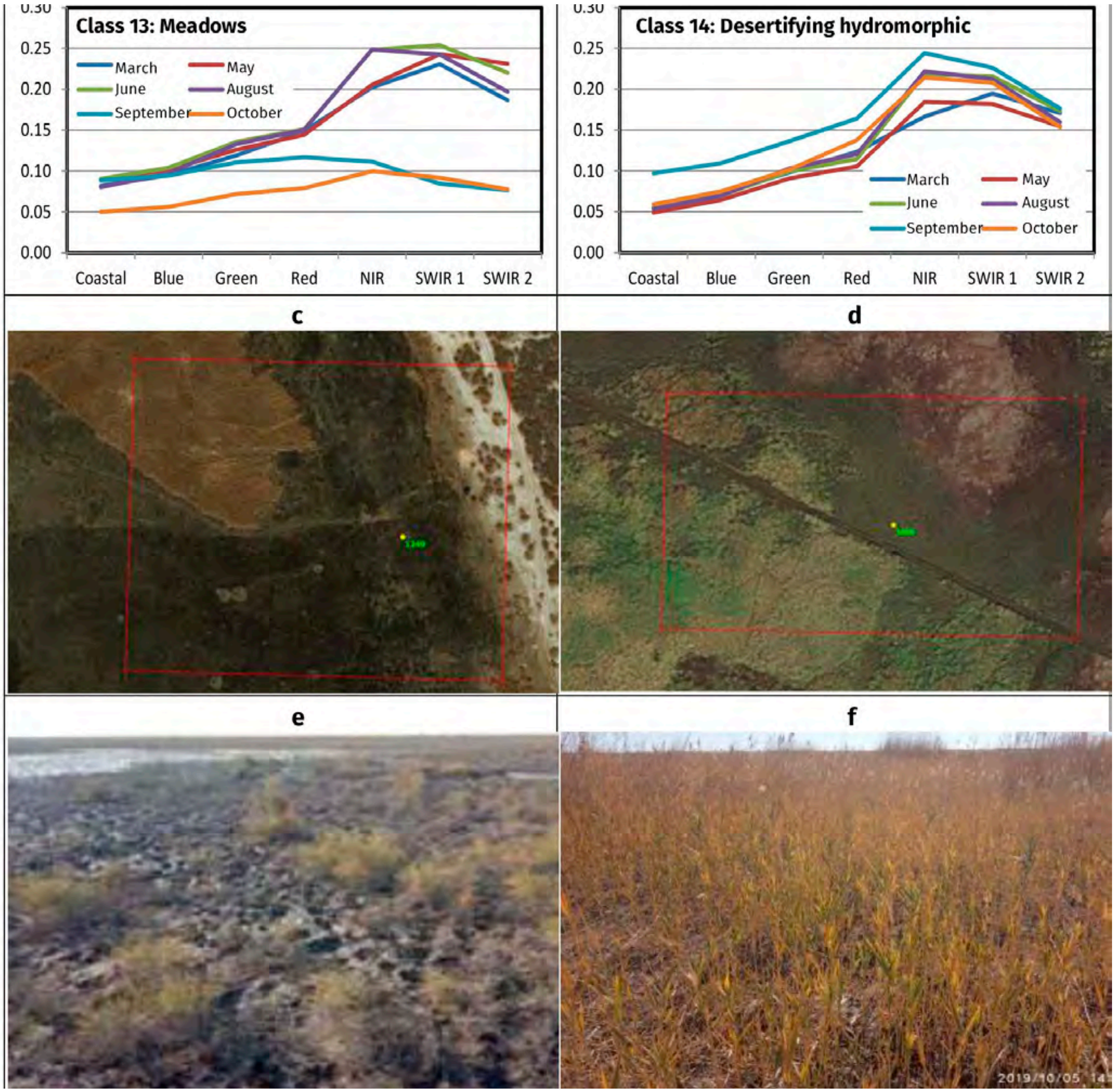


Fig. 119. Reflection coefficient of meadows on alluvial plains and desertifying hydromorphic in different Landsat 8 OLI spectral channels for March-October 2019-2020: With shrubs (a, c, e) and with reeds (b, d, f)

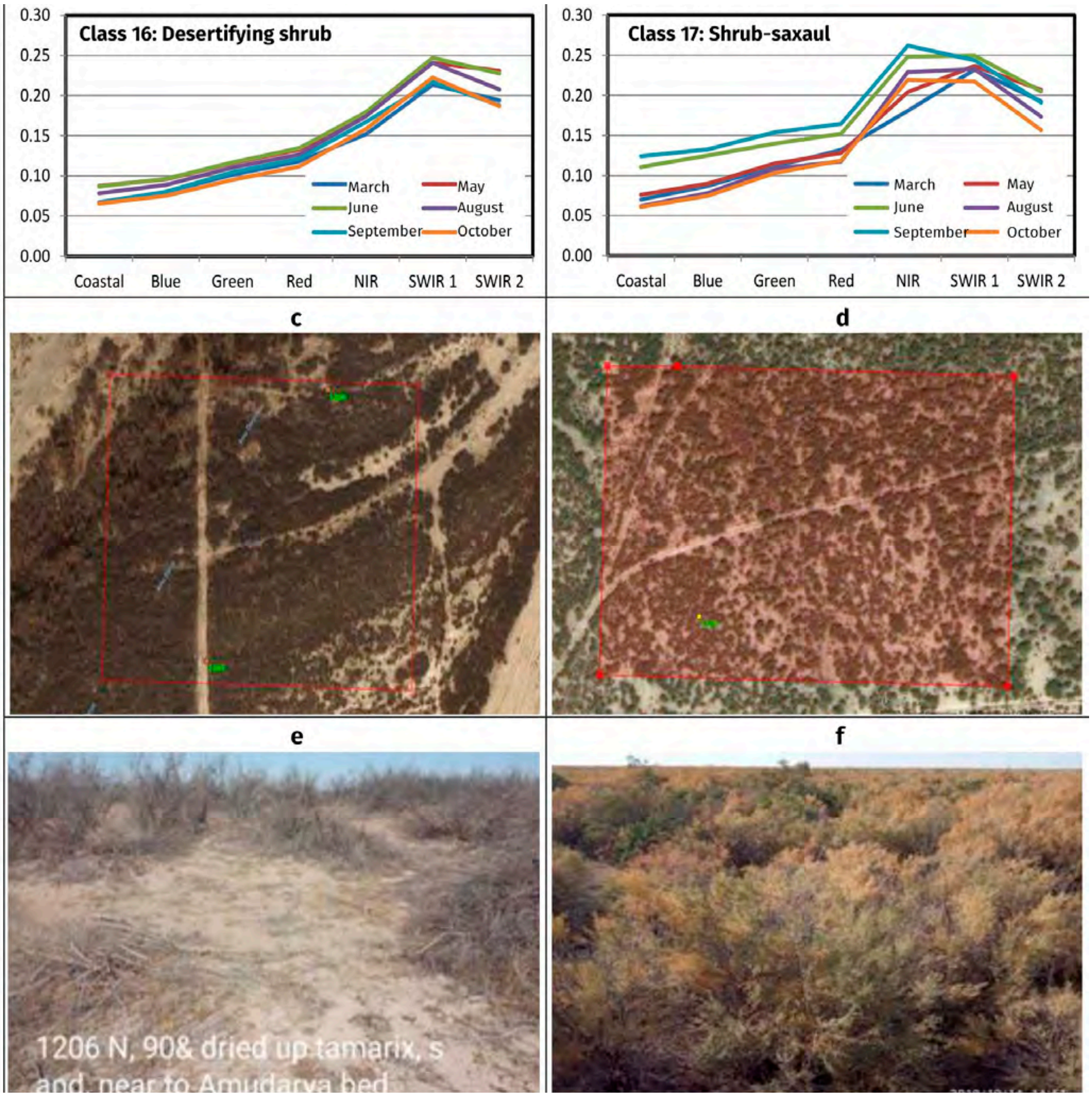


Fig. 120. Reflection coefficient of desertifying shrub and shrub-saxaul thickets in different spectral channels Landsat 8 OLI for March-October 2019-2020:With drying (a, c, e) and with abundant shrub cover (b, d, f)

6.7. Assessment of land cover and soil erosion risks in the Aralkum based on Earth Observation data

6.7.1. Background and purpose of this document

The overall objective of this study is to analyse the landscape change of the Aralkum Desert from 2006 to the research undertaken in 2019-2020. This assessment is based on the analysis of Earth Observation (EO) satellite data. It is accompanied by an assessment of environmental hazard changes in terms of aeolian/wind erosion, one of the main sources of dust storms in the region. The land cover and environmental hazard maps help decision makers plan forest plantings by providing information on erosion risk. This document presents the data, tested methods and gives recommendations for their use. In addition, it provides recommendations and practical conclusions regarding the use of the developed tools not only for defining plantation sites, but also for monitoring them. It should be noted that this paper focuses on the presentation of the data and methodology used to analyse land cover maps based on satellite images.

6.7.2. Research area

In the literature, the surface area of the Aral Sea in 1960 was usually reported as being between 67,000 and 68,000 km2, depending on the data source and the methodology used to estimate the area (Létolle et al., 2007; Micklin, 2010). Estimates based on satellite data (Löw et al., 2013) showed that the landscape changed dramatically in a period of about a decade (2000-2008). While in 2000 the Aral Sea and smaller water bodies covered a huge part of the studied area, by 2008 they had significantly decreased, leaving behind only small water bodies, such as the Rybatsky, Djiltyrbas and Sudochie lakes, which were preserved from drying out due to artificial embankments. The vegetation cover is characterised by the current primary succession on the dried seabed.

The Aral Sea basin is characterised by a highly continental climate with cold winters and hot summers. The average annual temperature in the southern part (at the 'Muynak' weather station in Uzbekistan, 59.02° E, 43.47° N) is 11.7 °C, the annual precipitation is 60 to 140 millimetres, but with high variability. In the northern part (the Aral Sea weather station in Kazakhstan, 61.67° E, 46.78° N) the mean annual temperature is 7.8° C, while the mean annual precipitation is 141 millimetres. Potential annual evaporation rates of 800-1,100 millimetres in the northern part and 1,000-1,300 millimetres in the southern part are characteristic (Breckle et al., 2012).

Technically, the studied area includes two separate polygons in the Uzbek part of the Aralkum Desert, i.e., the Aral Sea shoreline from about 1960 (Fig. 121). These two selected polygons roughly correspond to the area where two field studies were conducted in 2019-2020, respectively (Chapter 6.7.4.1). The area of these two polygons:

- Polygon #1 studied area (visited in 2019), of about 0.65 million hectares.
- Polygon #2 studied area (visited in 2020), of about 0.60 million hectares.

Two polygons of the studied area are shown, with the Landsat 8 image taken in October 2019 shown in the background.

6.7.3. Goals

The main objectives of this study are to:

- Create two land cover maps for 2006 and 2019-2020, respectively;
- Create two environmental risk maps in terms of soil erosion risk based on two land cover maps, and;
- Develop a quantitative assessment of the change in land cover area and the area at risk of erosion based on these maps.

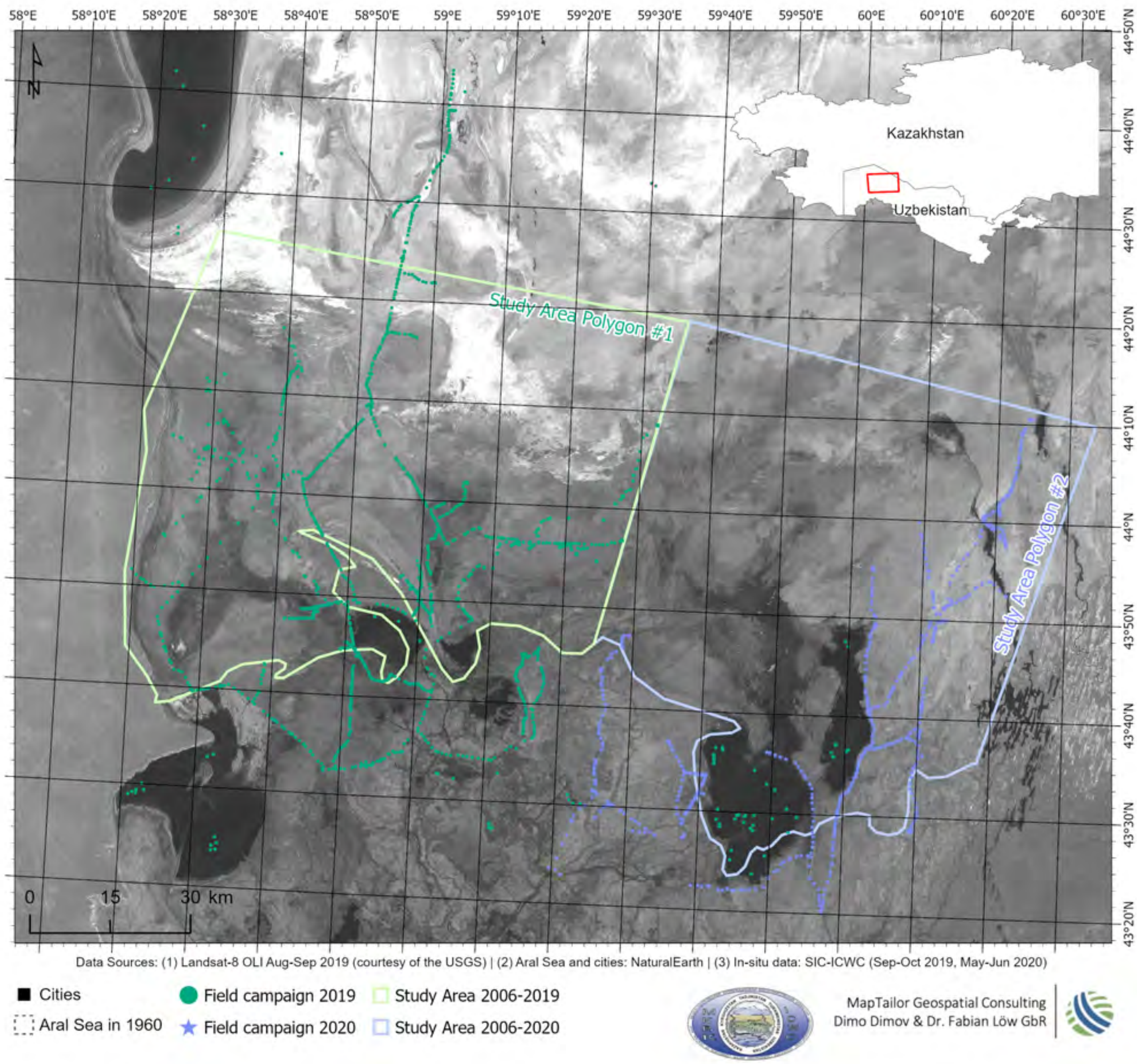


Fig. 121. The Uzbek part of the Aralkum Desert, for instance the area within the Aral Sea shoreline of around 1960

6.7.4. Data sets used

6.7.4.1. Ground control data

The key data set for this study was an exhaustive set of ground control data obtained during field visits to Aralkum. The purpose of this data is to calibrate and validate the algorithms that create land cover maps based on satellite images (see Chapter 6.7.5.3). A team of specialists from SIC ICWC, as well as the International Innovation Center of the Aral Sea Region under the President of the Republic of Uzbekistan (IICP), the Karakalpak Hydrogeological Expedition, and the Institute of Bioorganic Chemistry of the Academy of Sciences of Uzbekistan visited the Uzbek part of Aralkum for the first time in October 2019, and for the second time in June 2020. The team collected information on the land cover at different sampling points (Fig. 122).

Photographs and GPS points were taken at each site. In addition, a complete set of land cover characteristics such as vegetation cover and soil composition or properties were recorded at each sampling point (Tables 31 and 32).

Sampling points contain information on 17 different land cover classes (Tables 31 and 32). More detailed information about the fieldwork and sampling strategy is presented in chapter 5.2.

6.7.4.2. Satellite data

Satellite data is the basis for analysis to create subject-related maps containing information about the land cover of the Aralkum Desert in different years. Images from the Landsat 5 and 8 missions for 2006 and 2019-2020, respectively, were used to create the maps.

For 2019 and 2006 we used 47 and 26 images for 4 Landsat fragments, respectively (tracks 161-162, lines 29-30) from August through October of each year. For 2020 we used 33 images from 4 Landsat fragments (tracks 161-162, lines 29-30). Some fragments only partially covered the two studied zones but were used to fill in the gaps and achieve full coverage within each polygon of the studied zone.

They were processed to obtain surface reflectance and were acquired from the U.S. Geological Survey (USGS) Global Archive and the Earth Resources Observation Center Science Data System (EROS).

The 2019 dataset included Landsat 8 Operational Land Imager (OLI) data. This ready-to-analyse dataset (USGS Landsat 8 Surface Reflectance Tier 1) is an atmospherically corrected surface reflectance from Landsat 8 OLI / TIRS sensors. These images contain five visible and near-infrared (VNIR) bands and two short-wave infrared (SWIR) bands processed to obtain an ortho-rectified surface reflectance image, and two thermal infrared (TIR) bands processed to obtain an ortho-rectified brightness temperature image (Table 12, Chapter 5.4).

The data were atmospherically corrected by the USGS using LaSRC and include a cloud, shadow, water, and snow mask created with CFMASK, as well as a saturation mask of each pixel. The strips of collected data are packaged in overlapping "frames" covering approximately 170 x 183 kilometres of standardised coordinate grid (https://landsat.gsfc.nasa.gov/the-worldwide-reference-system/).

The 2006 dataset included data from the Landsat 5 Thematic Mapper (TM). This ready-to-analyse dataset (USGS Landsat 5 Surface Reflectance Tier 1) is an atmospherically corrected surface reflectance from Landsat 5 TM sensors. These images contain four visible and near-infrared (VNIR) and two short-wave infrared (SWIR) bands processed to produce ortho-rectified surface reflectance, and one thermal infrared (TIR) band processed to produce ortho-rectified brightness temperature images.

The VNIR and SWIR bands have a resolution of 30 metres per pixel. These data have been atmospherically corrected with LEDAPS and include a cloud, shadow, water, and snow mask created with CFMASK, as well as a pixel saturation mask. The strips of collected data are packed into overlapping "frames" covering approximately 170 x 183 kilometres of standardised coordinate grid.

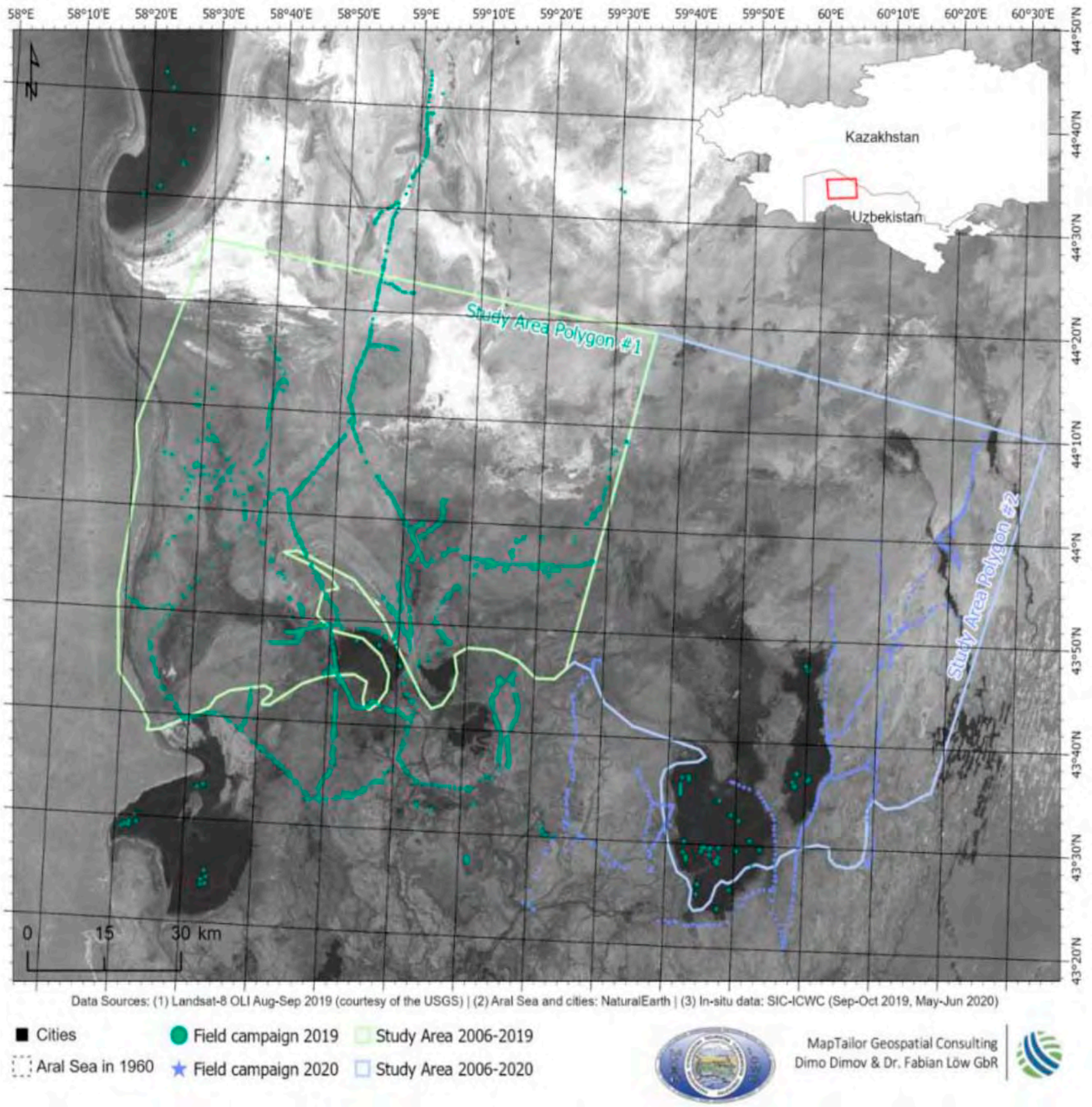


Fig. 122. Sampling points in the southern Aralkum during the two field visits in 2019 and 2020.

Table 31

Summary table, point descriptions 2019

id	27	28
Site ID:	28	29
Date:	22.09.2019	22.09.2019
Time:		
Prepared by:	Zaitov	Zaitov
unsupervised_17class	8	10
Облачность	1	1
местность	S	S
Почва/Литология		
Статус растительности посадка реч.-P, аэросев-S, механич. посев-M, самозарос	N	N
Растение покрытое пылем (да -Y/ нет-N)	N	N
Растение после поджога (да -Y/ нет-N)	N	N
Доминант растительность или массив (ENG/RUS)	1.Haloxylon aphyllum Iljin. (Саксаул чёрный) 2.Tamarix hispida Willd. (Гребенщик опушенный) 3.одно лет трава	1.Haloxylon aphyllum Iljin. (Саксаул чёрный) 2.Tamarix hispida Willd. (Гребенщик опушенный) 3.одно лет трава
Форма (дерево-T/ кустарник -S/ травяной -H)	S	S
Обилие данные ботаника	1.cop32.sp2	1.cop2 2.sp2
Высота доминирующего растения, cm		
Пространственное распростр (непрерывная – Ct/ кусок -Fr)	Fr	Fr
Форма листьев (широколист -BL/ игольчатый -NL / безлистный -A)	NL	NL
Тип ассоциации от ботаника	Джингилово- черносаксауловая	Джингилово- черносаксауловая
Название ассоциации по ярусам от ботаника	1.Haloxylon aphyllum Iljin. (Саксаул чёрный) 2.Tamarix hispida Willd. (Гребенщик опушенный) 3.одно лет трава	1.Haloxylon aphyllum Iljin. (Саксаул чёрный) 2.Tamarix hispida Willd. (Гребенщик опушенный) 3.одно лет трава
Обилие ассоциации по ярусам от ботаника	1.cop3 2.sp2	1.cop22.sp2
Общая покрытия, %	sp, 40-50%	sp, 35-40%
Влажность почвы (визуально сухая -D, мокрая -W, влажная -M)	D	D
Вода (P/DV/WL: устойчивая во время вегет. периода/суточная вариация во вре 0вегет./заболоченная)	P	P
Травянистый (да-Y/ нет-N)	N	N
Пухлая / подвижные пески: (барханы -D/ плоский -F)	F	F
Структура (S/Si/C: песок/ил/глина)	Si	Si
Соли: (C/A/N: корка/накопленный/нет)	N	N
Тип корки: (Sa/Si, No-N) (Sa/Si: соль / ил)	N	N
Редкая вегетация: (древесный -W /травяной -H)		
Искусственно без растительности **(постройки -B**/ нет-NB)	N B	N B
Саранча (да -Y/ нет -N)	N	N
После скотобоя (да -Y/ нет-N)	Y	Y
Другие		
Кол-во фотки в папке	T.028	29
Внутри или наружи авто (да/нет)	28	29

Table 32.

Summary table, point descriptions 2020

Point_id	date	time	gps_id	alt	class	coverage	description
1	31.5	6:20	1596	57.5497	15	30	Dried karabarak (1 photo), jingyl
2	31.5	6:25	1597	57.90842	16	10	Dried karabarak, takyry (1 photo), jingyl
3	31.5	6:28	1598	59.15299	16	7	Dried karabarak (1 photo), jingyl
4	31.5	6:30	1599	57.42653	16	5	Dried karabarak, saxaul, appears jingyl
4a	31.5	6:34	1600	54.83256	16	10	Tamarix drying out, trampled by cattle
5	31.5	6:45	1601	56.22124	14	70	Yantak, jingyl, green
6	31.5	6:47	1602	55.1508	16	10	Dried tamarix, salted
7	31.5	6:49	1603	57.39928	16	7	Dried tamarix, salted
8	31.5	6:50	1604	53.75542	16	10	Dried tamarix, salted
9	31.5	6:52	1605	56.4446	16	15	Dried tamarix, salted. saxaul rare
10	31.5	6:54	1606	57.02411	16	15	Dried tamarix, salted
11	31.5	6:57	1607	50.52042	15	25	Karabarak, sveda dries out, tamarix 60-70 cm, takyr soil
12	31.5	7:04	1608	51.46349	15	18	Karabarak, sveda dries out, tamarix 60-70 cm, takyr soil
13	31.5	7:16	1609	56.68664	5	5	Saline soil
14	31.5	7:20	1610	55.36214	17	40	Jingyl, turangul (tree), takyrs, sands
14a	31.5	7:25	1611	53.29633	17	40	Jingyl, turangul (tree), takyrs, sands
15	31.5	7:35	1612	55.53936	16	7	Salted, tamarix, isyricum
16	31.5	7:37	1613	50.78876	16	15	Tamarix tall
17	31.5	7:40	1614	50.4669	15	48	Amber, tamarix green
18	31.5	7:43	1615	51.37117	13	80	Amber, reed, wet soil, covered with grasses
19	31.5	7:45	1616	51.70303	14	60	Yantak, reed, jingyl, climacoptera grasses
20	31.5	7:53	1617	49.47135	15	30	Tamarix after the fire, reeds
21	31.5	7:55	1618	50.68083	15	30	Tamarix, reed, amber
22	31.5	7:57	1619	48.82779	15	40	Tamarix, reed, amber
23	31.5	7:58	1620	51.75824	15	45	Tamarix, reed, amber

Table 33.

The notation of classes according to field data and the degree of ecological hazard assigned to each land cover class. Distribution of land cover classes according to the degree of ecological hazard, namely the degree of erosion risk (Dukhovny et al., 2008)

Class ID	Description	Ecological hazard level	Number of sampling points (1st expedition, October 2019)	Number of sampling points (2nd expedition, June 2020)
Water				
1.1 (1)	Water surface	II	25	2
1.2 (2)	Shallows, sometimes with reeds	II	10	10
Solonchak				
2.1 (3)	Marsh without vegetation or with Saltwort communities	I	1	0
2.2 (4)	Wet coastal with seashells, sometimes with isolated specimens of sarsazan and saltwort	I	0	0
2.3 (5)	Cork-puffed and cork without vegetation, sometimes with single specimens of shrubs (karabarak, tamarix)	III	40	15
2.4 (6)	Solonchak with overblown sandy cover with sparse swan and selinum communities	IV	162	34
2.5 (7)	Saltwort solonchak of closed depressions without vegetation, sometimes framed by sarsazanites	I	3	7
Sands				
3.1 (8)	Plains (with shell rocks) without vegetation or with sparse shrubs (saxaul, tamarix)	IV	89	51
3.2 (9)	Dunes without vegetation	IV	2	8
3.3 (10)	Shallow-hilly (weakly fixed) with sparse communities of wormwood, shrubs, and selinum crops	IV	20	47
3.4 (11)	Hilly and hilly-ridgy without vegetation and weakly fixed.	III	33	4
3.5 (12)	Hilly, hilly-ridgy fixed with ephemeral wormwood-shrub communities	II	303	66
Deltaic and accumulative plains				
4.1 (13)	Meadows on alluvial plains (reedy, mixed grass-cereals) on alluvial-meadow, swamp-meadow and meadow-bog soils	I	2	30

Class ID	Description	Ecological hazard level	Number of sampling points (1st expedition, October 2019)	Number of sampling points (2nd expedition, June 2020)
4.2 (14)	Deserted hydromorphic cereal-halophytic-grasses with shrubs	II	118	34
4.3 (15)	Shrub thickets (halophytic: tamarix, karabarak)	I	280	126
4.4 (16)	Desert shrublands	III	274	80
4.5 (17)	Shrub/saxaul (desert forests/artificial plantations)	I	54	18

6.7.5. Methods

The methodology consists of several successive steps. First, ground control data were prepared (Chapter 6.7.5.1) and some pre-processing had to be applied to the satellite images (see Chapter 6.7.5.2). The classifier algorithm was then calibrated based on the prepared ground control data and the pre-processed images, and land cover maps for 2006 and 2019/2020 respectively, were created (Chapter 6.7.5.3). Two land cover maps were translated into designated ecological risk areas (Chapter 6.7.5.4). Finally, an accuracy assessment was carried out to assess the quality of the maps, as well as a quantitative assessment of the land cover and ecological risk zones for both years of observation based on the maps (Chapters 6.7.5.5 and 6.7.5.6).

6.7.5.1. Pre-processing of ground control data

The final class conventions used in the mapping consisted of 10 instead of 17 classes (Table 34). Some classes, such as plain, dune and shallow hilly (3.1, 3.2 and 3.3), contain land cover characteristics that cannot be uniquely distinguished on satellite images. As a consequence, their spectral signatures looked very similar and initial tests showed that the classifier algorithms could not distinguish some classes well enough. Therefore, we combined several of the classes (Fig. 123). In addition to the ground survey benchmark data, additional selection points were taken for some classes on the screen because it was difficult to enter these landscapes during the 2019-2020 expeditions: Water/1.1., Shallow Water/1.2. and Marsh Soils/2.1.; this was done through the visual interpretation of Landsat imagery. Some drop-off points or samples that were represented by mixed pixels were removed. In addition, wet-soil/2.2 class locations were not available and could not be highlighted on the screen, and as a result this class was skipped.

At the same time, despite a large set of ground and screen samples, the total data set was partially unbalanced. For instance, the number of control locations by land cover classes was unevenly distributed. This is explained by the fact that the area was not completely accessible.

In the context of supervised classification, unbalanced calibration samples are often compensated by adding more elements (oversampling) or by removing elements (under-sampling) from a sample, to obtain a more balanced set of calibration data. In this study, the R software (in the DMwR package, version 0.4.1) applied a method of resampling synthesised minorities (SMOTE) (Chawla et al., 2002) to create synthetic calibration samples for a smaller class so that the training class fraction

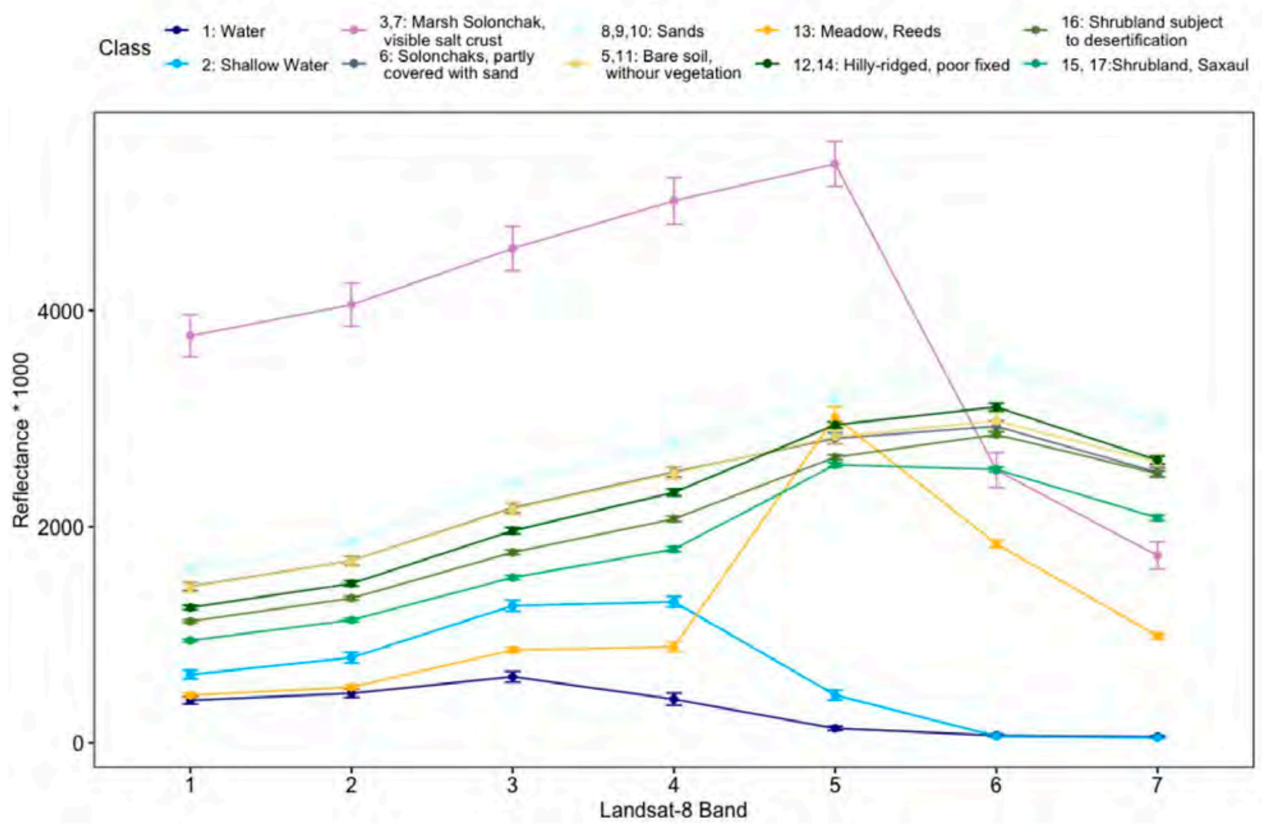


Fig. 123. Multispectral land cover class signatures in the 2019 ground control data and Landsat 8 OLI images from October 2019

takes their native location into account. The basic idea of SMOTE is to artificially generate new samples of the smaller class using bootstrapping and k-nearest neighbours. As a hybrid method, SMOTE offers both over-sampling of the smaller class and under-sampling of the larger class.

The final number of samples is shown in Table 34.

6.7.5.2. Satellite imagery pre-processing

The percentage of areas for each image affected by cloud cover or cloud shadow (pixels without data) was calculated based on the mask function (Fmask) algorithm (Zhu & Woodcock, 2012), which combines cloud cover and cloud shadow areas into a separate class. Images with the percentage of pixels without data greater than 90 percent and images without orthorectification, based on their metadata, were skipped (not loaded).

Clouds and haze were subsequently removed by evaluating data quality assessment layers (which contain pixel quality attributes generated by the CFMASK algorithm) in Landsat Level 1 products. Pixels marked as (i) cloud shadow, (ii) cloud and (iii) high confidence cloud and pinnate clouds were removed.

The median reflectance band values for each observation year (2006 and 2019/2020) were then calculated for two periods including (i) Period-1 from May to July, and (ii) Period-2 from

Table 34.

Final land cover map conventions, the land cover maps contain 10 classes, and the number of samples represents the final sample after various cross-checks

Source ID of the classes	New ID	Description	The number of ground points and locations on the screen in 2019 and 2020 together	Number of SMOTE sample points in 2019 and 2020 together
1.1 (1)	1	Water surface	48	112
1.2 (2)	2	Shallows, sometimes with reeds	22	132
2.1 (3), 2.5 (7)	3	Marsh and shora solonchak soils without vegetation or with communities of saltwort, partially visible salt crusts	44	127
2.4 (6)	6	Solonchak with overblown sandy cover with sparse swan and selinum communities	196	566
3.1 (8), 3.2 (9), 3.3 (10)	10	Plains (with shell rocks) without vegetation or with sparse shrubs (saxaul, tamarix), dunes without vegetation, shallow hilly (weakly fixed) with sparse communities of wormwood, shrubs and selinum crops	180	600
2.3 (5), 3.4 (11)	11	Crusty-puffy and crusty without vegetation, sometimes with isolated specimens of bushes (karabarak, tamarix), hilly and hilly-ridgy without vegetation and weakly fixed	92	247
4.1 (13)	13	Meadows on alluvial plains (reedy, mixed grass-cereals) on alluvial-meadow, swamp-meadow and meadow-bog soils	58	139
3.5 (12), 4.2 (14)	14	Hilly, hilly-ridgy fixed with ephemeral wormwood-shrub communities, desertifying hydromorphic cereals-halophytic grasses with shrubs	521	1,416
4.4 (16)	16	Desert-bushy	354	1,001
4.3 (15), 4.5 (17)	17	Shrubby thickets (halophytic: tamarix, karabarak), shrubby saxaul (desert forests/ artificial plantations)	478	1,292

Table 35.

Landsat strips and derivatives used to create maps of land cover - each set of derivatives was calculated twice, once for Period-1 from May to July, and again for Period-2 from August to October

Title	Description	Number of derivatives (2 periods)	Links
Landsat B1-B7 multispectral bands	• Median values of reflectivity for two periods	6 * 2	
Tasselled Cap Indices	• Luminance level median values over two periods • Green level median values over two periods • Median values of humidity for two periods	3 *2	(Kauth and Thomas, 1976)
Normalized Relative Vegetation Index (NDVI)	• Median values of NDVI for two periods • Minimum values of NDVI for two periods • Maximum values of NDVI for two periods • Standard deviation of NDVI values for two periods	4 *2	(Rouse et al., 1974)
Spectral finite elements	• Median values of bare soil by two periods • Median values of vegetation by two periods • Median values of water by two periods	3 *2	(Bullock et al., 2020)

August to October. In this way, gaps resulting from previous cloud masking were temporarily filled (Griffiths et al., 2019).

Landsat data have multispectral bands that allow differentiation of different land cover classes. To increase the degree of class separation, a complete set of the following derivatives from satellite images (predicator variables for the classifier algorithm) was calculated:

Landsat multispectral bands

To have comparable input data for supervised image classification, only the multispectral bands that exist in both TM and OLI sensors were retained, including blue, green, red, near-infrared, and two shortwave infrared bands (6 bands).

Tasselled Cap

The Tasselled Cap Transformation (TCT) is a method commonly used in land cover mapping or other classification projects (Kauth & Thomas, 1976). It uses a linear combination of satellite imagery bands and a specialised coefficient matrix to create an n-band image with the first three bands containing most of the useful information, similar to the Principal Component Method. The first three bands created usually represent brightness, green level and humidity. The coefficient matrix (Baig et al., 2014) (Crist & Cicone, 1984), which is unique to each sensor, is based on image statistics and empirical observations.

Normalized Relative Vegetation Index

The Normalized Relative Vegetation Index (NDVI) is an index of plant green mass or photosynthetic activity and is one of the most commonly used vegetation indices (Rouse et al., 1974). Vegetation indices are based on the observation that different surfaces reflect different types of light differently. Specifically, photosynthetically active vegetation absorbs most of the red light hitting it, while reflecting most of the near-infrared light. Vegetation that is dead or under stress reflects more red light and less infrared. Similarly, surfaces without vegetation have a much more uniform reflection coefficient across the entire light spectrum. By taking the ratio of red to near-infrared from a remotely sensed image, we can determine the greenness index of the vegetation. The Normalized Relative Vegetation Index (NDVI) is probably the most common of these ratios for vegetation.

NDVI is calculated on a pixel-by-pixel basis as the normalised difference between the red and near-infrared bands of the image:

$$NDVI = \frac{NIR - RED}{NIR + RED}$$

Where

NIR is the value of the near-infrared range

for the cell,

RED is red range value for the raster cell.

Spectral finite elements

Multiple Endmember Spectral Mixture Analysis (MESMA) is a method for estimating the proportion of each pixel covered by a series of known cover types – in other words, determining the likely composition of each pixel in an image (Dennison & Roberts, 2003). Pixels containing multiple cover types are called mixed pixels. "Pure" pixels contain only one feature or class. For example, a mixed pixel may contain vegetation, bare soil and soil crust. Subpixel analysis methods determine the constituent parts of mixed pixels by predicting the fraction of a pixel that belongs to a particular class or feature based on the spectral characteristics of its final elements. Brightness is converted into fractions of spectral end members that correspond to features on the ground.

Spectral finite elements are "pure" spectra corresponding to each of the land cover classes. Ideally, the spectral finite elements make up most of the spectral variability of the image and serve as the basis for determining the spectral composition of mixed pixels. Thus, the definition of land cover classes and the selection of suitable finite elements for each of these classes play a major role in MESMA. Finite elements derived from the real image are usually preferred, since in this case no calibration between the selected finite elements and the measured spectra is needed.

In this study, the following three general classes of land cover were defined as finite elements:

- Vegetation
- Bare soil
- Water

The multispectral signatures that define the end elements are derived by selecting pixels from the 2019 Landsat images and using GPS ground control data (Chapter 6.7.4.1).

6.7.5.3. Creating land cover maps

We used the Random Forest (RF) classifier (Breiman, 2001) in the "R" programming language (implemented in the "Random Forest" package, version 4.6-14) to classify input data (see previous chapter) and map land cover classes. RF generates a set of decision trees by constructing random samples with substitutions from the training data and determining the best partition at each node of the decision tree, considering the maximum number of randomly selected features (maximum attributes). We tested different parameter ranges for a number of trees and the maximum number of features and finally used 200 trees and 10 percent of the input features considered in each partitioning to parameterise the RF classification models. We trained the RF model for the combined input data for 2019 and 2020 to improve the accuracy of the maps. We then applied the calibrated model to classify the input data in 2006, 2019 (Polygon #1 only), and 2020 (Polygon #2 only) to create land cover maps for these two years.

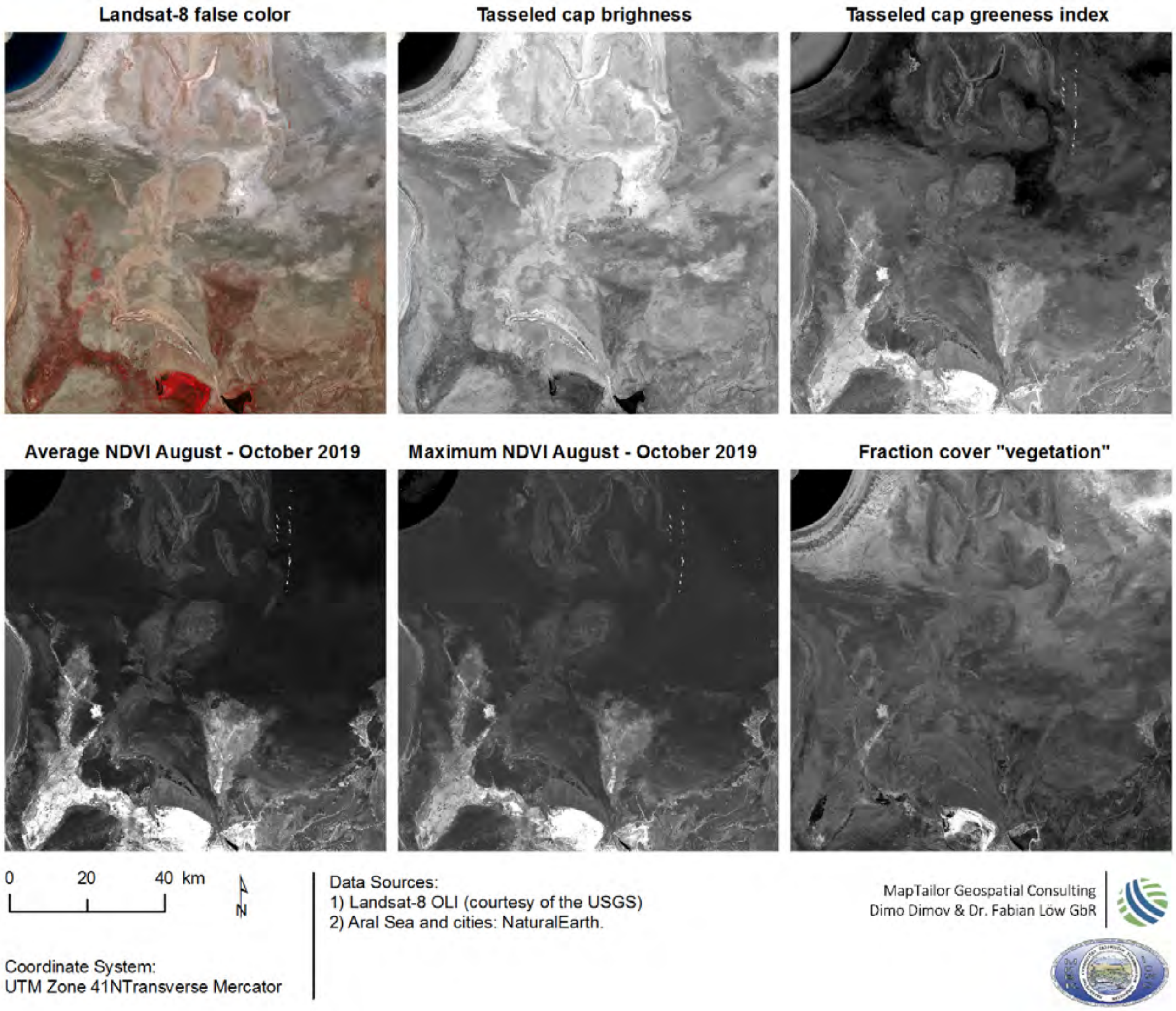


Fig. 124. Examples of calculation of some input features for land cover maps

6.7.5.4. *Creating environmental risk maps*

Environmental risk was defined as the risk of soil erosion, according to a previous study (Dukhovny et al., 2008). To map the risks the land cover classes were classified into four different risk classes (Table 33).

6.7.5.5. *Accuracy assessment*

Quality, defined as the accuracy of land cover maps, was assessed using standard imprecision matrices (Congalton, 1991). Control data (Chapter 6.7.5.1) were used to assess the overall accuracy of classification and classification by class. The main goals of the validation are to provide a brief assessment of the accuracy of each mapping product. Following the standard computation-based approach, the classification maps are validated by calculating inaccuracy matrices (the 'error matrix' as show in Table 36) (Congalton, 1991; Foode, 2002). This is a feature-conjugation matrix (where m is the number of classes) between a random sample of field indicators (which should be more reliable than the classification and thus considered true values) and the corresponding classified pixels.

The common element of the matrix n_ij is the number of pixels with correct class i and class on map j, and the frequency of ground observations and observations on the map are given by the edge values of rows and columns, respectively. Using the error matrix, various values can be calculated to estimate the classification accuracy:

- Overall accuracy (OA) (the share of correctly classified pixels) is calculated by dividing the sum of the values on the main diagonal by the total number of pixels:

$$OA = \frac{\sum_{i=1}^{m} n_{ii}}{n}$$

- Constructor accuracy (PA, skip errors) for each class is calculated by dividing the diagonal element by the total number in the row and gives for each class the probability of correct classification, and its complement, the weight of off-diagonal elements, is the skip error (the proportion of that class that is not mapped):

$$PA = \frac{n_{ii}}{n_{i+}}$$

- • The user accuracy (UA, validity errors) for each class is calculated by dividing the diagonal element by the total number in the column and gives, for each class, the probability

Table 36.

Elements of the inaccuracy matrix

		Prediction (e.g., map classification)				
Validation (e.g., ground control)	Class	1	*j*	*i*	*m*	Sum.
	1	n_{11}				
	i		n_{ij}			$n_{(i+)}$
				n_{ii}		
	m				n_{mm}	
Total	n_{+j}					n

that a pixel on the map actually represents that category on the ground. Its complement is the validity error (points misclassified in that class):

$$UA = \frac{n_{ii}}{n_{+j}}$$

- The F1-measure is also calculated for each class. It is a weighted average between Accuracy and Completeness. Accuracy is the ratio of correctly predicted positive observations to the total number of positively predicted observations. High Accuracy refers to the low proportion of incorrectly predicted positive observations (i.e., false positives). In turn, Completeness (sensitivity) is the ratio of correctly predicted positive observations to total observations in the actual class.

6.7.5.6. Assessment of land cover area

The most direct method for estimating land cover area from a classified image is based on multiplying the number of pixels in maps classified as one class by the pixel size. It can be recommended as a standard methodology for estimating area in a monitoring tool, and it is almost the only one practiced in remote sensing (RS) (FAO, 2015). However, discrepancies can occur in area estimation due to omissions or map errors (Gallego et al., 2008). To estimate the proportion of land cover classes, the map was re-projected to UTM-40N.

6.7.6. Results

The description of the results is broken down into three areas: (i) the quality (accuracy) of the land cover map in 2019, (ii) land cover status and change between 2006 and 2019, and (iii) associated changes in environmental risk areas (in terms of erosion risk). Note that the results are focused on the Uzbek part of the Aral Sea, considering its original size in 1960.

6.7.6.1. Evaluation of the accuracy of the random forest classifier

An evaluation of the accuracy of the 2019 land cover map showed that the overall classification accuracy was 0.88 (lower confidence limit 0.87, upper confidence limit 0.89).

According to the F1 measure, the most accurately mapped land cover categories were Class-1: water (0.98), Class-13: grassland/reeds (0.91), Class-3: marsh and shora solonchak soils (0.98), and Class-2: shallow water. The least accurately identified classes were Class-10: Plains (0.84) and Class-11: Desert Crusty-Puffy and Crusty Soils.

According to the inaccuracy matrix (Table 38), Class-14: hilly, hilly-ridgy weakly fixed, Class-16: desertifying shrublands, and Class-17: shrub thickets, are often mislabelled by the RF classifier. According to field sampling, all classes are characterised to some degree by the presence of shrubs. As for the composition of these classes (vegetation, soils), smooth transitions exist between classes, making it difficult for the classifier model to make a clear distinction.

Overall, the accuracy assessment shows that the quality of the maps is high.

6.7.6.2. Classification of land cover

Two annual land cover maps with ten land cover classes in each were created, one for 2006 (Fig. 125) and one for 2019 (Fig. 126). When comparing the two maps, the drying of the eastern part of the Aral Sea becomes apparent. In 2006 shallow water covered the eastern part, but by 2019 the water had almost completely receded, leaving behind a salt desert consisting mostly of marsh and shora solonchak and other solonchak soils. The western water body was affected to a lesser extent, and a narrow strip of marsh and shora solonchak emerged near the eastern shore of the western Aral Sea.

Table 37.

Evaluating the accuracy of the random forest classifier model based on the combined 2019/2020 benchmark data

Accuracy measure	1: Water	10: Plains	11: Crusty puffy and crusty without vegetation	13: Meadows/ Reeds	14: Hilly, hilly-ridgy, weakly fixed.	16: Desert shrublands	17: Shrubbery, thickets	2: Shallow water	6: Solonchaks	3: Marsh and shora solonchak soils
User Accuracy	1.00	0.85	0.89	0.94	0.87	0.86	0.85	1.00	0.90	0.98
Builder accuracy	0.97	0.84	0.76	0.89	0.88	0.86	0.87	0.86	0.91	0.97
F1	0.98	0.84	0.82	0.91	0.87	0.86	0.86	0.93	0.91	0.98

Table 38.

Inaccuracy matrix to estimate the accuracy of the random forest classifier based on the combined control data for 2019/2020

	Control										
Prediction	**Classes**	**1**	**10**	**11**	**13**	**14**	**16**	**17**	**2**	**6**	**3**
	1	59	0	0	0	0	0	0	0	0	0
	10	0	233	9	1	12	5	7	0	7	0
	11	0	0	90	0	1	0	5	1	4	0
	13	0	0	0	63	4	0	0	0	0	0
	14	2	20	10	0	650	21	42	0	6	0
	16	0	13	2	1	23	423	25	2	3	2
	17	0	8	1	6	40	43	572	3	3	0
	2	0	0	0	0	0	0	0	57	0	0
	6	0	5	6	0	7	0	5	3	243	0
	3	0	0	1	0	0	0	0	0	0	65

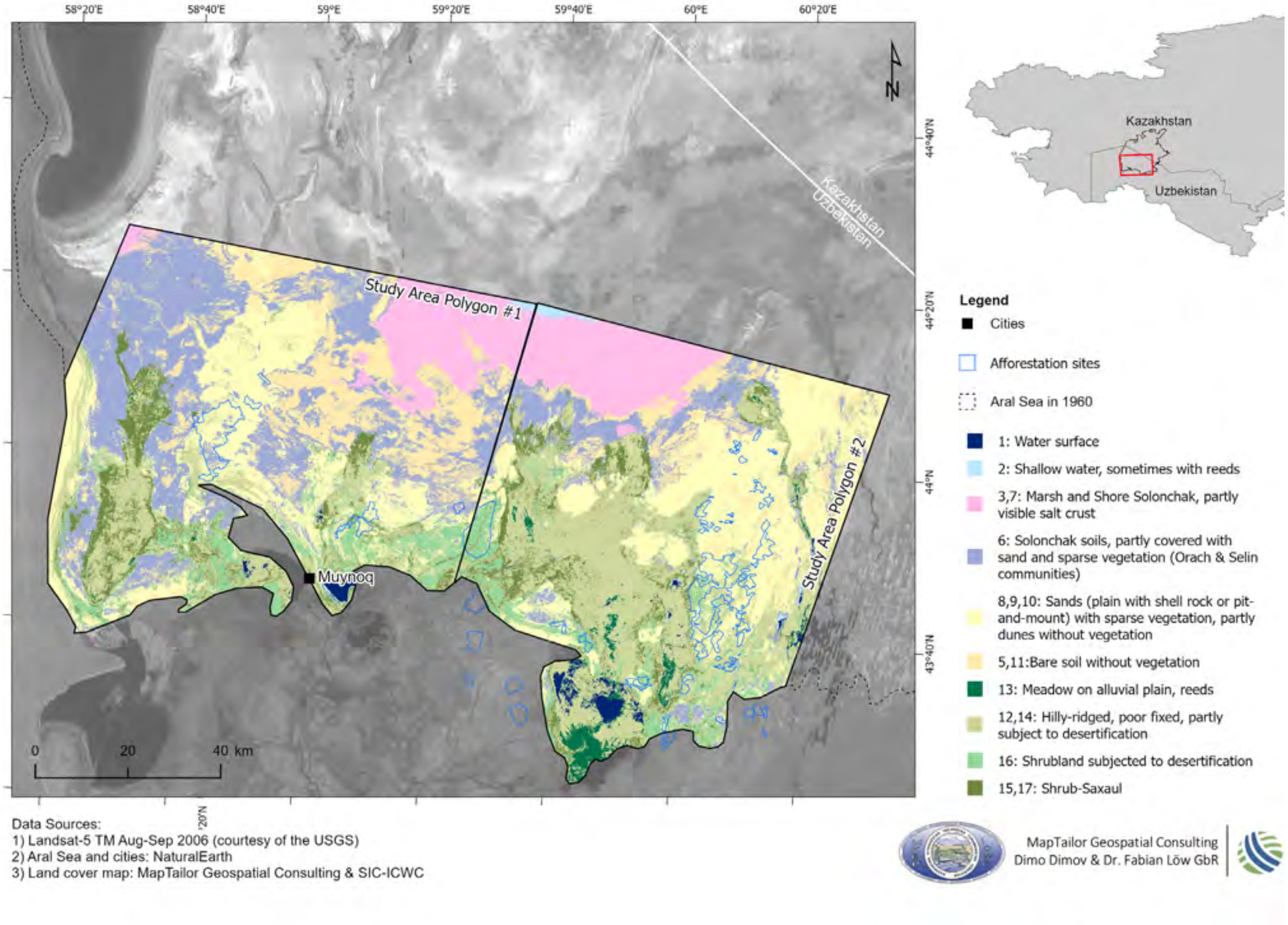


Fig. 125. Land cover in Aralkum in 2006

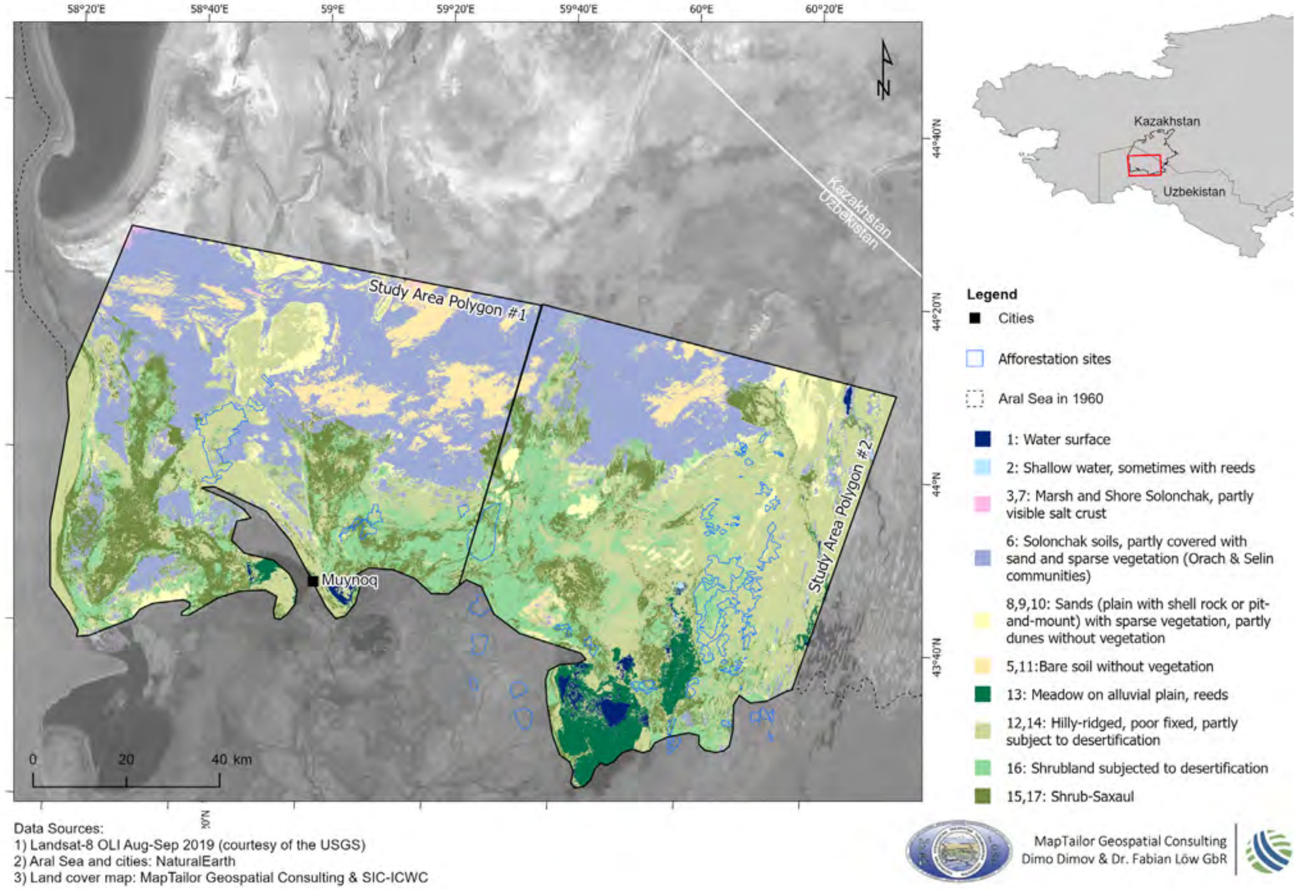


Fig. 126. Land cover in Aralkum in 2019

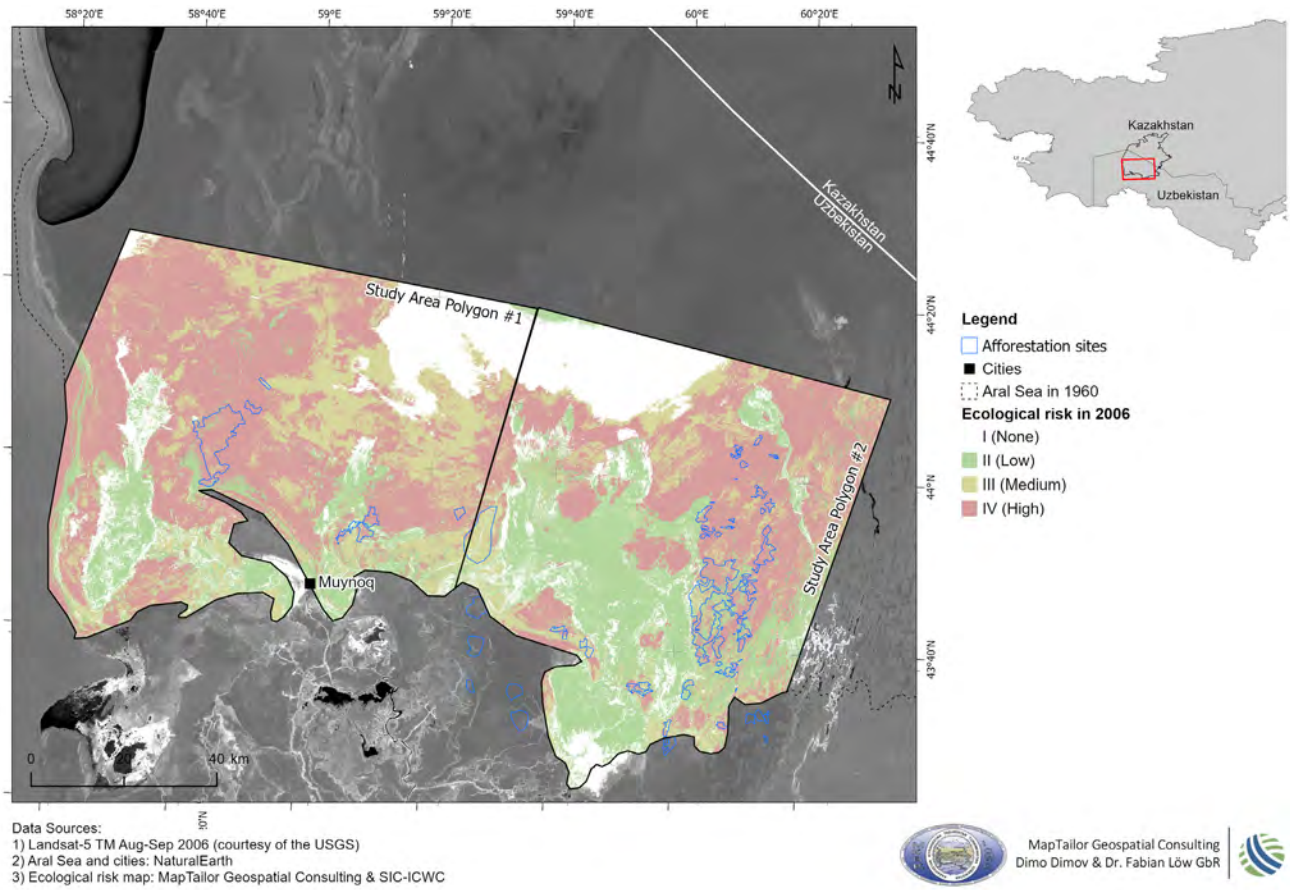


Fig. 127. Environmental risks in Aralkum in 2006

6.7.6.3. Environmental risk maps

Each category on the land cover maps can be translated into environmental hazard classes in terms of wind erosion risk. This information is critical for understanding the spatial and temporal dynamics of areas at risk of erosion. Finally, this information is useful for identifying new locations for afforestation, for instance those with the highest erosion risk. Figs. 127 and 128 show environmental risk maps for 2006 and 2019, respectively.

6.7.6.4. Summary of land cover changes and environmental hazards

With the retreat of the Aral Sea between 2006 and 2019, a wide swath of land appeared on the outer edge of the new shoreline in 2019 (Figs. 125 and 126). In particular saline soils emerged, greatly increasing the environmental hazards in these locations across three categories (Fig. 129). In contrast, the sites south of the dried seabed, which were already uncovered in 2006, saw a partial improvement in the ecological situation (in terms of erosion risk). This can be partly explained by the continuation of plant growth succession and the emergence of shrub vegetation communities.

As one can see from the maps, in 2006, available forest plantations were carried out in some places mostly characterised by high environmental hazards, such as ‘IV (High)’ (Fig. 127). In 2019, their hazard status decreased significantly, mostly to category ‘II (Low)’ (Fig. 128).

Evaluation of the maps for two different years allowed for a quantitative assessment of changes in land cover area and ecological hazard. Tables 39 and 40 summarise the change in land cover area, and Tables 41 and 42 summarise the change in ecological hazard zones.

6.7.7. Discussion

This study developed a methodology based on Earth Observation (EO) to map and quantify land cover conditions in different years. It is based on open satellite data, and the methodology has been calibrated and validated against collected field reference data.

The proposed method is innovative in that it improves existing mapping strategies used in the Aralkum Desert by using machine learning algorithms and multi-temporal satellite data as inputs. Regarding the input data, the choice of different vegetation indices and spectral decomposition adds value by increasing the classification accuracy compared to using only the Landsat multispectral bands.

Unfortunately, the previous map of land use and land cover from 2006 created by a past project (Dukhovny et al., 2008) could not be used in this assessment because the method could not be replicated and control data for 2006 were not available. However, based on the method used in this study, this gap could be filled, and the method provides a basis for scaling it to larger regions and different years.

Creating temporal composites contributes to this spatial and temporal “portability” of the technological process, because it removes the burden of searching for cloudless images and creates comparable input data for different years. For example, by using the proposed strategy two sets of input data can be created for different years, specifically 2006, 2019 and 2020, which have similarly different temporal attributes. This is a prerequisite for applying the classifier algorithm, which was calibrated for one year (2019-2020), to classify the composite for another year (2006). It should be noted that due to the lack of benchmark data for 2006, the map of land use and land cover created as part of this study could not be validated through accuracy assessment.

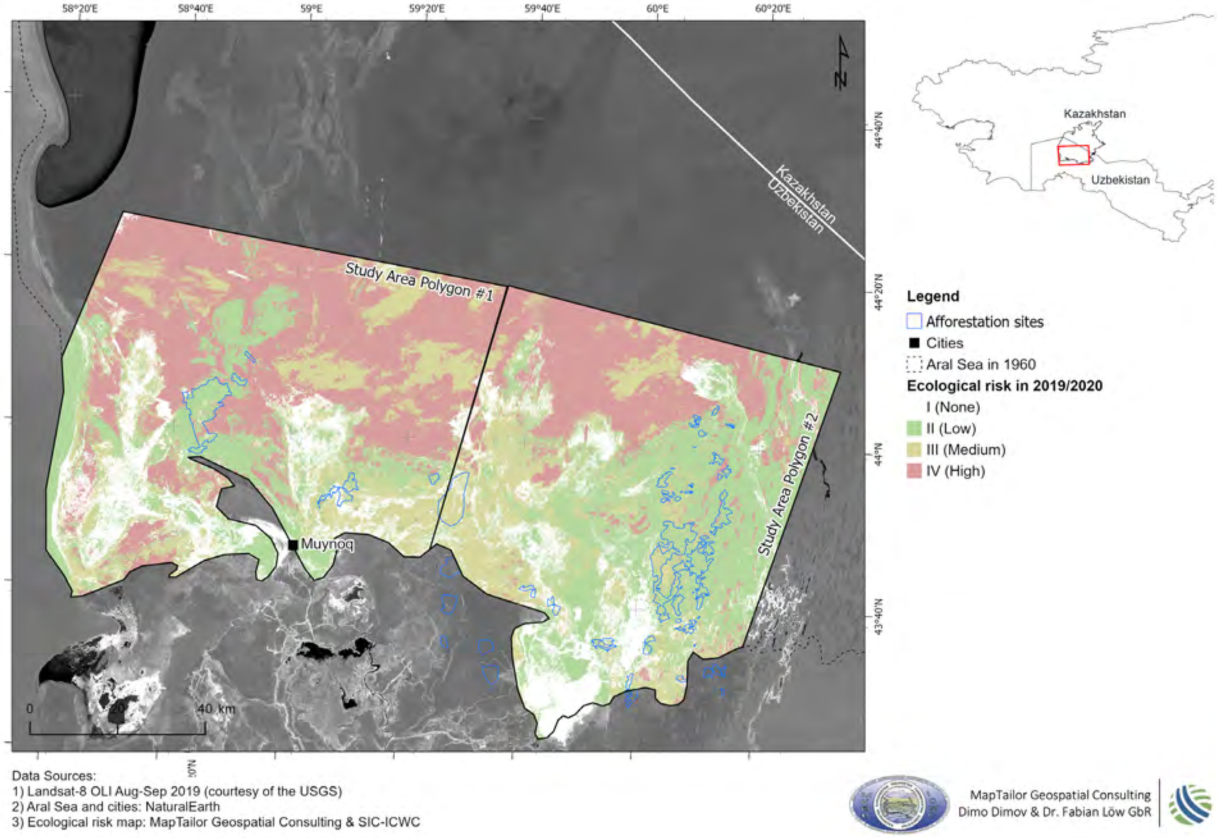


Fig. 128. Environmental risks in Aralkum in 2019

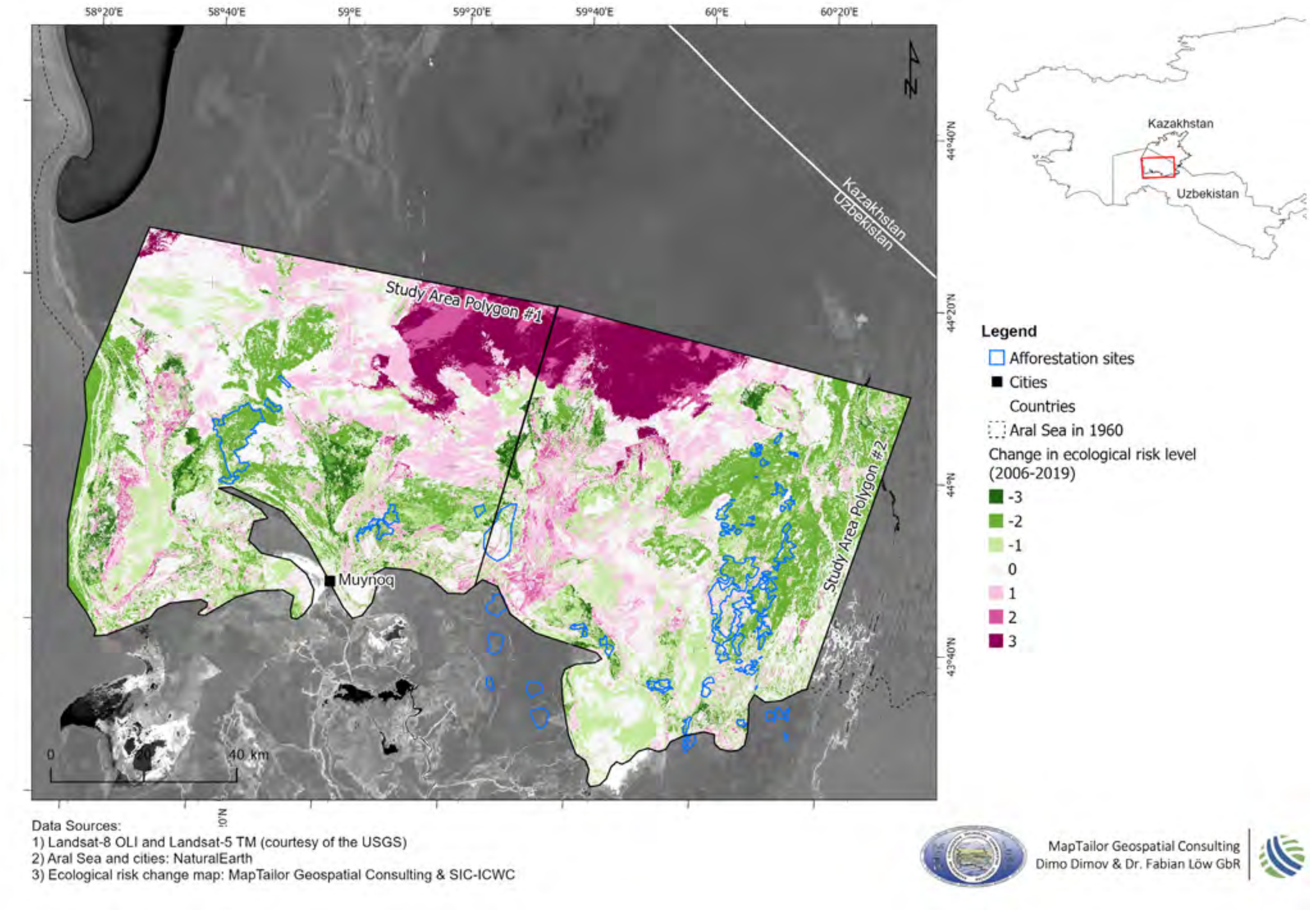


Fig. 129. Changes in environmental hazard classes from 2006 to 2019, with positive values indicating an increase in the level of environmental hazard, and negative values indicating a decrease

Table 39.

Areas of land cover categories within the technical studies area in 2006 and 2019, in the Polygon #1 research area

ID source class (New ID)	Description	Area (ha) in 2019	% of area of technical study in 2019	Area (ha) in 2006	% of area of technical study in 2006	Diffe-rence 2019-2006
1.1 (1)	Water surface	1 614.33	0.25	2 747.61	0.42	-1 133.28
1.2 (2)	Shallow water, sometimes with reeds	11.25	0.00	1 202.58	0.18	-1 191.33
2.1 (3)	Marshes without vegetation or with communities of saltwort	1 456.83	0.22	62 746.20	9.60	-61 289.37
2.3 (5), 3.4 (11)	Crusty-puffy and crusty, without vegetation, sometimes with isolated specimens of shrubs (karabarak, tamarix), hilly and hilly-ridgy without vegetation and weakly fixed	246 080.97	37.67	186 826.41	28.60	59 254.56
2.4 (6)	Solonchak with overblown sandy cover with sparse communities of goosefoot and saltwort	33 210.27	5.08	116 324.37	17.81	-83 114.10
3.1 (8), 3.2 (9), 3.3 (10)	Plains (with shell rocks) without vegetation or with sparse shrubs (saxaul, tamarix), dunes without vegetation, shallow hilly (weakly fixed) with sparse communities of wormwood, shrubs and selinum crops	68 454.27	10.48	120 684.42	18.47	-52 230.15
3.5 (12), 4.2 (14)	Hilly, hilly-ridgy weakly fixed with ephemeral wormwood-shrub communities, desertifying, hydromorphic cereals-halophytic-miscellaneous grasses with shrubs	2 369.25	0.36	680.31	0.10	1 688.94
4.1 (13)	Meadows on alluvial plains (reedy, mixed grass and cereals) on alluvial-meadow, swamp-meadow and meadow-swamp soils	136 871.55	20.95	89 370.81	13.68	47 500.74
4.3 (15), 4.5 (17)	Shrub thickets (halophytic: tamarix, karabarak), shrub-saxaul (desert forests/artificial plantations)	67 908.33	10.39	35 004.69	5.36	32 903.64
4.4 (16)	Desert shrublands	95 308.92	14.59	37 699.56	5.77	57 609.36
Total area		653 285.97	100.00	653 285.97	100.00	

Table 40.

Areas of land cover categories within the technical studied area in 2006 and 2020, in the Polygon #2 research area

ID source class (New ID)	Description	Area (ha) in 2020	% of area of technical study in 2020	Area (ha) in 2006	% of area of technical study in 2006	Diffe-rence 2020-2006
1.1 (1)	Water surface	8 254.17	1.38	7 717.59	1.29	536.58
1.2 (2)	Shallow water, sometimes with reeds	1 020.06	0.17	3 238.20	0.54	-2 218.14
2.1 (3)	Marsh without vegetation or with communities of saltwort	417.87	0.07	61 529.49	10.31	-61 111.62
2.3 (5), 3.4 (11)	Crusty-puffy and crusty, without vegetation, sometimes with isolated specimens of shrubs (karabarak, tamarix), hilly and hilly-ridgy without vegetation and weakly fixed	103 379.67	17.33	49 574.34	8.31	53 805.33
2.4 (6)	Solonchak with overblown sandy cover with sparse communities of goosefoot and saltwort	31 469.67	5.28	151 947.54	25.47	-120 477.87
3.1 (8), 3.2 (9), 3.3 (10)	Plains (with shells) without vegetation or with sparse shrubs (saxaul, tamarix), dunes without vegetation, shallow hilly (weakly fixed) with sparse communities of wormwood, shrubs and selinum crops	22 970.79	3.85	47 771.91	8.01	-24 801.12
3.5 (12), 4.2 (14)	Hilly, hilly-ridgy weakly fixed with ephemeral wormwood-shrub communities, desertifying, hydromorphic cereals-halophytic-miscellaneous grasses with shrubs	34 538.13	5.79	13 507.02	2.26	21 031.11
4.1 (13)	Meadows on alluvial plains (reedy, mixed grass and cereals) on alluvial-meadow, swamp-meadow and meadow-swamp soils	225 349.38	37.78	189 518.94	31.77	35 830.44
4.3 (15), 4.5 (17)	Shrub thickets (halophytic: tamarix, karabarak), shrub-saxaul (desert forests/artificial plantations)	105 190.29	17.63	34 873.56	5.85	70 316.73
4.4 (16)	Desert shrublands	63 961.20	10.72	36 864.63	6.18	27 096.57
Total area		596 551.23	100.00	596 551.23	100.00	

Table 41.

Areas of environmental hazard categories in 2006 and 2019, in the Polygon #1 research area

Environmental Hazard Class	Description	Area (ha) in 2019	% of area of technical study in 2019	Area (ha) in 2006	% of area of technical study in 2006	Difference 2019-2006
I	Not available	99 135.99	15.17	101 126.10	15.48	-1 990.11
II	Low	138 497.13	21.20	93 321.00	14.28	45 176.13
III	Medium	136 362.60	20.87	155 689.10	23.83	-19 326.50
IV	High	279 291.24	42.75	303 150.80	46.40	-23 859.56
Total area		653 285.97	100.00	653 285.97	100.00	

Table 42.

Areas of environmental hazard categories in 2006 and 2020, in the Polygon #2 research area

Environmental Hazard Class	Description	Area (ha) in 2020	% of area of technical study in 2020	Area (ha) in 2006	% of area of technical study in 2006	Difference 2020-2006
I	Not available	98 917.20	16.58	111 901.14	18.76	-12 983.94
II	Low	234 623.60	39.33	200 474.73	33.61	34 148.87
III	Medium	128 161.10	21.48	82 645.47	13.85	45 515.63
IV	High	134 849.30	22.60	201 521.88	33.78	-66 672.58
Total area		596 551.23	100.00	596 551.23	100.00	596 551.23

6.7.8. Recommendations and practical conclusions

- This method can be extended so that it can be fully used to map 17 land cover classes and related ecological hazards, both for other years and for the Aralkum Desert (Uzbek part) as a whole. To this end, we recommend continuing ground expeditions to collect relevant information in the field and using Earth Observation (EO) satellite images to identify possible afforestation sites. In particular we suggest supplementing the existing control data with additional expeditions to cover places where fewer samples were taken and to be able to classify all 17 initial land cover classes (we classified ten classes in this study). It is recommended that the north-eastern, northern and north-western parts of the studied area should be targeted to achieve spatially balanced samples.
- According to this methodology, maps of the land cover and the associated environmental hazard (in terms of wind erosion risk) have been produced. This information can be used to spatially identify regions where measures to reduce wind erosion should be imple-

mented, for example, through the planting of shrublands (forest plantations).

- We propose to use and further extend the already developed methodology to address other relevant stages of the project management cycle in the context of afforestation of the dried Aral Sea bed (Fig. 130):
- The use of satellite Earth Observation (EO) in combination with other relevant geodata to map the environmental and meteorological conditions that determine the suitability of land for afforestation (land suitability). This step determines where environmental conditions are favourable for afforestation.
- Using Earth Observation (EO) satellites to monitor the development of existing or new afforestation areas. In addition to Landsat, other open satellite data, such as Sentinel from the Copernicus Earth Observation programme and very high-resolution satellite data, should be combined. This step will provide information on the success of already conducted afforestation.

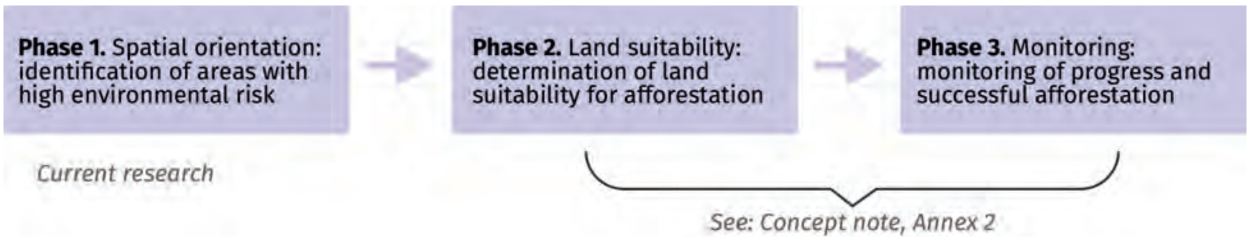


Fig. 130. Conceptual scheme of integrated forest plantation planning and monitoring based on Earth Observation and other geodata

7 Discussion

7.1. Changing the soil cover and its environmental hazards

The soil cover of the dried seabed is an indicator of environmental stability.

In the classification of soils, the name and properties of a particular soil variety area included in an assessment of environmental stability. The map of 2020 identifies 50 soil differences. All soil varieties fit within the characterization of risk classes developed and adopted in 2005 and included in the book published in 2008 (Dukhovny et al., 2008).

There is some brief information about the principles of the 17 classes and their association into risk groups. In terms of soil coverage, the environmental risk group primarily includes sand massifs, such as barchans, dunes, sand hills if they are loose or weakly consolidated, and soils covered with a sand plume.

Solonchaks are ranked in the order of environmental risk, including hydromorphic solonchaks (excessively hydromorphic, semi-hydromorphic and moderately hydromorphic), semi-automorphic and automorphic soils.

Hydromorphic solonchaks become dangerous when they dry out as the leaching regime of marsh solonchaks changes to the habitual water-salt regime, salt accumulates in the surface horizons, a salt crust is formed, and the salt is carried over long distances by the wind.

The most susceptible to erosion among the semi-hydromorphic and semi-automorphic solonchaks are puffed, crust-puffed solonchaks. The puffed solonchak has a powdery top layer which is a source of dust and salts. The crust-puffed solonchaks become a source of dust and salts when the crust is destroyed. Such solonchaks are active producers of salts carried by the wind outside the Aral Sea basin.

Overgrowing solonchaks with artificial plantings or self-overgrowth, lowers the ecological hazard and significantly reduces it when solonchaks transition to desert-sandy soils.

Desert-sandy soils are mostly formed on the layered soils of alluvial-marine deposits of the Amudarya avandelta and lake-marine deposits of the Adjibay and Djiltyrbas bays, and often have sorted, fine fractional particles. Being subjected to mechanical destruction, they become erosion-hazardous.

Studies of soil cover have determined the direction of soil formation and the time required for transition from one soil variety to another (Sektimenko, 1991; Dukhovny et al., 2008).

It is known that marsh and wet solonchaks have uniform salt distribution along the profile and chloride salinity in the first period of drying. With drying, salts accumulate in the upper horizons (Fig. 131). Over time and with the lowering of the water table, marsh solonchaks transform into hydromorphic and then into automorphic and desert-sandy soils (Fig. 132 and 133).

The above example is a classical scheme of soil transformation in the Aral Sea, and its classification from hydromorphic to automorphic.

The overall process of soil change is influenced by local effects. The main one is periodic moistening from water sources of bays, rivers and collectors. Another impact is siltation, which makes adjustments in the assessment of the ecological risk of soil cover.

Fig. 134 shows the distribution of salts across the profile of a semi-hydromorphic solonchak section 5(2), in which the soil profile is non-saline due to desalinisation. The soil becomes more hazardous in the environmental risk assessment due to the transfer of sand.

Soil flooding from bays also has an impact. In this case, desertified saxaul shrub forests may be in the ecological risk group.

The results of studies show that flooding of the area can have both positive and negative effects. It is shown that the flooding of saxaul, causing the soil to become supersaturated with

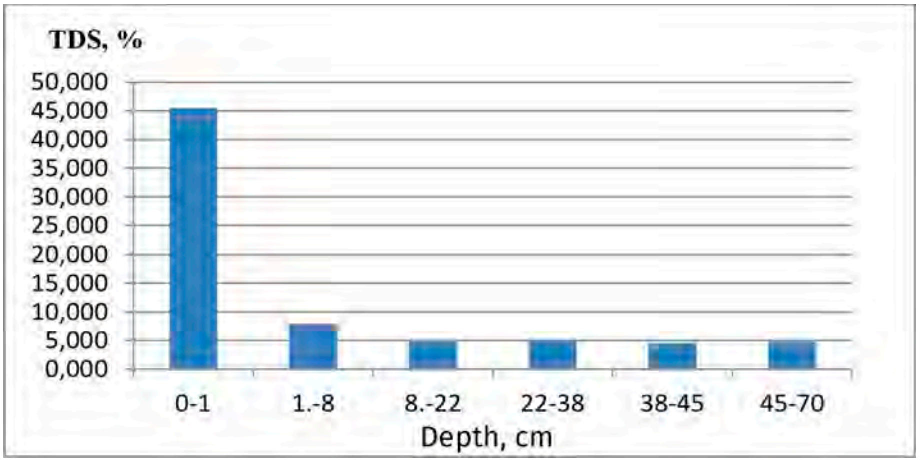


Fig. 131. Salt distribution (TDS, percentage) in the profile of a moderatehydromorphic solonchak, section 18

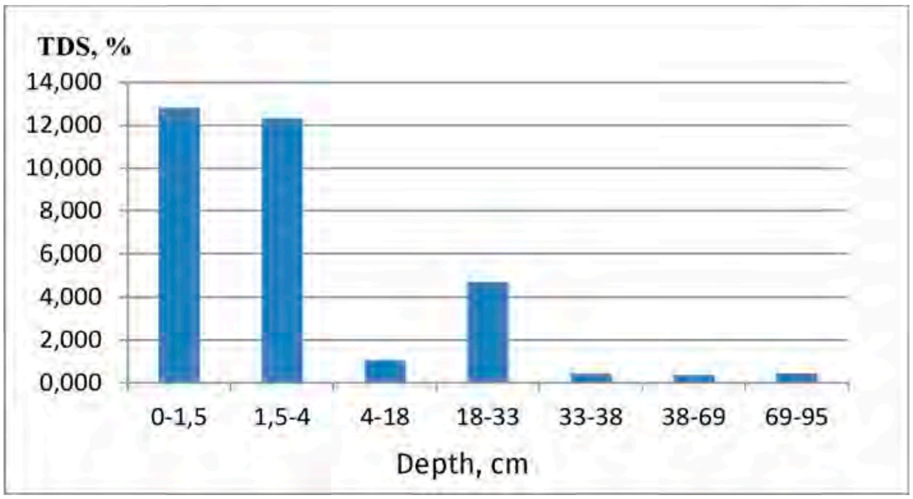


Fig. 132. Salt distribution (TDS, percentage) in the profile of a strong-crust, automorphic solonchak, section 29

water, leads to a diseased plant and its subsequent death as observed near Djiltyrbas Bay.

The change of karabarak vegetation to saxaul when the soil dries out cannot be regarded as desertification.

The study of soil cover through a comparison of soil conditions over a number of years concludes that soil conditions, despite the seemingly "wild" part of the land (the dried seabed), are largely subjected to positive and negative anthropogenic influences.

In the Muynak area, there is little of the protected natural soil cover left. The presence of more than 45 drilling rigs and their access roads causes soil destruction. An example of this negative impact is evident in the area of old saxaul plantings north of Rybatsky Bay. Although fa-

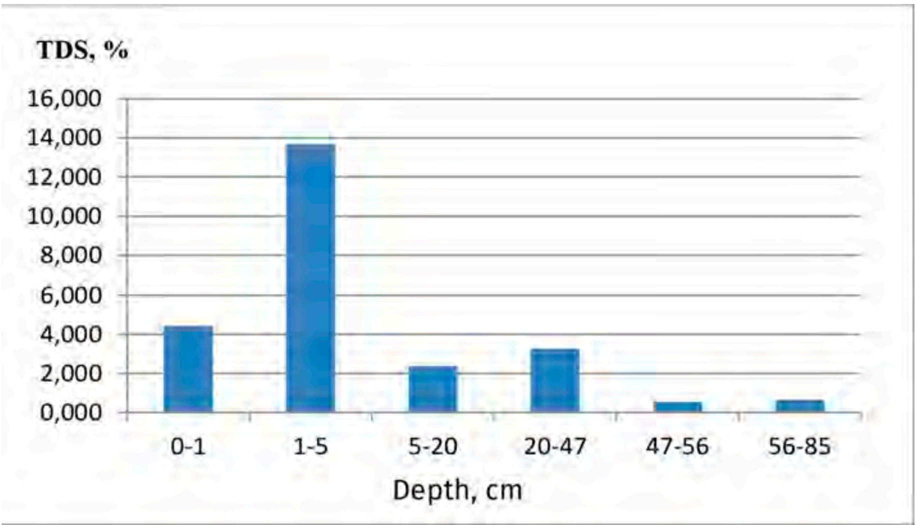


Fig. 133. Salt distribution (TDS, percentage) in the profile of desert-sandy soil, section 30

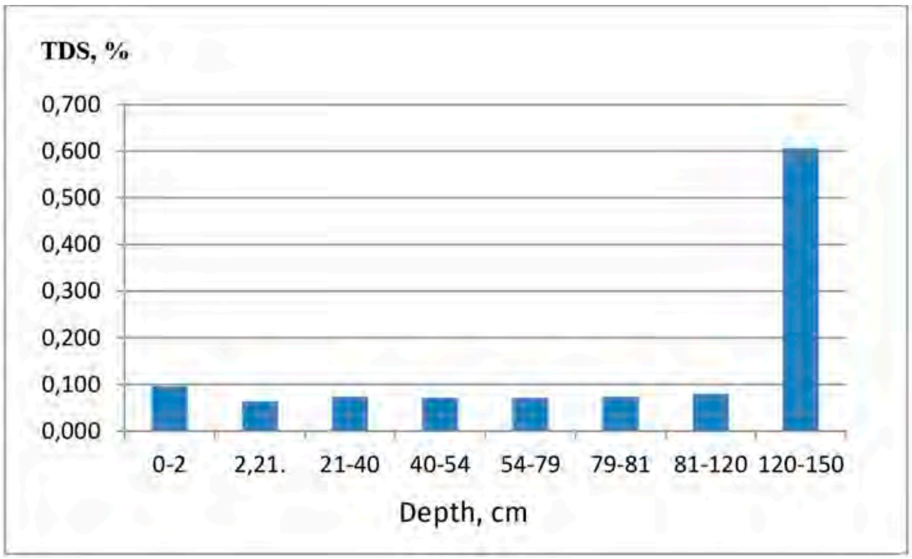


Fig. 134. Salt distribution (TDS, percentage) in the profile of a semi-hydromorphic sandy solonchak, section 5(2)

vourable conditions have been created to preserve the soil and forest planting, machines continuously shuttling from well to well destroy the already strengthened soils under the plantings.

In the area of the Kazakhdarya, meadow-alluvial soils change into solonchaks due to changes in the channel of the Amudarya River, associated with the operation of the Mejdurechenskaya Dam.

In the Djiltyrbas zone, being a zone of plantations of four forestry farms, the anthropogenic impact is positive. But even here desertification is manifested, which is associated with catastrophic drainage of the East Sea, the active movement of sand, and the overlapping of soils with sandy covers.

The results (Tables 43 and 44) of soil surveys from 1990, 2005-2006, and the 2019-2020 expeditions were used to identify the general course of the processes.

The comparison was made in the borders of the studied areas. During the period from 1990 to 2020, there was a significant decrease in hydromorphic solonchaks by 15.1 percent due to the development of aridization process and, accordingly, an increase in automorphic solonchaks by 14.6 percent, a decrease in the groundwater table and a transition of hydromorphic soils into their automorphic analogues, zonal soil formation and sanding. Since 2006, hydromorphic character is maintained more or less steadily due to periodic flooding of every 5-7 years. The formation of desert-sandy soils takes place, which is a positive sign. The increase of sand cover (Tables 43 and 44) indicates intensification of the erosion processes on the dried bed.

Table 43.

Change in soil cover in 1990 and 2020

Soils	% of the total study area		
	1990	2020	Changes, %
Hydromorphic and semi-hydromorphic	72,7	57,5	-15,1
Automorphic and semi-automorphic	10,90	16,3	5,4
Desert-sandy		5,7	5,7
Sand	16,4	19,9	3,5
Desert grassland		0,6	0,6

Table 44.

Change in soil cover in 2006 and 2020

Soils	% of the total study area		
	2006	2020	Changes, %
Hydromorphic and semi-hydromorphic	56,3	57,5	1,2
Automorphic and semi-automorphic	18,4	16,3	-2,2
Desert-sandy	2,6	5,7	3,1
Sand	9,3	19,9	10,6
Desert grassland	13,4	0,6	-12,7

All examples show that the dried seabed is an unstable ecological system that needs to be studied. Given the dynamism of the processes occurring on the dried seabed, continuous monitoring is necessary not only to know the current situation, but also to learn how to manage the processes and develop a strategy for preserving the unique laboratory of soil formation.

7.2. Measures to reduce the negative effects of the desiccation of the Aral Sea

As indicated earlier, the drying up of the Aral Sea has not only led to the monotonous development of desertification in an area deprived of water sources but has also increased salinity. This result affected the ecosystem of lake systems, and in addition it affected the development of agriculture (livestock and fish farming), the health of the local population, and eco-tourism.

In practice there are three processes happening here, including the draining of the sea bottom, desertification on the former sea bottom, and anthropogenic influences. Anthropogenic factors are both beneficial and detrimental. On the one hand, they try to help nature preserve the delta and overcome desertification by afforestation, while they also allow uncontrolled or poorly-controlled technogenic processes to cause damage to the protected nature.

The first phenomenon of the drying seabed is that the territory that has emerged from under the water cover has lost its hydromorphic features. As its shore edge is removed and the water table decreases, the seabed gradually acquires more and more signs of aridization and desertification. However, it is during this period, as shown by studies of past expeditions, that biological and microbiological processes begin to develop on this former barren parent base, resulting in the process of soil formation and the creation of possible productivity (Stulina G., Verkhovtseva N., & Gorbacheva M., 2019). Practically in this part of the territory, there is a competition between the growing self-protective forces of nature aimed at productivity and the creation of fertility, and the destructive forces of desertification, amplified by arid climate conditions. At the same time, as aeolian deflation forms barchans and dunes, appearing as if being a destructive factor itself, this may actually play a positive role at the initial stage of the sea level emergence and the drying of coastal solonchaks. By forming a small layer of sandy cover, they will have a positive effect on the establishment of emerging vegetation, and especially the development of self-overgrowth. From this moment, there is a possibility of humankind's positive impact on nature by starting the timely processing of coastal solonchaks with the device of sand-filled furrows, but at the same time, not allowing for the beginning of the formation of barchans by using reed cage devices.

The most important role of humans is to organize the strict regulation of this new desert's use. The destruction of the natural equilibrium must not be allowed, but instead the development of two main areas of landscape stabilisation must be undertaken with the afforestation of the desert area, while sustaining the partially unstable area of the former delta which is under the influence of the inflow of river water and partial discharges from collectors.

It is crucial to maintain the constancy of growing conditions. In the process of expeditions, numerous facts of saxaul dying due to hydromorphic conditions and on the other hand the drying out of moisture-loving vegetation in the long-term absence of watering were observed. Here, dendrological measures can do little. However, the attention of operational agencies, by both water and land managements to create and maintain certain conditions is very important. This applies equally to preventing the destruction of terrain and forest plantations by vehicles and road construction, which destroy plants that have already taken root and disturb the stabilised terrain. The exploration and production works of oil and gas wells, numbering more than 50, require special attention. Each well leads to the destruction of the relief on at least 2-3 hectares. Although all contracts with oil and gas production and exploration stipulate mandatory conditions for relief restoration and compensation for environmental protection measures, nevertheless the effectiveness of these actions on the part of both executive organizations and local and environmental organizations is not visible.

Based on the above principles and summarising the results of the two expeditions, it seems advisable to focus the attention of governmental, specialized and local bodies on the implementation of the following actions and measures:

1. The primary goal, based on the tasks set by the Government based on the initiatives of President Sh. Mirziyoyev, is the management of the dried and drained seabed and the Aral Sea cost.

To that end:

1.1 To entrust the general management of the designated territory to the Government of Karakalpakstan, delegating Karakalpakstan to conduct control of permissions and monitoring activities in this territory.

1.2 Assign responsibilities:

a. Responsibility **for sustainable water supply** should be entrusted to the Ministries of Water Resources of Uzbekistan and Karakalpakstan. These responsibilities include the Amudarya River delta, the complex of reservoirs fed from the Mejdurechenskaya Reservoir, the drainage water protection zone and Sudochie Lake, as well as the right bank collector, Djiltyrbas, Kokdarya and Kazakhdarya, and all collectors discharging water into the Aral Sea region based on the agreement with the 'Amudarya' Basin Water Association.

b. Responsibility for the development and observance of certain strict rules of protection of the natural complex of the Aralkum Desert should be entrusted to the State Committee of Ecology of Uzbekistan and Karakalpakstan, declaring Aralkum a protected area, paying special attention to the conservation of landscape and plantations, and to monitor all companies' projects that can harm nature conservation.

c. To entrust the planning and implementation of forest plantations in strict accordance with the zoning of the territory on the sustainability of zonal forest plantations, care of forest plantations, and phyto-control to the State Forestry Committee of the Republic of Uzbekistan.

d. To entrust control over the development, use and maintenance of pastures, as well as the maintenance of wells on pasture stands, to the Ministry of Agriculture of the Republic together with Goskomgeologiya.

1.3 Thanks to UNDP funding, the monitoring of the dried seabed resumed after ten years. In combination with remote sensing, this allowed for the coverage of 1,249,000 hectares of the dried seabed out of 2.7 million hectares that are inside Uzbekistan's territory. The data of the expedition turned out to be much more productive than the previous ones in terms of the information collected about the changes taking place in the surveyed area. They revealed a definite decrease in the percentage of the ecological risk zone, although they found the need to increase the volume of research in order to clarify the attributes in 6 of the available 17 classes. GIS-RS specialists also require expanding research. They suggest "supplementing existing benchmark data with additional expeditions to cover locations where fewer samples were taken, and to be able to classify all 17-source land cover classes by targeting the north-east, north and north-west parts of the study area to achieve spatially balanced samples." This will provide a complete picture of the dried seabed on the territory of Uzbekistan and give a working tool to all organizations responsible for the management of the territory. This will also allow for a unified cartographic basis for their work in comparison with the dynamics of ten years ago. In the future, it is recommended to conduct one ground expedition per year, selecting the terrain where remote measurements will detect the maximum changes.

2. It is proposed to use the developed methodology of combined remote sensing observations to address other relevant stages of the territory management cycle of afforestation of the Aral Sea's dried seabed:

a. To map the environmental and meteorological conditions that determine the suitability of land for afforestation (land suitability). This step determines where environmental conditions are favourable for afforestation.

b. To monitor the development of existing or new afforestation areas. The developed methodology uses combinations of other open satellite data, such as Sentinel and very high- resolution satellite data, in addition to Landsat. This step will provide information on the status of the already conducted afforestation.

3. It is proposed to make an inventory of all available water wells with their division into those suitable for pasture water supply, and separately, those with hot water for balneological purposes. Organize the arrangement of wells and their target use for certain needs based on this data.

4. In order to create a guaranteed water supply to the delta and maintain the hydromorphic component of sustainable development of the dried seabed, switch the discharge of collector-drainage water of the Khorezm Oasis from the Daryalyk collector to the Amudarya River delta.

5. In order to prevent the unauthorised construction of local roads, it is necessary to develop and approve a plan for the construction of blacktop roads in the Aral Sea region and on the dried seabed, to stabilise the routes of traffic in the area based on the identifying of the most visited places.

6. In the territory under consideration, there are a large number of dilapidated and abandoned buildings and premises previously operated by forest farmers, anglers, pasture farms and scientific stations. It is necessary to instruct the local authorities of the Muynak, Karauzyak, Kungrad and Takhtakupyr districts to conduct an inventory of these buildings, together with the Government of Karakalpakstan, and to determine their intended use. Practical solutions could be for the organization of tourist routes, and where there are working wells nearby, for shepherds or the development of health centres.

7. According to the recommendations of the botanist of the expedition, it is advisable to organize the collection and processing of medicinal plants, which are rich in the flora of the Aralkum Desert. It is necessary to entrust the Ministry of Health of Uzbekistan and Uzpharmprom to organize a factory of medicinal plants in Muynak.

8. Special attention should be given to the study of self-overgrowing processes. During the past expeditions, it was found that the area of self-overgrowing covered 200,000 hectares and a little less than the preserved artificial plantations were registered. Now the area of new self-overgrown plantations is again 160,000 hectares, since the last expeditions of less than ten years ago). The results of determining the risk classes of ecological assessment, given below, at the same time caught the above-mentioned value of self-overgrowing and gave an opportunity to compare it with the indicators of remote measurements.

Table 45.

Assessment of the dried seabed for 2019-2020

№ expedition	Risk class	Degree of environmental risk	Area, %	Thousand ha
I	I	N/A	16,9	110,36
	II	Low	30,2	192,29
	III	Medium	30,3	197,95
	IV	High	22,4	146,33
Total				653,285
Self-overgrowth			16,6	96,6
II	I	N/A	25,2	150,33
	II	Low	30,7	183,14
	III	Medium	34,0	202,83
	IV	High	9,42	56,20
Total				596,55
Self-overgrowth			10.7	64,3

Fig. 135. Points of the 2019 expedition: T. 619-620

Description of location: Haloxylon aphyllum Iljin. (black Saxaul, previously planted by French company), abundance characteristic - scattered (Sp) with 25-35 percent coverage, damaged by locusts (photo of 2 October 2019 where dead locusts under saxaul can be seen)

Fig. 136. Points of the 2020 expedition: T. 207-211

Description of location: Haloxylon aphyllum Iljin. (black saxual, self-overgrowing), abundance characteristic - scattered (Sr) with coverage of 15-25 percent, damaged by powdery mildew (photo of 4 June 2020 where dried branches of 4–5-year-old Saxaul are visible)

9. It is necessary to strengthen work on plant protection (use of pesticides/biopesticides) against pests, insects, and diseases (such as locusts and powdery mildew). Currently, the Government of Uzbekistan pays special attention to the afforestation of the dried bed of the Aral Sea by bringing the forest area to 1.2 million hectares. However, the expeditions we conducted in 2019-2020 show that locusts and powdery mildew damage the old self-overgrown saxauls that exist.

10. One of the measures to mitigate the negative impact of the environmental crisis in the Aral Sea region is to maintain the system of natural water bodies in the Aral Sea water area, as indicated in the Strategy for the Transition to a Green Economy for the 2019-2030 Period. Phase II of the project 'Creation of small local water bodies in the Amudarya River delta is being implemented. This requires continuous systematic monitoring of phenomena and processes occurring in the territory of local water bodies of the Aral Sea, the results of which will justify management decisions to ensure environmental security and socio-economic stability of the region.

11. Our work on monitoring the drained seabed in 2005-2011 and 2019-2020 with the participation of the International Innovation Center of the Aral Sea Region (IICAS) under the President of the Republic of Uzbekistan, allows for the immediate construction of a Geographic Information System (GIS). The GIS will be based on available materials of a 1.2 million hectare area, and will be completed after another three expeditions on the remaining 1.5 million hectares. The proposed system could become a reliable instrument of the IICP and serve as the basis and guide for any events and innovations that will be held in this region under the orchestration of the IICP.

This system should include following GIS layers:

- Population, residential areas, and townships with indicators of demographics, welfare and economic dynamics;
- Roads, power lines and communications;
- Past and current sector activities with reflection of distribution zones (including fish farming, irrigation, muskrat breeding, grazing, growing medicinal plants and the extraction of medicinal crustaceans, and mining);
- Geomorphology;
- Soil layers and the formation of the soil-forming process;
- Landscapes in their dynamics in conjunction with the retreat and hesitation of the sea, results of remote monitoring of water bodies and wetlands carried out by SIC ICWC, risk maps and aeolian or salt degradation;
- Botany and afforestation;
- Hydrogeological reports with indicators of clusters and rows of wells, their operational indicators, and levels of ground and underground waters.

Using this system, IICP will be able to perform a recommendatory role, and coordinate developing innovations in the Aral Sea region, for both pre-existing industries (fish farming, muskrat breeding, animal husbandry, mining, production of local building materials) and new industries (greenhouses, medicinal plants, balneological treatment, and others). It will not only be possible to organize training for local residents, but also for those from beyond who will be interested in participating in this innovation process. It is recommended that development attract large investors and profit-making organizations, rather than small start-up projects (although their contribution is not excluded).

8 Conclusions

1. Thanks to the funding of two expeditions for the monitoring of the dried seabed in 2019-2020, it became possible to resume, after almost a decade's break, the work in observing and collecting data on landscape, soil, vegetation, ground and surface water conditions in the area covering about 40 percent of the dried seabed on the Uzbek site of the former seabed, particularly 1,200,000 hectares of its south-west and south-east parts.

2. Two complex expeditions were organized by SIC ICWC with the involvement of specialists from the International Innovation Center of the Aral Sea Region under the President of the Republic of Uzbekistan. In addition, the expeditions were joined by scientists from the Institute of Organic Chemistry and the permanent expedition of Uzhydroingeo in Karakalpakstan, with the participation of remote sensing specialists from the German company Map Tailor. All this allowed for a comprehensive assessment of the territory from geomorphological, hydrogeological, landscape, soil, ecological, dendrological and botanical points of view, as well as a comparison with the results of the previous expeditions in 2006-2010.

3. The systematic approach to the assessment of the observed phenomena and changes allowed us to characterise the dual process of transformation of the dried seabed and the emerging ecological situation, as presented in Chapter 7.2., and to determine the need to organize a strict regulation of the system of use of this new desert. At the same time, the requirements of this regulation are formulated not to allow the destruction of the natural equilibrium, but to help in the development of two main areas of landscape stabilisation, notably afforestation of the dry cost and in parallel, ensuring the sustainability in the partially unstable area of the former delta, which is under the influence of the inflow of river water and to some extent collector discharges. For this purpose, it is proposed to create a system of management of the dried and drained seabed and the Aral Sea region, assigning responsibility for individual elements of management to relevant organizations of Uzbekistan and Karakalpakstan.

4. Considering that the total area of dried seabed on the territory of the republic is almost 3 million hectares, it is urgently necessary, starting from the spring of 2021, to organize a similar comprehensive ground and remote sensing study of the remaining area with the specification of indicators of some six classes that are difficult to determine from space. For 2022 it could be organized to complete the mapping of the entire territory for the development and management of the dried seabed. The primary task is to identify risk zones and a programme of protective forest plantations to prevent the expansion of risk zone. In future works, it is necessary to pay attention to the development of recommendations on the use of all available wells

for water supply, balneology and pastoralism, and the development of desert tourism through the reconstruction and repair of existing dilapidated buildings.

5. It is necessary to organize permanent monitoring of the indicators of sustainability of the Aralkum Desert and the Aral Sea region natural complex, through year-round space observations (including the use of drones to survey the Aralkum Desert's inaccessible places), and the conducting of surveys of ecologically unstable zones at least once a year. It is necessary to introduce this practice into mandatory activities of the International Innovation Center of the Aral Sea Region under the President of the Republic of Uzbekistan.

6. This study developed a methodology based on Earth Observation (EO) satellite from space to map and quantify land cover conditions in different years. The proposed method is innovative in that it improves existing mapping strategies in the Aralkum Desert by using machine learning algorithms and multi-temporal satellite data as inputs.

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