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SOLVING HYDROECOLOGICAL PROBLEMS IN THE ARAL SEA REGION USING GIS TECHNOLOGIES

Abstract. *The reservoirs and small water bodies of the Amu Darya delta are of great ecological and social importance for the population of the Aral Sea region. The Amudarya River delta is a dynamic water system consisting of many channels, irrigation canals, drainage collectors, lakes and other small water bodies objects. During the flood period the lakes and reservoirs are filled with water; during the period when the water level in the Amu Darya River decreases then the level in many reservoirs decreases significantly and some dry up. To reduce the risk of drying out of the large lakes of the Aral Sea region the dams were erected to regulate the level in Lake Sudochye. In published sources show the analysis of environmental indicators is descriptive or statistical in nature. This paper shows the possibilities of using GIS technologies for monitoring the environmental situation and in searching for optimal management of the hydrological regime of regulated water bodies in order to achieve an ecological balance between different biological objects. The use of GIS technologies makes it possible to predict the number of populations of the animal world if the number of populations is determined by the size of the living space necessary for the reproduction and existence of a particular biological species. Using the water balance equation, the filling level of Lake Sudochye was calculated for a favorable ecological balance.*

Key words *: ecology, GIS, reservoir, population, vegetation, hydrology, water balance.*

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РЕШЕНИЕ ГИДРОЭКОЛОГИЧЕСКИХ ЗАДАЧ СРЕДСТВАМИ ГИС-ТЕХНОЛОГИЙ В ПРИАРАЛЬЕ

Аннотация. *Водоемы дельты Амударьи имеют большое экологическое и социальное значение для населения Приаралья. Дельта реки Амударьи представляет собой динамическую водную систему, состоящую из множества протоков, оросительных каналов, дренажных коллекторов, водоемов. В период половодья водоемы наполняются водой, в период снижения уровня воды в реке Амударье во многих водоемах значительно снижается уровень, а некоторые пересыхают. Для снижения риска пересыхания крупных озер Приаралья возведены дамбы, посредством которых осуществляется регулирование уровня в озере Судочье. В опубликованных источниках анализ экологических индикаторов имеет описательный или статистический характер. В данной работе показаны возможности применения ГИС технологий для мониторинга экологической обстановки и в поиске оптимального управления гидрологическим режимом регулируемых водных объектов с целью достижения экологического баланса между различными биологическими видами. Применение ГИС технологий позволяет прогнозировать численность популяций животного мира, если численность популяций определяется размером жизненного пространства необходимого для размножения и существования конкретного биологического вида. С использованием уравнения водного баланса рассчитан уровень наполнения озера Судочье для благоприятного экологического равновесия.*

***Ключевые слова**: экология, ГИС, водоем, популяция, растительность, гидрология, водный баланс.*

Introduction and problem statement. The conservation and rational use of biodiversity in Uzbekistan is a necessary condition for ensuring environmental safety and sustainable development of the country, as well as the adaptation of natural and economic systems to ongoing climate change processes.

State policy and measures taken in the field of environmental protection and sustainable use of natural resources in Uzbekistan are based on the principles of integration of economic and environmental policies for the conservation and restoration of the natural environment. Monitoring is a fundamental tool for measuring the effectiveness of actions taken to conserve biodiversity and for identifying biological trends, both natural and anthropogenic.

Of particular concern in Central Asia, including Uzbekistan, are the processes of desertification and the high level of anthropogenic impact on desert ecosystems. Particular attention is paid to the problems of biodiversity in the Aral crisis zone. In the context of climate change and while maintaining the current situation, the continued drying of the remaining reservoirs of the Amu Darya delta and increasing salinity inevitably leads to the suppression of active biological life in the Aral Sea region.

The existing wetlands of the Amu Darya delta respond strongly to changes in water supply, air temperature and precipitation. The drying out of the studied lakes in the summer leads to large losses of fish adapted to life in these reservoirs, as well as to damage to fisheries.

Changes in the hydrological regime led to an increase in the salinity of many lakes, which caused changes in hydrochemical parameters, led to a change in vegetation and the disappearance of many species of water-submerged plants.

The studies carried out in 2021-2023 showed the depletion of the flora of aquatic higher vegetation in Karakalpakstan. From the previously presented 21 families representing 60 species, 15 species of higher aquatic plants from various genera have now remained.

Given the scarcity of water resources in the Southern Aral Sea region, the lakes of the Amu Darya delta are the most vulnerable ecosystems. One of the “dangerous” threats to all wetlands is the burning of last year’s reed beds in order to obtain young growth suitable for consumption by livestock. However, the biggest, main threat to the biodiversity of flora and fauna is the complete drying out of water bodies.

Thus, the Southern Aral Sea region with its vast territory, diversity of ecosystems and species composition needs the development of special research aimed at inventorying, assessing the state of biodiversity, developing an environmental monitoring system, and developing principles and methods for preserving natural ecosystems. In this regard, constant monitoring and improvement of security measures is necessary.

Study of the problem. When solving various environmental problems, especially when analyzing biological factors, the use of mathematical methods is often limited to statistics.

In published sources, the analysis of environmental indicators is either descriptive or statistical. The problem of studying floodplains of rivers in humid and urbanized areas throughout the world is given special attention [1, 16, 17]. GIS tools can serve to identify optimal hydrological regimes for water bodies from an environmental point of view [11]. The use of GIS makes it possible to predict the development of populations across a territory, provided that certain patterns of development of a biological species are discovered depending on environmental conditions.

The water ecosystems of the Amu Darya delta are a single complex consisting of a network of main irrigation canals, collectors, lakes and lake systems, united by a single source of water supply - the Amu Darya [9]. The existence of the entire natural complex depends entirely on the water supply conditions of the Amu Darya.

In the past, Lake Sudochye was a large, but shallow, basin on the territory of the Amu Darya delta . It occupied the Aybugir lowland . In this capacity, Sudochye is already marked

on the sea map of A.I. Butakov (1848-1849), where the swampy lake Aybugir or Laudan is indicated. The lake extended 24 km southeast of the shore of the Aral Sea, an area southwest of Cape Urga.

The eastern cliff runs along the western shore of the lake Ustyurt plateau.

Previously, Sudochye was fed by the channels of the Amu Darya river Raushan and Priemuzyak and was connected by the channel to the Aral Sea [18].

The water surface area of the lake reached 350 km², while its length reached 250 km with an average width of 15 km and an average depth of 2 m. Water mineralization varied in the range of 0.6-1.7 ‰. Sudochye served as a spawning ground semi-anadromous fish species, up to 2000 tons of fish were caught per year.

In the 1950-1970s, due to land irrigation, the inflow into the lake decreased significantly, and it completely lost its significance. In the 1960s, due to a decrease in the level of the Aral Sea and the blocking of the Raushan channel, which interrupted the flow of almost all river water, Sudochye began to dry out. In 1968, the shallowed lake broke up into separate reservoirs. In 1972, its area was 96 km².

However, at the same time, the inflow is restored, mainly due to collector and drainage waters. Water from the Amu Darya began to be diverted to Sudochye through the Kungrad collector and the Main collector. The condition of the lake turned out to be completely dependent on the water regime of these canals. The " National Encyclopedia of Uzbekistan " notes that the size and mineralization of the lake are subject to rapid changes.

The aim and objectives of the work. The main goal of this research is to determine the possibility of using GIS technologies to analyze the ecological state of a reservoir under various filling regimes and to identify the most optimal hydrological regime for the system's resistance to the risks of reducing biological diversity.

Among the research objectives, the most prominent are the tasks of constructing a mathematical model based on fundamental environmental limitations for individual biological species and the risks of population decline.

To identify the optimal hydrological regime of Lake Sudochye when implementing regulated water supply to the lake, taking into account water losses due to transpiration by vegetation, the conditions of existence of certain species of animals and vegetation.

Materials and methods. The work used methods for analyzing the terrain and bathygraphy data using GIS technologies. The source materials are satellite terrain data. Published sources on species, canal and hydraulic engineering.

Results and its discussion. A distinctive feature of the Amu Darya delta is the vulnerable nature of its ecosystems, due to the hot climate and increasing water shortages due to the redistribution of the river's water resources in the upstream areas of the basin. This significantly limits fish productivity and the development of game animals, muskrats and birds.

The Amudarya River delta is a dynamic water system consisting of many channels, irrigation canals, drainage collectors, and reservoirs. During the flood period, the reservoirs are filled with water; during the period of decrease in the water level in the Amudarya River, the level in many reservoirs decreases significantly, and some dry up (Fig. 1).

Satellite images depicting the Amu Darya delta show the dynamics of water bodies. In the summer, reservoirs dry out significantly and the coastline, marked by bright outcrops of salt deposits, stands out clearly in the photographs.

Drought 2000-2001 led to extensive drying out of water bodies in the coastal zone of the Amudarya and to the total death of commercial fish populations in the region, undermining the resource base of fisheries, reducing the number of wild birds and the disappearance of the muskrat.

Biological indicators include species of plants and animals, including fish, which can be used to assess the state of the environment and monitor its quality and changes. Indicators of the well-being of water bodies are the high bioproductivity of ecosystems and the development of hunting and commercial game, fish productivity, and aquatic vegetation [11].

Abiotic indicators: water exchange, depth of the water system, water level fluctuations, hydrological regime, transparency, salinity, oxygen concentration in water, open water surface.

Biotic indicators include the development of aquatic vegetation, the development of coastal vegetation, the production of reeds and other vegetation, phytoplankton, zooplankton, zoobenthos, periphyton, avifauna - species diversity, the nature of stay in a reservoir, ichthyofauna - the structure of communities and conditions of reproduction.



Fig. 1. Current (12/10/2022) state of the Amu Darya delta (Landsat satellite image Copernicus)

The main requirement for a regulated hydrological regime of a water body is the fulfillment of water balance conditions [13]. The main restrictions on the hydrological regime of the lake are the creation of conditions for the life support of the populations of biological species inhabiting the object. The second condition is the need to maintain the filling of the lake with water to certain level marks in order to ensure the minimum possible preservation of the habitat [12].

First of all, it is necessary to determine the main biological species living in the Sudochye reservoir and surrounding areas [14].

Lake Sudochye is home to 24 species of fish, 230 species of birds (118 species are hydrophiles), of which 24 are included in the Red List of the International Union for Conservation of Nature and 12 in the Red Book of Uzbekistan, as well as more than 30 species of mammals (of which 2 species are included in the Red Book of Uzbekistan and 3 species in the Red List).

From spring to autumn, Lake Sudochye plays an important role as a place of mass concentration of waterfowl. During the spring migration season, the number of waterfowl in the lake basins exceeds more than 100 thousand. Local residents use the lake for fishing and collecting reeds for livestock and building materials.

According to the observations of researchers [10]: 114 species of birds belonging to 15 orders and 34 families were recorded on the territory of the Sudochye system and adjacent territories. Birds distributed by orders: Podicipediformes - 5 species, Pelecaniformes - 3, Ciconiiformes - 4, Phoenicopteriformes - 1, Anseriformes - 17, Falconiformes - 9, Galliformes - 2, Gruiformes - 1, Charadriiformes - 18, Columbiformes - 2, Strigiformes - 2, Caprimulgiformes - 1, Coraciformes - 2, Piciformes -1, Passeriformes - 46.

Similar data were obtained when analyzing reed beds of lakes in the Sudochye wetland in the summer and autumn of 2020. Biologists found [10] that high water mineralization had a

depressing effect on the development of reeds, which was expressed in a decrease in its growth and biomass, and a low number of young stems. A particularly more negative impact of increased water mineralization was evident in the reed thickets of the southern part of the lake, where dead communities of this plant were more common.

In some cases, the dependence of the development of populations, among other things, is directly determined by the depth of the reservoir of their distribution. Some species are almost rigidly tied to the depths of the reservoir in a certain interval. It is a known fact that for the normal functioning of organisms there are certain habitat criteria. Moreover, for each of the criteria there is a certain acceptable range, beyond which the population is doomed to extinction.

Naturally, within the range there may be some optimum at which the population size will be at its maximum level, all other things being equal. For example, according to research by the UNESCO Caspian Floating University [4], among the feeding conditions of bream in the area of Maly Zhemchuzhny Island (Northern Caspian), it was revealed that "... that the most favorable conditions have developed in the depth zone from 3.0 to 6,0 *м*, at which the feeding index was the maximum. For sturgeon, these are depths from 0 to 12*м*.

According to studies of the reaction of juvenile Caspian crayfish, it was revealed that the optimal salinity for them should be considered the range of 3-6‰".

According to the results of biological studies [5] in the reservoirs of the Aral Sea region, the optimal depths for the development of juvenile fish are depths from 20 to 30 sm. Various hydrological and hydraulic regimes of collector-drainage canals, water from which flows into Lake Sudochye, were taken into account [5].

To select the optimal regulation mode, a digital model of the relief of the earth's surface of the adjacent territories and the bathymetric surface of the lake was built, which made it possible to calculate water losses due to evaporation from the water surface, transpiration by coastal vegetation, water supply requirements in different seasons of the year and other necessary parameters [7].

Many factors, including biological ones, were taken into account as criteria for optimizing the hydrological regime.

Migratory birds are of great ecological importance for the Sudochye wetlands. In different seasons of the year, birds occupy coastal areas of the water surface and settle on the shores of the lake.

Of the biological factors, the following criteria were adopted:

- In winter, it is necessary to maintain a stable water level, since when it fluctuates, especially when it rises, mass death of muskrats is possible, settling along the banks in burrows-"huts" and hibernating in winter.
- Favorable conditions for the development of juvenile fish occur at depths below 30 sm the surface during the period from spawning to adulthood (May-August).
- The development of reed, which is of commercial importance, occurs at depths of up to three meters from the surface of the water.

The modeling results were displayed in a GIS and presented in quantitative form. The distribution of reeds across the territory was assumed for places with depths up to 3 meters. Transpiration was calculated according to this area. Based on the research materials, a table of vegetation evaporation of reed per unit area was compiled (Table 1).

Table 1

Seasonal progression of water losses due to transpiration by reeds and evaporation from open water surface [18]

Months	April	May	June	July	August	September	October	Per season
Transpiration reed, mm	29.0	119.0	321.0	394.0	218.0	103.0	34.0	1298
Evaporation from water surfaces, mm	96	208	272	320	304	208	112	1552

To calculate evaporation from an open water surface, we used empirical formulas recommended in the Guidelines for calculating evaporation from the surface of water bodies [8], which take into account : the maximum elasticity of water vapor, calculated from water temperature, absolute humidity at altitude 2 meters, altitude position above sea level, coefficient depending on the temperature difference between water and air, wind speed based on observations at weather stations in the Aral Sea region [15].

The calculations used operating data from Uzhydromet hydrometeorological stations located in the Aral Sea region. The hydrometeorological precipitation regime was taken based on average monthly values over a long-term period based on materials from Uzhydromet (Table 2).

The table shows the number of days with rain. This is an important factor in terms of runoff from the surface of surrounding areas. Obviously, with such an amount of precipitation, only the water that flows from the coastal areas enters the reservoir from the surface.

Table 2

Climatic characteristics in the Amu Darya delta
(based on materials from Uzhydromet)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average temperature (°C)	-2.7	-0.5	7.3	15	22.4	27.4	29.4	27.5	20.6	12.3	3.9	-1.4
minimum temperature (°C)	-6.6	-5.4	1	8.1	15.3	20	22.4	20.6	14.1	6.5	-0.6	-4.9
maximum temperature (°C)	1.8	5	13.5	21.1	28.5	33.5	35.4	33.8	26.9	18.3	9	3
Precipitation (mm)	12	11	19	19	15	6	2	2	4	9	11	11
Humidity (%)	68	64	53	43	35	30	31	32	37	49	66	68
Rainy days (D)	2	2	3	3	3	1	1	0	1	2	2	2

The main thing is to take into account the slight slopes of the surface itself, but also the soils that make up these territories [6] and these are mainly desert sands, with a small amount of soil.

The water balance equation for calculating the water level and water surface area can be written in a simple form:

$$\Delta W/\Delta t = X + K - E - T - C \quad (1)$$

where $\Delta W/\Delta t$ is the change in the volume of water (W) over time t , X is the amount of precipitation over time t , K is the drainage of the reservoirs, E *is* evaporation, T is transpiration, C is the discharge through the dam.

The area occupied by reeds and the area of open water depend on the water level in the lake. This determines the consumable parts of the lake's water balance.

Figure 2 shows one of the calculation options. The areas occupied by reeds and open water surface are shown; the calculations used the capabilities of GIS technologies [3].

Here it is necessary to note the fact that the result of constructing a GIS calculation map, built from topographic maps at a scale of 1:25000, was compared with a satellite image of the same territory, and it turned out that some areas of the digital elevation model did not correspond to the image.

Where there was a water surface in the image, there was land on the DEM. When setting different levels of reservoir filling on the DEM, the image did not match the satellite image.

Since the satellite image is an objective reflection of reality, it became clear that the topographic maps were either outdated or had significant errors in their construction. To clarify the DEM, appropriate adjustments were made.

A digital elevation model was tested using topographic maps. Relief elevations and water-filled areas were identified. Water-filled areas stood out especially brightly on satellite images and were bordered by bright stripes of the coastal line.

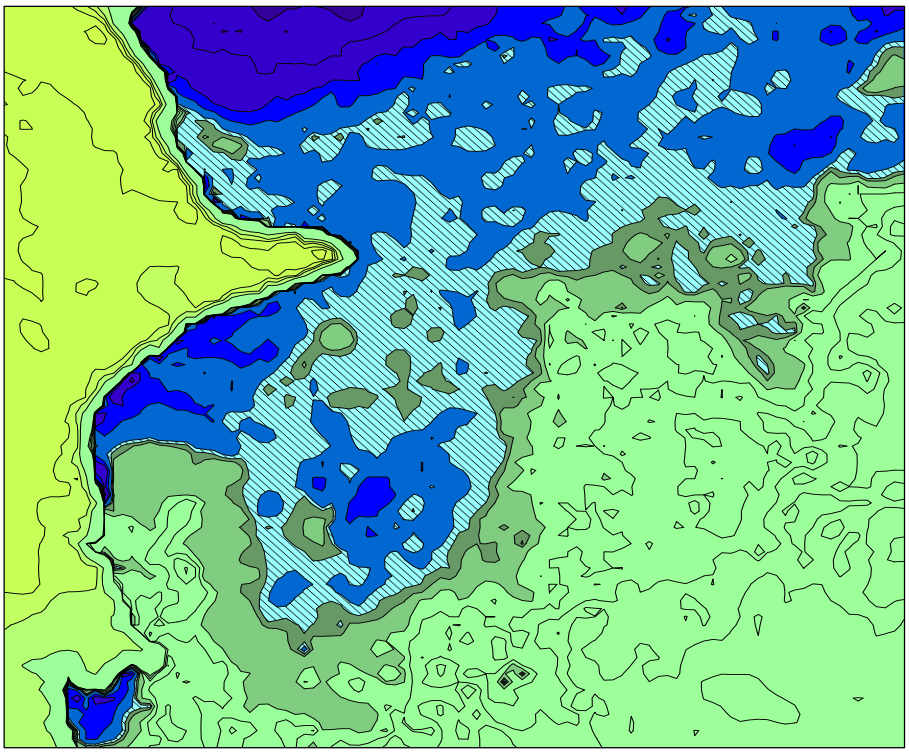


Fig. 2. Displaying the calculation result of one of the options for filling Lake Sudochye at the mark 52,6 m. Dark areas are open water surface. Hatching - reed thickets.

These stripes occur when the capillary level of groundwater exceeds the surface and salts from evaporated water are deposited on the surface of the earth. This circumstance is reflected by a brighter contour around water bodies located in the zone of intense evaporation. Salts on the surface of the earth are objects of stronger reflectivity.

Thus, the digital relief model, built from topographic maps, was corrected by additional geodetic measurements on the ground in the area of Lake Sudochye, according to the methodology proposed [2].

As mentioned above, for optimal development of fish fry, depths of up to 30 sm. Using a digital relief model, a histogram of the distribution of depths was constructed 30 sm (in relation to the volume and area of the mirror) at different filling levels of the reservoir.

The distribution of depths over the territory of Lake Sudochye was calculated 30 sm. According to the histogram of depth distribution of 30 cm, the maximum value of the territory area is at 52.6.

If we assume that the number of fish fry is determined and depends on the conventional unit of space per individual, then during the growth of fry, it should be considered optimal for the fish population to maintain the lake filling level at. 52,6 м, at which the volume of water with depths up to 30 sm will be maximum. Figure 3 shows the contour of the area with depths up 30 sm to the water level in the lake at mark 52,6 м.

The optimal filling level is determined based on the dependence of the distribution of biological species on the filling depth.

Thus, the use of a digital relief model and bathymetric characteristics makes it possible to determine the optimal filling level and hydrological regime of a reservoir to increase the number of biological objects according to known dependencies.

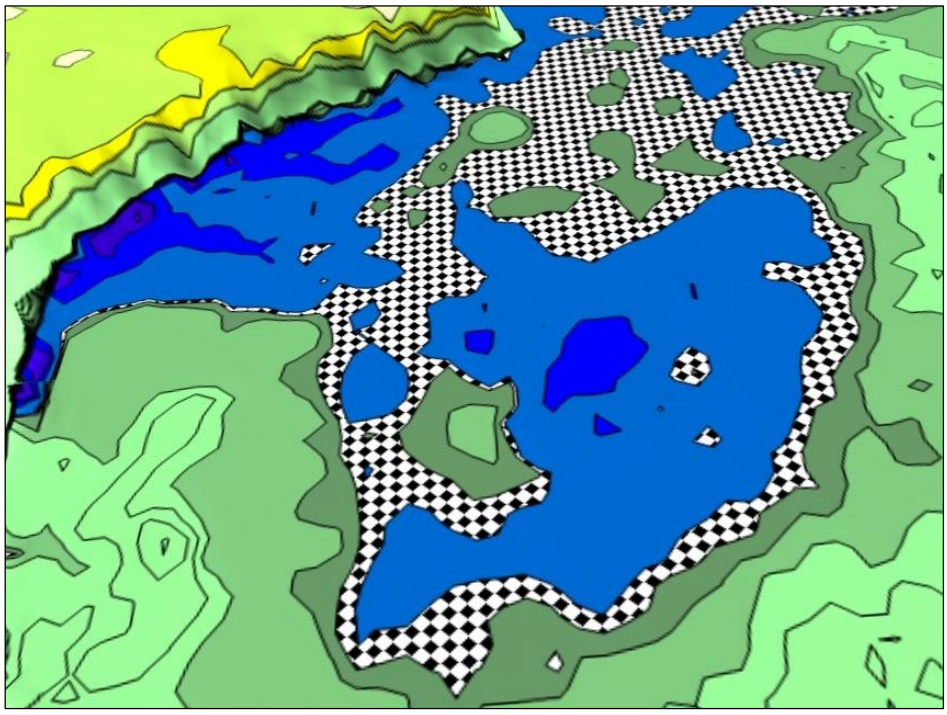


Fig. 3. Digital relief model of Lake Sudochye at the water level of 52.6 m. Hatching shows areas favorable for juvenile fish (depths up to 30 sm)

Conclusions. The application of science-based principles allows us to develop technological solutions using GIS capabilities to assess water bodies in the territorial distribution and distribution of vegetation.

Scientifically based technological solutions make it possible to calculate the optimal mode for managing a regulated reservoir. If the characteristics of a reservoir are known (filling level, calculated depths for different water supplies, etc.), then it becomes possible to set the hydrological regime of water supply based on the known parameters of the life activity of biological species.

The use of GIS technologies to select an environmental basis for decision making allows us to calculate the management regime of a reservoir that is most favorable for biological productivity.

In the case where the water regime of a reservoir is unregulated, it is possible to predict the development of biological species based on known bathygraphy factors that determine population size.

As a result of research on Lake Sudochye, the optimal filling level was established at around 52.6 meters. By maintaining the water level at 52.6 meters, the area of depths up to 30 cm will be maximum, which will increase the conditions for obtaining the maximum number of fish in the lake. This level can be maintained during the period May-August.

In winter, it is necessary to maintain the lake's filling level at a constant level to prevent flooding of the muskrat's huts. Evaporation and transpiration in winter are minimal and it is possible to discharge excess water through the dam gateways.

Areas occupied by reeds will serve as a favorable habitat for waterfowl during migration.

The use of a digital relief model and bathygraphy data makes it possible to assess the manifestation of the hydrological regime of a reservoir and predict the impact of water bodies on the environment.

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