

GIS FOR SUSTAINABLE WATER DEVELOPMENT IN CENTRAL ASIA

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The Geographic Information System is one of the modern technological tools being used mostly for visual spatial analyses of information. The spatial data within the GIS database are all related to the tabular database and serves as an interface which allows the user to access tabular data by pointing at objects on a map.

The first efforts to establish the regional GIS and Database in Central Asia was supported by the EU TACIS Program under WARMAP Project (Water Resources Management and Agricultural Production in Central Asia) in 1995-2000. The Information System on water and land resources (WARMIS) was designed to support decision-making process in water sector in Central Asia. It was the first practical tool for comprehensive assessment of water situation (balancing available water resources and allocation of water among river reaches, administrative territories and water management systems – in accordance with demands).

Later on (during 2003-2006), the WARMIS was transformed into the actually existing Central Asian Regional Water Information Base (CAREWIB – www.cawater-info.net). It was done by Scientific-Information Center of ICWC together with UNECE/SPECA and UNEP/GRID with financial and technical support the Swiss Agency for Development and Cooperation (SDC)

The recent GIS database is linked with CAREWIB DB through uniform coding of spatial and database entities. For GIS establishment there were used different topographic maps, thematic maps, satellite images, and field observations. The basic cartographic information (digital cartography) includes:

- Administrative sub-division of the Central Asian countries.
- Water infrastructure in Central Asia – rivers, canals, drainage collectors and escapes, water intakes, dams and reservoirs, and others.
- Observation network- gauging stations, weather stations, etc.
- Industrial objects, including hydro power plants and thermal power plants.

The problem of desertification in the Aral Sea basin is one of the principal subjects for which GIS applied. Recently, SIC ICWC conducted a number of field investigation activities on environmental disaster caused by the Aral Sea desiccation (level drop). Besides reduction in volume and area of the sea and increase of sea salinity, the main consequence of desiccation is the occurrence of vast salt desert, with current area above 5 million hectares at the exposed former sea bottom. As a result, the unique freshwater body has changed into a salty lake with accompanying huge new salt desert at the interface of three sandy deserts.

Desert ground, which is saline (5-20 kg/m³), poorly fixed with vegetation is subjected to intensive defoliation. Wind blows the salts over adjacent areas. The exposed seabed represents an example of arid salt accumulation and formation of various types of solonchaks and saline soils. Shallow highly-saline groundwater in the coast contributes to continuous salinization of the seabed. The exposed bed, especially Eastern and Northern parts, became the main sources of dust storms and the centers of dust and salt that are blown to adjacent areas.

Factors of intensive desertification in this part are divided into 2 groups: primary factors that also led to the sea level drop and the retreat of the shore; and, secondary factors directly caused by

shrinking of the sea. Naturally, the both factors are interlinked and mutually increase the negative effects on the environment.

Characteristics of the Prearalie habitat degradation under impacts of the sea desiccation are presented in the paper (INTAS, August 2001) published by the SIC ICWC. Summary of the basic degradation effects are the following:

- Decrease of the lakes surface in the Amudarya delta from 400,000 hectares in 1960 to 26,000 hectares.
- Fish productivity decreased by 20 times in comparison with 1960.
- Groundwater table lowering up to 8 meters depending on the distance from the sea shore.
- Development of salt and dust transfer within the belt of 500 km wide with load capacity of 0.1-2.0 t/ha.
- Top-soil changes: an hydromorphous soil area reduced from 630,000 to 80,000 hectares.
- The area covered by solonchak increased from 85,000 to 273,000 hectares.
- Considerable climate changes are observed during last decade.
- The reed and tugai forest areas decreased, etc.

All these affects have resulted in economic losses amounting to US\$ 115 million and social losses estimated in the amount of US\$ 28.8 million annually. Economic losses are divided into direct and indirect ones. The **direct losses** include:

1. *Agriculture*: Irrigated agriculture in the impact zone; Fishery industry; Musk-rat catch; Cane collection; Cattle breeding.
2. *Recreation and tourism*
3. *Industry*: processing industries for Fishery; Fur production; Cane production.
4. *Transport*: Lowering of traffic flows.

Indirect economic losses: Higher costs of fish processing; Losses of capital funds; Freezing and retirement of capital funds.

Social losses: Migration of population; Loss of skilled labor; Health hazards; Shorter life span; Lower living standard; Deteriorated water supply; National income losses; Growing unemployment and loss of workplaces; Loss of territories for recreation and tourism.

It should be noted that ecological changes related to the sea desiccation have been accompanied by water inflow reduction and, consequently, deterioration of potable water supply. This fact, in turn, has caused a growth of sickness rate of the population. It was clearly demonstrated in the paper "The Aral Crisis and Medical-Social Problems of Karakalpakstan" (Ataniyazova, 2001). Unfavorable socio-economic and sanitary conditions of life have negatively affected population health in the Aral Sea zone (Prearalie). Medical examination of adult population in Karakalpakstan showed health deviations in 63.5% of cases (66% of children). The occurrence of intestinal infectious diseases among the local population exceeds 3 times the average level in CIS states (UNDP, 1998).

Worsening of economic and environmental situation in the Amudarya downstream has deteriorated population health not only in Prearalie, but in the whole downstream region. It is due to the following reasons:

- worsening of river and ground water quality, first of all, this is percentage of pesticides, herbicides, and salts in water;
- worsening of climate in Prearalie;
- general slowdown of economic development in the region, including in Prearalie.

A comparison of average rates of population growth in Uzbekistan and Karakalpakstan shows that population growth in Karakalpakstan in the recent years is slightly below the Uzbekistan level, while the situation was quite opposite before 1990. Reduced natural rates of population growth are due to such factors as infant, child and mother mortality; birth, mortality and morbidity rates and migration processes. Research under the INTAS Project has shown that maximum socio-economic damage is concentrated around Mezhdurechenskoye reservoir and especially near Muynak city (see Figure 1).

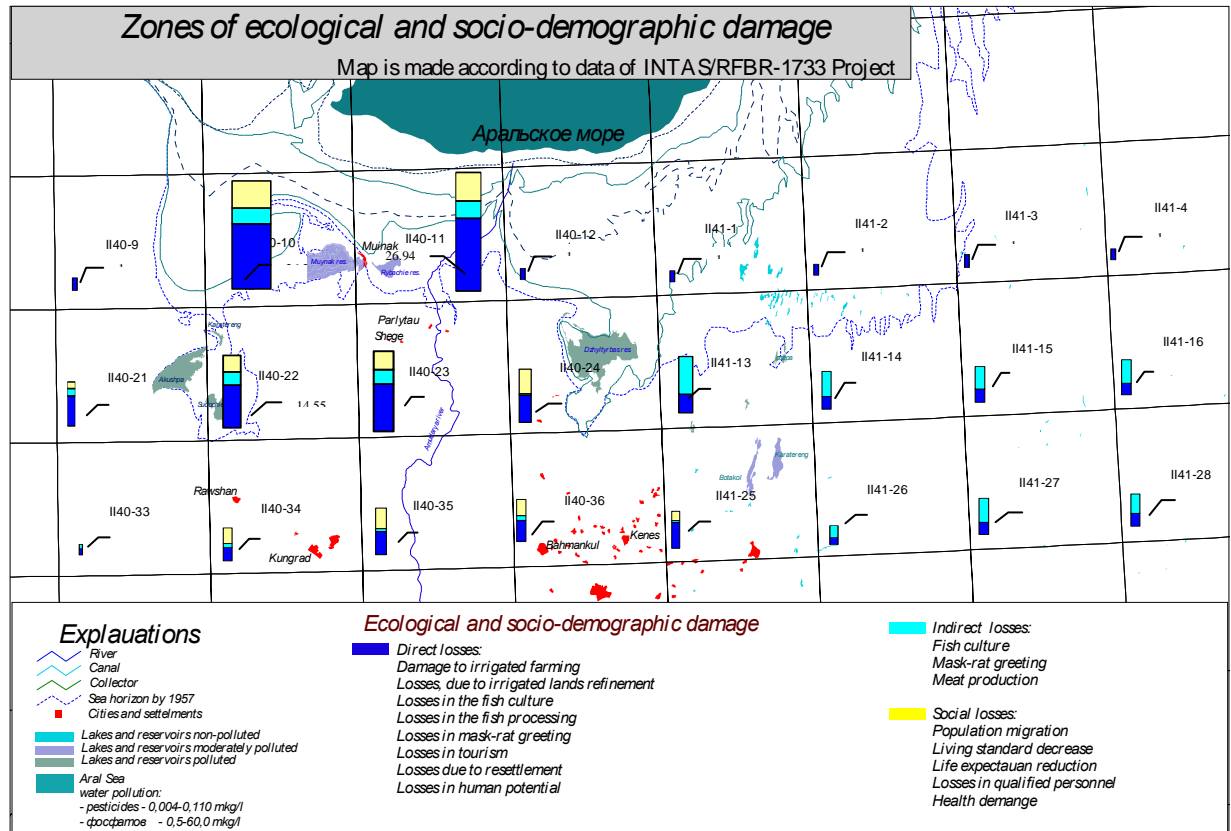


Figure 1. Zones of ecological and socio-demographic damages in the Aral Sea surrounding

Environmentally unstable landscapes were identified through assessment of current hydrological, ecological, and hydrogeological status of Southern Prearalie (Figure 2). Unstable landscapes refer to the areas where exogenous processes are taking place and represent a danger to population in Southern Prearalie. For identification of environmentally unstable landscapes, GIS was used and sources of information were: “Southern Prearalie landscape map” (SANIIRI, 1990), topographic maps at different scales, Landsat satellite images, and Landscape map of 2000 that was provided by the Project NATO SFP # 974101. Through spatial analysis of all available materials, the two most risky zones were identified:

Zone 1 – «environmentally critical zones» within the area of Southern Prearalie. They are characterized by dynamic unstable landscapes (shifting sand in form of barhan and dunes). The area remained unchanged over the recent 10 years is 127,500 hectares.

Zone 2 – «environmentally unstable zones» that are characterized by potentially unstable ladscapes (sandy soil, with groundwater depth of more than 5 m and poor vegetation). This zone remains risky over the last 8-20 years and covers 533,600 hectares.

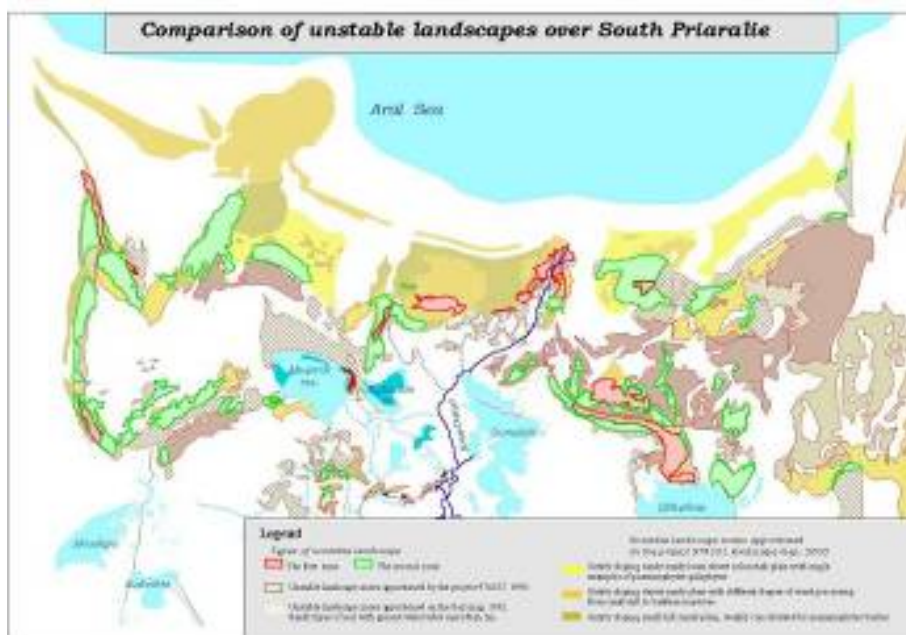
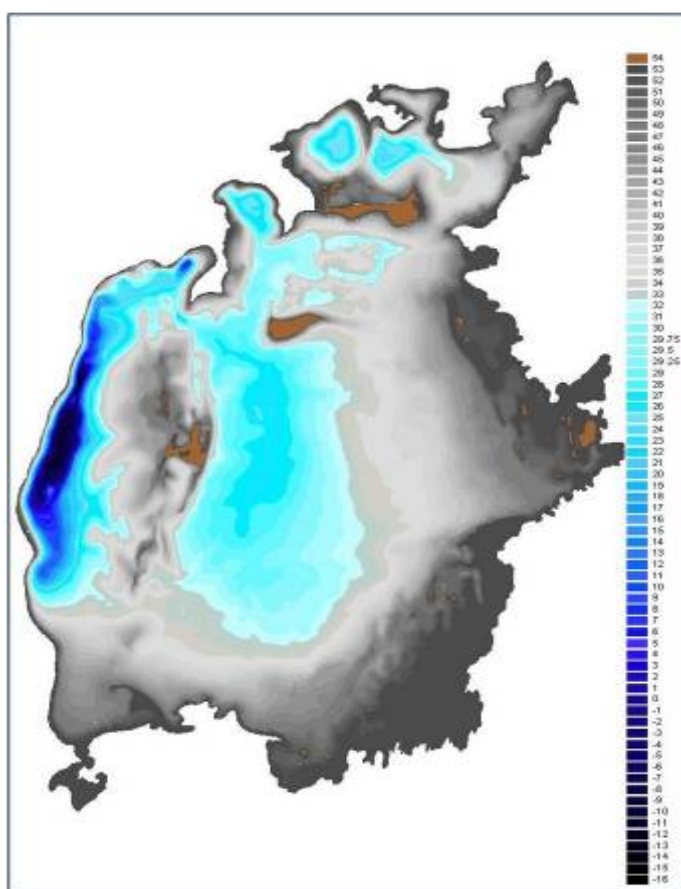


Figure 2. Comparison of unstable landscapes

Thus, taking into account that the strongest desertification factor is the progressing of Aeolian processes and of salt and dust transportation from the exposed seabed and from adjacent deserts due to permanent winds, one may certainly say that the area of the exposed seabed represents a serious danger to population in given region. Therefore, afforestation of unstable landscapes is of primary importance for Prearalie.



Future of the sea itself was analyzed in the project INTAS-Aral- 01-0511 “Restoration of ecosystem and bioproductivity in the Aral Sea under water shortage conditions” (REBASOWS), the objective of which was to model various alternatives of sea functioning.

In particular, for assessment of ecosystem degradation in the zone of environmental disaster, we created the cartographic base for the Aral Sea and its coastal zone, Prearalie (Aral Sea - bathymetric map of the Aral Sea with contour line cut of 1 meter (Figure 3.), actual data on the status of the Aral Sea for different years, water infrastructure in Uzbek and Kazakh parts of Prearalie).

Various thematic and topographic maps were used to create the electronic map of the Aral Sea isobaths. Topographic maps, such as the Aral Sea isobaths map, the Aral Sea sounding map, and topographic maps were produced in the period from 1940 to

1980, and naturally these maps do not represent completely the current status of the locality since the main source data for the maps were sea (pilot) charts.

Since the beginning of shrinkage, hydrothermal, hydrological, and biogenic regimes of the Aral Sea have been changing. This in turn leads to the change in natural processes related to formation of macro- and micro-relief of the seabed. The exposed seabed is subject to denudation processes caused mainly by wind erosion - this leads to changes in macro- and micro-relief on some parts of the seabed. Available satellite information was used to assess such changes in macro- and micro- relief of the seabed.

As an example, Figure 4 shows changes in the seabed relief within Tshe-Bas Bay (the left side of the Figure represents relief derived from the Aral Sea isobaths map, while the right side shows the status of site by April 2001).

Evaluation of the adequacy of data produced during processing of thematic maps and images has shown that there exist some changes in the Aral Sea microrelief.

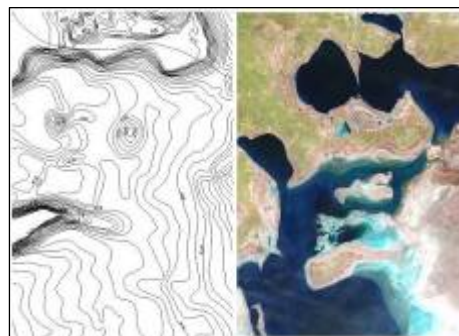


Figure 4. Relief transformation in Tshe-Bas Bay

Under the GEF Project's component "Wetland restoration in Sudochie lake", engineering design was undertaken to restore wetlands with controllable water and salt regime, as well as social and environmental monitoring was conducted. The objective was to achieve environmentally-sustainable conditions in lake Sudochie. A vivid example of the negative effect of low water was the environmental situation in Sudochie wetland - the largest lake system in South Prearalie. Until 2000, the water surface of the wetland had reached 42,000 hectares, while by the end of 2001, it decreased to 6,500 hectares. The fish species in the lakes were deteriorated: high productive fish species, such as Silver Carp, Grass Carp, and Sazan were replaced by less productive ones - Crucian Carp, Roach, and not valuable trash fish. As a result of shallowing and drying up of the wetland's lakes, all reeds and cattail bushes serving as a source of feed and protection for musk rat, local and migratory birds found themselves in dry land.

This complex environmental situation was observed throughout the whole Amudarya delta. Only Muinak and Rybachiyy bays were preserved, but here also, reeds and cattail bushes found themselves in dry land and nesting places of water fowls were destroyed by jackals and foxes. Additionally, the fish stock of the remaining water bodies suffered from overfishing by local people and numerous fisherman groups. Thus, stable natural landscapes practically disappeared as a result of low water in Prearalie. Unstable, mainly degrading landscape became prevalent here. In 1999-2000, main plant varieties in the Sudochie wetland were saltwort, karabarak, and tamarks, to a lesser degree. Due to intensive grazing, moisture deficit, and locust attacks, reed meadows were suppressed.

The work on water distribution apart of the dried seabed has been taken as a basis for development of the ecologically sustainable profile of Prearalie in its new form. The GEF Agency's Project, Component E "Sudochie Wetland Restoration", which designed and implemented engineering measures for the restoration of the wetland, with regulated water-salt regime, was first-born in this respect. The project's objective was to achieve an environmentally stable situation in the territory of the wetland. Moreover, social and ecological monitoring was undertaken within Sudochie wetland. At present, the project has been completed, and the Sudochie Lake is functioning stably enough to mitigate the negative consequences of the Aral Sea desiccation (Figure 5).



Figure 5. Sudochie Lake

Since August 2000, intensive watering-up of Sudochie lake system took place. In 2002, the two-year period of low-water gave place to a period of quite high water availability. An inevitable effect of modification in water regime of wetlands is the change in environmental conditions. Observations in 2002 showed that the water surface of Sudochie system had increased by 40-50%. Thus, under the conditions of a year of high water availability, a the set of structures started to operate and the regime of Sudochie lake regarding water level and flow distribution indicated to correspond in the desired way. Another positive effect of the Sudochie wetland restoration is the vegetational overgrowing of the former Adjibay bay, whereto water is discharged periodically from the Sudochie wetland.

In those projects, the comprehensive land cover change analysis was made:

Dynamics of change in wetlands, lakes, and reservoirs in the Amudarya and Syrdarya deltas, assessed by Landsat images (Assessment of the modified status of reclaimed lands was based on large-scale soil studies carried out within the project network. Four stages of large-scale soil studies of the irrigated area were carried out in Uzbekistan:

- First stage - completed in the 1930-ties;
- Second stage - from 1957 to 1967;
- Third stage - from 1982 to 1987;
- Fourth stage – from 1990 to 1995.
- *Table 1).*
- Dynamics of change in soil cover in the Amudarya and Syrdarya deltas. Estimation was based on soil maps for 1960.
- Dynamics of change in landscapes in the Amudarya and Syrdarya deltas. Changes in natural systems were assessed through field observations and image processing (classification) results.
- Siltation processes in Mezhdurechie reservoir (Amudarya river delta) were assessed using bathymetric maps, geodetic survey; satellite images were used to estimate water surface areas for various period of time.

This work initiated SIC ICWC's remote monitoring over water bodies in Prearalie. The results given in Assessment of the modified status of reclaimed lands was based on large-scale soil studies carried out within the project network. Four stages of large-scale soil studies of the irrigated area were carried out in Uzbekistan:

- First stage - completed in the 1930-ties;
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Table 1 clearly demonstrate dynamics of wetland area, depending on low-water (2001) and high-water (2005) periods, when the watered area increased by 2.5 times.

Assessment of the modified status of reclaimed lands was based on large-scale soil studies carried out within the project network. Four stages of large-scale soil studies of the irrigated area were carried out in Uzbekistan:

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Table 1: Wetland areas in the Amudarya river delta (hectares)

No.	Water body	Date				
		April 2000	June 2001	August 2002	June 2005	August 2006
1.	Sudochie	41897.73	9570.04	6497.2	62146.73	59302.73
2.	Mejdurechie	10050.42	592.79*	18375.21	19738.06	5633.97
3.	Ribachiy	5317.64	2019.68	5513.1	5631.72	6319.38
4.	Muinak	8623.34	1292.23	5163.2	9514.86	16567.9
5.	Zhylytyrbas	29357.73	5277.33	27620.5	125938.9	80993.93
6.	Former Adjibay Bay	10980.9	656.53	6784.7	39887.68	29676.83
7.	Dumalak	4576.89	927.23	6784.9	19608.71	27119.0
8.	Adjibay 2 *)	-	-	-	6025.87	4848.33
9.	Makpalkol	-	-	-	4028.73	3590.45
	<i>Total</i>	127639.83	21062.1	79552.71	329285.69	234052.5

*) Adjibay 2 - Artificial structure located northward of Ribachiy and Muinak reservoirs

For the project INTAS objectives the analysis was based on the results of the second, third and fourth stages. Meadow flood plain and alluvial soils are common in the Amudarya delta. Prior to a stable drying of the Aral Sea their area within the delta was estimated at about 550,000 hectares. Typical conditions of meadow soil formation are complicated by regular flooding by floodwater with subsequent drying.

The studies of soil variations were based on comparison of the 1960 and present mapping information. While the flooded area has considerably reduced, so has the area occupied by these soils. Due to specific hydrological and climatic conditions the meadow flood plain and alluvial soils are subject to rapid drying, ground water level decreases, thus the soils are transformed to meadow takyrs and takyrs soils. The overall situation in the Aral Sea region is as follows. Takyrs and solonchaks soils have increased 91,000 hectares, solonchaks and sands – 43,000 hectares; fixed and loose sands with spots of desert sand soils and solonchaks – 130,000 hectares. Transformations in takyr solonchak soils with spots of sand soils and solonchaks, and also gray-brown solonchak-like soils are negligible. Meadow and wetland solonchak and non-saline soils have reduced 266,600 hectares.

For more than ten years SIC ICWC has been carrying out studies within Amudarya river delta and the exposed Aral Sea bed, and since 2005 has been performing systematic monitoring over the dried seabed together with GTZ. The appearance of desertification processes in the

Amudarya and the Syrdarya river deltas started in the 1960s, which created a need for monitoring these areas in order to assess the possibilities of mitigating the negative consequences of the ecological disaster caused by the Aral Sea desiccation. One possible way of mitigation is the creation of artificial water bodies on the exposed bed; furthermore, it is necessary to identify areas for phyto reclamation (afforestation). SIC ICWC used remote sensing data for a set of tasks, for example: target landscape mapping; evaluation of changes in the area of wetlands; evaluation of dynamics of open water surface; allocation of territories subjected to erosion, etc. The current hydrological, environmental and hydro-geological conditions were assessed according to several directions and stages. The following four main stages of GIS development could be outlined:

- Preparation of initial materials (selection of topographic and thematic maps and satellite imageries);
- Information input - digitizing, development of linear and polygonal topologies, input of attributive information;
- Systematization of topographic and thematic information;
- Specification of morphometric characteristics of natural and man-made water bodies.

The main activities under establishing GIS were as follows:

- Handling thematic maps representing the historic and current state of the study area;
- Processing field data submitted by the NGO “ECO Prearalie” and SANIIRI;
- Three different schemes of placing the system of man-made reservoirs and water infrastructure in the Amudarya delta are tied to the coordinate system;
- Specifying the lay-out and area of natural and man-made water bodies based on the documents submitted by the NGO “ECO Prearalie” and the firm “Aralconsult” as well as on the LANDSAT satellite image.

The use of information representing conditions of the South Prearalie for various dates made it possible to evaluate sedimentation processes in a number of natural water bodies and transformation of their beds due to changes in morphology of the territory as a result of changes in landscape-forming factors of the South Prearalie. The accuracy of results was verified using available satellite images. The GIS Group used topographic maps (1: 25,000 scale) to identify morphologic characteristics of the Djiltirbas and Mezdureche wetlands. As a result of these studies, schematic maps were generated showing the layout of the man-made water bodies, and corresponding sites’ topology for 2000 (Figure 6).

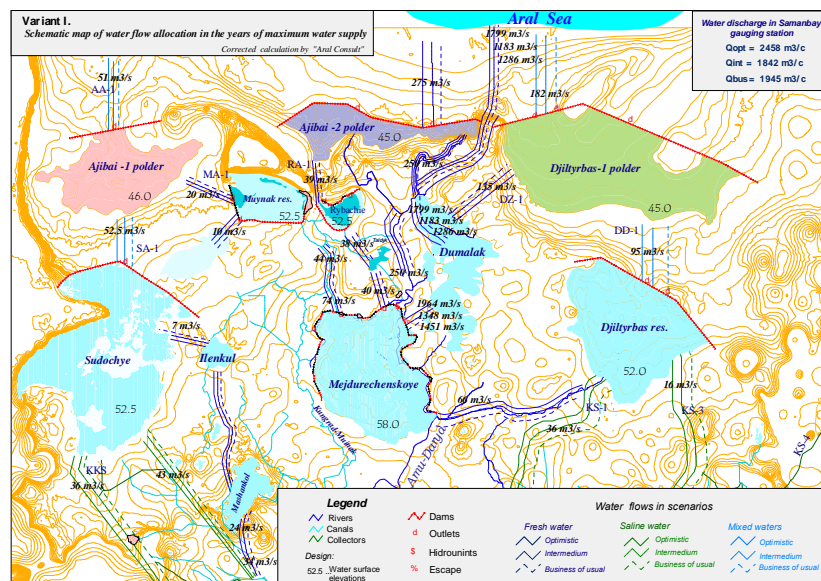
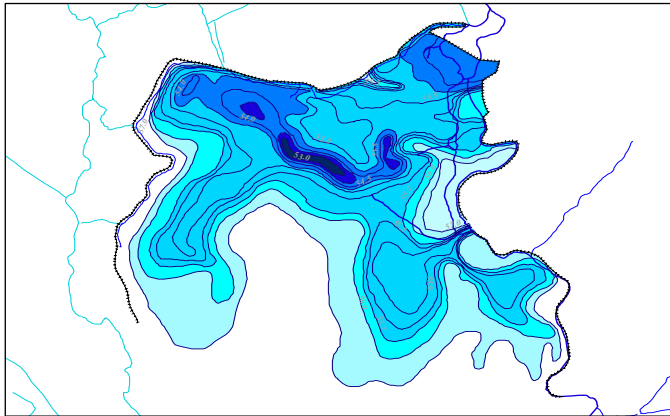


Figure 6. The layout of the man-made water bodies, suggested by SIC ICWC

The spatial analysis shows that the selected scheme of locating polders in the zone of wind erosion processes ensures the greatest extent of environmental security for the most densely populated areas. The GIS Group has digitized a detailed map of the dried seabed from 1994. Comparison of this map with the soil map of 1992 shows that as the sea shrinks, a new-dried bed is being affected by similar salinization processes, i.e. a new-dried bed is comprised of the seaside hydromorphic and excessive hydromorphic solonchaks (including salt marshes) with groundwater levels ranging from 0.1 to 2.0 m. The detailed study of the territory using thematic maps and available field data demonstrates the main trends of landscape changes in the South Prearalie over the period of 1990-2002.



Mezdureche Lake. Data from field topographic surveys (the NGO “ECO Prearalie” and "Aralconsult"), image processing and other information were used as a source for the detailed assessment of Mezdureche Lake morphologic characteristics and sedimentation processes.

Figure 7. Bathymetric Chart of Lake Mezdureche (ECO “Prearalie”)

The bathymetric chart of Mezdureche Lake as of July 2002 (“ECO Prearalie”) demonstrates outcomes of field works. Table 2 shows data derived from processing the bathymetric chart of Mezdureche Lake (1: 50,000 scale).

Table 2. Results of ECO Prearalie’s Data Processing

(1 m increment; intermediate isolines are rounded; for instance, the value of 54.5 is rounded to 55)

	dS (m ²)	Sum S (m ²)	W (m ³)	Sum S (ha)	W (million m ³)
53	769,806.5	769,806.50	769,806.50	76.98	0.77
54	16,875,462.6	17,645,269.10	9,977,344.30	1,764.53	9.98
55	65,646,827.0	83,292,096.10	60,446,026.90	8,329.21	60.45
56	108,237,171.1	191,529,267.20	197,856,708.55	19,152.93	197.86
57	77,253,651.0	268,782,918.20	428,012,801.25	26,878.29	428.01



The comparison of data of “Aralconsult” and the NGO “ECO Prearalie” and results of satellite image processing are given in Figure 8. As an illustration of derived data accuracy, the result of a LANDSAT image processing is shown. The area of Mezdureche wetland was **16,758.38 ha** by August 4, 2002 that correspond actually the on-line data from Karakalpakstan.

Figure 8. Mezdureche wetland

Within the framework of the projects such as NATO SFP # 974357 and GTZ “Stabilization and use of the exposed seabed of the Aral Sea in Central Asia” we classified the exposed seabed according to degree of environmental hazard for natural systems that are wetlands and for population. For the investigations on the desiccated Aral Sea bed, two types of satellite images were used: IRS-1D LISS-III and Landsat-5 TM. For the environmental monitoring tasks, SIC ICWC used the following main stages of initial remote studies, as described in paper (Vostokova Ye.A., and others, 1988):

- Selection of source cartographic information for studying the territory.
- Preprocessing of satellite images.
- Selection of sites for control and detailed study.
- Determination of routes for field studies.
- Unsupervised classification of the images for preparation of field check.
- Development of the land cover classification scheme.
- Supervised classification.
- Creation of thematic map.

As a result of the analysis of the thematic maps and field observations, also considering the relationships between major natural components such as relief, soil, and vegetation, the following basic landscape types of natural-territorial systems were selected:

1. Arid-denudation plateaus and isolated hills
2. Plains of deposition
 - 2.1. Landscapes of marine plains
 - 2.1.1. Landscapes of the exposed seabed
 - 2.1.2. Landscape of lacustrine-alluvial plains
 - 2.2. Landscapes of alluvial-delta plains
 - 2.2.1. Emerging delta landscapes on the exposed seabed
 - 2.2.2. Fore-delta (advancement deltas) of 70s-80s
 - 2.2.3. Modern drying alluvial-deltaic plain
3. Holocene delta (former islands, straits and bays of the Akeptkin archipelago).

The analysis of information, map legends and classifications found more than 40 conditions of different landscapes. In order to adjust this multitude of landscape classes to the potentials of the used RS data, experts from GTZ, TERRA and SIC ICWC agreed on the list of the thematic land cover classes listed below. This cutback enables an assessment of erosion risk degree and track desertification dynamics whilst ensuring a satisfying separability of classes in the satellite image. This classification scheme was finally applied to the Landsat-TM data of 2006. The reduction to 17 classes was performed by grouping of spectrally similar items.

Water

- 1.1. Water
- 1.2. Shallow water, sometimes with reed

Solonchaks

- 2.1. Marsh solonchak
- 2.2. Salt marsh-coastal solonchak
- 2.3. Crust-puffed and crust solonchak
- 2.4. Solonchak with blown sandy cover
- 2.5. Shor solonchak of closed sinks

Sands

- 3.1. Plain sand (with shell rock)
- 3.2. Dune sand, without vegetation

- 3.3. Pit-and-mount sand (poor fixed)
- 3.4. Hilly and hilly-ridgy, poor fixed sands, without vegetation.
- 3.5. Hilly, hilly-ridgy fixed sands

Delta and deposition plains.

- 4.1. Meadows on alluvial plains (reed, herb, cereals on alluvial-meadow, swampy meadow and meadow-bog soils)
- 4.2. Hydromorphic soil subjected to desertification
- 4.3. Shrubs (halophytic vegetation: tamarix, karabarak)
- 4.4. Shrubs subjected to desertification
- 4.5. Shrubby-haloxylon

Analysis of the spectral profiles of the individual classes revealed their unique reflectance characteristics. Field observations were used for selection of reference sites in images, while the adequacy of the selected reference sites was estimated on the basis of spectral profiles. Moreover, the profiles were compared to the generalized curves from paper (B.V.Vinogradov, 1966) where published a summary of the optical properties of vegetation in arid zones.

For the supervised classification, training samples for all above-mentioned classes were collected in the Landsat image. For each class, the histograms of the training samples were analyzed in order to reach a normally distributed set of samples. The closer the histogram is to normal distribution, the better the training set described the target class. While collecting the training sites (signatures) on the image, all samples were checked for their suitability for separating the classes. After characteristics of each reference site were got, image's pixels have been divided into class-references, i.e. supervised classification has been performed. A Minimum Distance method was accepted as the most reliable for given research. The Minimum Distance method is based on deterministic approach. Here pixel is associated with a reference site, the Euclidean distance to the center of which in the space of attributes is minimal. Figure 9 demonstrates the results of supervised classification.

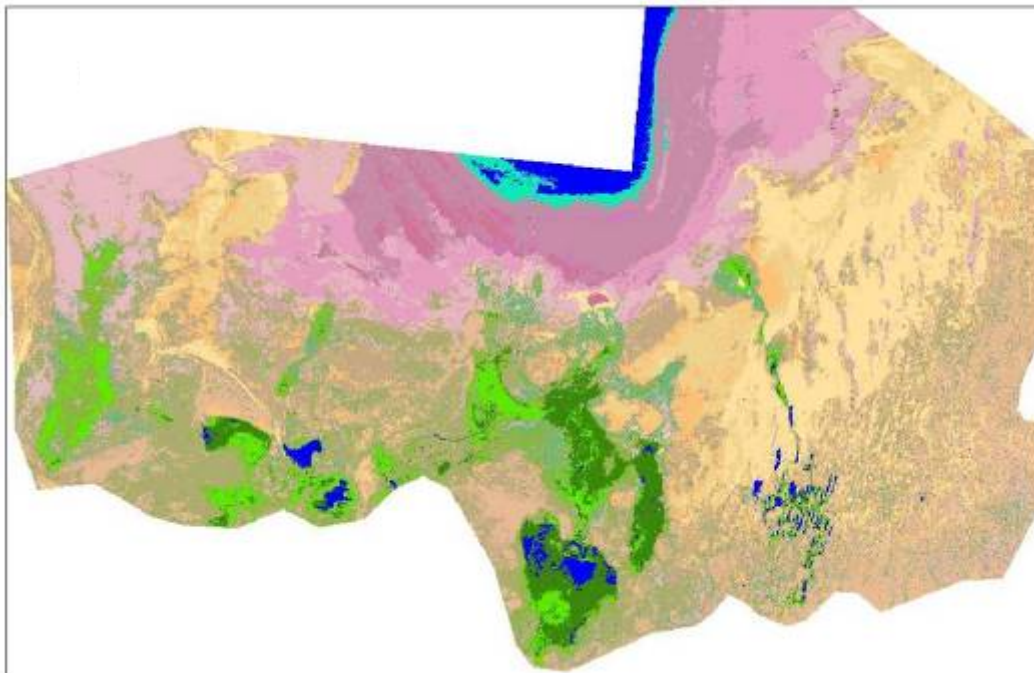



















Figure 9. The results of supervised classification

Table 3: Legend of the land cover map(Figure 9)

<i>NN</i>	<i>Class</i>	<i>Color</i>	<i>Area (ha)</i>	<i>%</i>
1	WATER			
1.1.	Water surface		72848,4	3,16
1.2.	Shallow water, sometimes with reed		25753,4	1,12
2	SOLONCHAK			
2.1.	Marsh soil, without vegetation or with saltwort community		176185,0	7,63
2.2.	Wet-coastal, with cockle-shell, spots of saltwort and sarsazan		163604,0	7,09
2.3.	Desert crust-puffed and crust soil, without vegetation, spots of bushes (karabarak, tamarisk)		24252,0	1,05
2.4.	Solonchak with blown sand cover, sparse orach and selen communities		233747,0	10,12
2.5.	Shor solonchak of closed sinks, without vegetation, sometimes in sarsazan setting		6461,0	0,28
3	SANDS			
3.1.	Plain (with shell rock), without vegetation or sparse bushes (saxaul, tamarisk)		231935,0	10,05
3.2.	Dune, without vegetation		161855,0	7,01
3.3.	Pit-and-mount (poor fixed) with sparse wormwood, bush communities and selen plantings		157498,0	6,82
3.4.	Hilly, hilly-ridge, without vegetation and poor fixed		197222,0	8,54
3.5.	Hilly, hilly-ridge, poor-fixed with ephemeral-wormwood-bush communities		199462,0	8,64
4.	PLAIN DELAIC AND OF DEPOSITION			
4.1.	Meadow on alluvial plains (reedy, forb-Gramineae) on alluvial-meadow, bog-meadow and meadow-bog soils		121101,0	5,25
4.2.	Subjected to desertification, hydromorphic Gramineae -halophyte-forb, with bushes		111891,0	4,85
4.3.	Shrub (halophyte: tamaskm karabarak)		149354,0	6,47
4.4.	Subjected to desertification, shrub		59368,0	2,57
4.5.	Shrub-saxaul (desert forest/artificial plantations)		216163,0	9,35
	TOTAL AREA		2308700	100

Analysis of the error matrix revealed the following measures:

- Overall classification accuracy = 77,90 %
- Overall Kappa statistics = 0,7509

Overall accuracy states the percentage of the validation samples classified correctly. Hereby, it is assumed that the validation dataset is true. The Kappa index of agreement differs in the underlying assumption: It is assumed that the tested classification and the validation samples are independent class assignments of equal reliability. It measures, how well the classification and the validation datasets match, taking chance agreement into account. This means that the match of a validation sample with a correct classified pixel can be merely incidental. A perfect match of classification and ground truth would lead to a value of 1. Both measures are well accepted for the evaluation of remote sensing classification results.

As a result of monitoring, risk map on the exposed seabed was produced (risks were estimated in terms of stability of existing wetlands and expediency of phyto-reclamation. Another objective of this study was the assessment of the ecological risk degree of the landscape types on the desiccated Aral Sea bed, in the means of desertification and soil erosion risk. At the workshop in Tashkent 2006, local and international specialists agreed on the assignment of 4 risk levels to the classes resulting from the land cover mapping. These “risk levels” inversively coincide with the

degree of landscape stability, i.e. level 1 being safe/stable up to level 4 showing maximum area instability and high ecological hazard. Each of the land cover class was assigned to one of the four hazard levels shown in Table 4, and explained below. During the assignment of the ecological hazard degree, the future development of the land cover classes by exogenic processes was also taken into consideration.

Table 4: Rating scale of ecological hazard for classification results

Degrees of ecological risk	Code	Land cover classes assigned (description below)
No (practically absent)	1	2.1 2.2 2.5 4.1 4.3 4.5
Low	2	1.1 1.2 3.5 4.2
Moderate	3	2.3 3.4 4.4
High	4	2.4 3.1 3.2 3.3

1. No risk (practically absent), given to the following classes:

- 2.1 Marsh solonchaks without vegetation or with saltwort communities;
- 2.2 Wet coastal solonchaks without vegetation, with rare isolated specimens of saltwort and sarsazan;
- 2.5 Shor solonchaks of closed depressions;

In the first years after exposition (3-6 years), the coastal and shor solonchaks don't present a hazard, as the groundwater table depth varies from 0.1 to 1.5 m, and a thin salty crust of 1-3 cm is formed on the surface which both protects the surface from aeolian erosion. Over a timespan of approximately 10 years, this protection can be considered as stable. Shor solonchaks can be regarded as stable, since they underly the hydromorphic regime during the major part of a year.

- 4.1 Meadows on alluvial plains (reed, herbs, cereals) on alluvial-meadow, bog-meadow and meadow-bog soils;
- 4.3 Shrubs (halophytic vegetation: tamarisk, karabarak);
- 4.5 Shrubby-haloxylon (desert forest/artificial plantations);

The landscapes belonging to palustrine plains periodically or permanently flooded by river and collector-drainage water do not represent a hazard because they also belong to the hydromorphic regime. Moreover, vegetation is one of the main stabilizing factors in dynamic landscapes. Meadows on alluvial plains have a sufficiently high projective cover, and shrubs contribute to fixing of otherwise unfixed sands and soils.

2. Low ecological risk:

- 1.1 Water surface in the delta;
- 1.2 Shallow water areas, sometimes with reed;

These classes are assigned to level 2, low ecological hazard. Their existence depends on water supply to the delta, i.e. on available river runoff during a year. When the water surface area decreases considerably in low water years, lake beds are being exposed, reed stands (*Phragmites australis*) dry out and may subsequently be subjected to fire. This puts both land cover classes into a potential risk class, but only during drought periods.

- 3.5 Fixed hilly, hilly-ridgy sands, with ephemeral-wormwood-shrub communities;
- 4.2 Hydromorphic soils subjected to desertification, with cereal-halophytic herb communities and shrubs.

3. Moderate ecological hazard.

- 2.3 Crust-puffed and crust solonchaks without vegetation, with rare isolated specimens of shrubs (karabarak, tamarisk);
- 3.4 Poorly fixed hilly and hilly-ridgy sands, without vegetation;
- 4.4 Soils subjected to desertification, covered with shrub vegetation.

Crust-puffed solonchaks are considered as one of the main source of salt and dust transport into atmosphere in saline desert environments. The soil subjected to desertification and covered with shrub vegetation represents a hazard in the view of vegetation cover degradation. This can lead, in turn, to intensive development of eolian erosion processes.. Hilly and hilly-ridgy sands not fixed with vegetation occupy vast territories on the dried bed of the Aral Sea and their thickness increases by 3-5 cm every year. The low vegetation cover (20% to 40%) cannot protect these surfaces from erosion which further increases the potential for aeolian salt and dust erosion.

4. High ecological hazard.

- 2.4 Solonchaks with blown sandy cover and sparse communities of orach and selin;
- 3.1 Plain sands (with shell) without vegetation or with sparse shrubs (saxaul, tamarisk);
- 3.2 Dune sands without vegetation;
- 3.3 Pit-and-mound sands (poorly fixed) with sparse communities of wormwood, shrubs and selin plantings.

These classes constitute territories with intensive development of exogenic (aeolian) processes and represent the highest ecological hazard due to the formation of salt and dust sources. Most part of the area is developed in automorphic regime. After the assignment of the risk levels to the land cover classes, the land cover dataset was recoded in *Erdas Imagine* image processing environment into the risk values. This enables the calculation of the spatial extent of the different risk classes. Based on the scale of ecological hazard and agreed class recoding, the results of the supervised classification transformed into a map showing the ecological hazard degree (Figure 10). Based on this map, an area calculation of each ecological hazard class was done (Table 5).

Table 5: Area estimation for the ecological hazard classes

Risk class	Area [ha]	Map color
No (practically absent)	858621.4	green
Low risk	311353	yellow
Moderate risk	280842	orange
High risk	785035	red

About 40% of the exposed seabed (within the Uzbek territory) can be regarded as safe (no risk), 25% represent low and moderate ecological hazard, and 35% are characterized as highly hazardous.

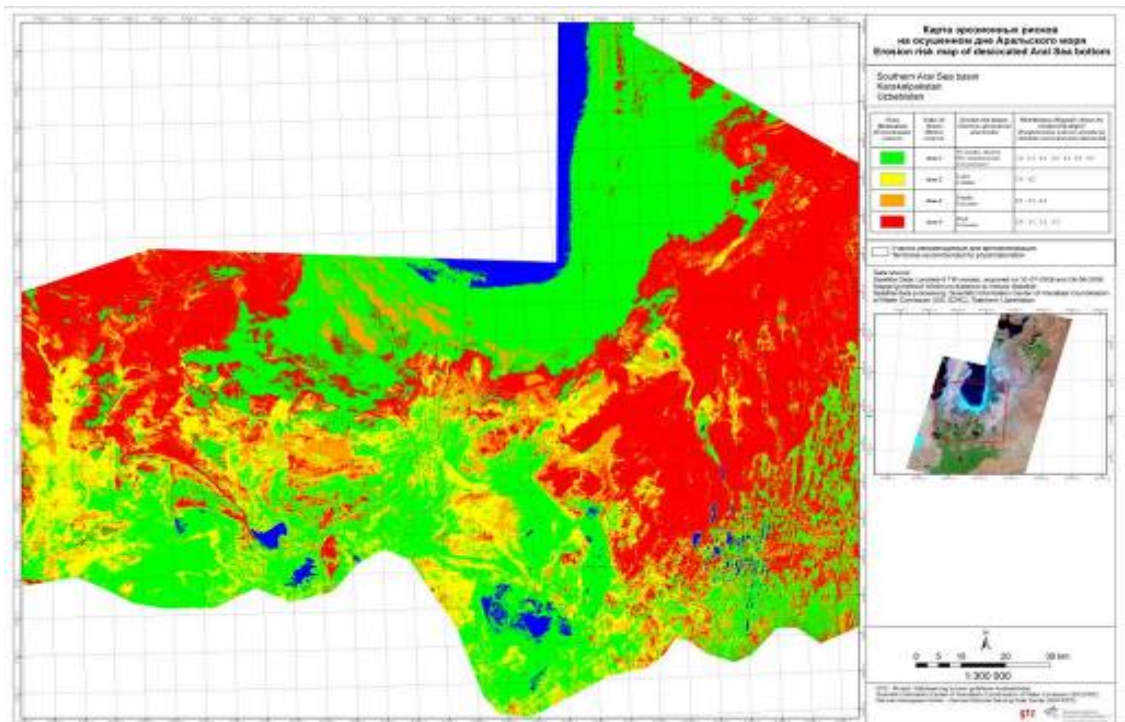


Figure 10. Map of erosion risks

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