Assessment of changes in vegetation cover of reservoir banks using GIS technologies

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Abstract. The article presents the dependence of changes in the vegetation cover of reservoir banks on geographical location, the area of shallow water depths up to 2 meters at the NPA and the configuration of the object. The analysis was carried out with the help of GIS technologies and maps were created to visualize the change in vegetation cover of reservoirs. Shurtna, Charvak and Kapchagai reservoirs were selected as objects. The results showed that temperature, location, shape, soil and water composition of the reservoir play a major role in overgrowth. It was also revealed that aquatic plants are adapted to seasonal temperature fluctuations. In spring and summer, when water temperature increases, active growth of aquatic vegetation begins. In fall and winter, when temperatures decrease, plant growth slows down and some species may go dormant. Landsat OLI satellite imagery was used to collect the data. This high-resolution satellite captures objects at 30 m/pixel resolution and has 11 spectral layers. These layers and resolutions allow large objects to be analyzed at high resolution

1 Introduction

Global climate change is now threatening all ecosystems on Earth and the species they support, as well as the services and resources they provide to people [1]. Freshwater is a precious resource and its future, along with the species and ecosystems it supports (nearly 7% of global biodiversity, despite freshwater being small in area and relative volume [2]), is uncertain. Freshwater ecosystems are among the most threatened. Threats from climate change, pollution, water harvesting, flooding and other stressors are widespread, and no freshwater ecosystem can be defended in the face of these threats [3]. Sources have been usurped for human consumption worldwide, and lakes in alpine, arctic, and boreal regions are being impacted by climate warming and airborne pollutants (e.g., [4]). De Graaf et al. (2019) [5] estimated that by 2050, two-thirds of the world's developed watersheds will reach environmental flow limits due to groundwater pumping. These impacts on freshwater ecosystems require a better understanding of these threats, how they affect biodiversity, and ways to counteract them. Among the key knowledge gaps are accurate global lists of freshwater-dependent species. Only relatively recently have important steps been taken to

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develop such lists [6]. Addressing such gaps will bring us closer to addressing the challenges of sustainable management of freshwater ecosystems. Each of the articles in this Virtual Special Issue (VSI) addresses knowledge gaps, with most articles focusing on a single major ecosystem type.

Continental aquatic ecosystems are among the most threatened and altered natural systems. Water is generally considered a free resource and wetlands are perceived by people as wastelands that should be converted into "useful" systems [6]. For coastal and inland waters, there is a continuous loss of natural wetlands and a continuous increase in artificial wetlands. A review by Davidson (2014) [7] showed that the recorded long-term loss of natural wetlands averages 54-57%, but since the 18th century, losses could be as high as 87%. Moreover, the author notes that there are insufficient data to provide a comprehensive overview of changes in wetlands worldwide, especially in Africa, Neotropical regions and Oceania. There is a lack of data, especially on temporal trends, as well as on some of the world's largest flooded forest areas, such as in the Amazon and Congo basins [8].

Due to the irregular location of rivers, lakes and other hydrological objects on the Earth's surface, artificial reservoirs have become a common planetary phenomenon. They include various ponds, canals, reservoirs, filtration ponds and other objects of unique economic and/or biospheric importance. The main purpose of creating reservoirs is to accumulate water for its subsequent use. In addition, a reservoir as an artificially created water object has a strategically significant function in the sectors of national economy and ecological biosphere [1].

The construction of regulating reservoirs makes it possible to partially or completely eliminate the conditions of such unfavorable phenomena as floods and floods. At the same time, in addition to reducing direct damage from them, the costs of construction and reconstruction of capital facilities in various sectors of the economy are also reduced due to lower costs of flood control. Creation of reservoirs solves the problem of water shortage in certain regions, and also solves the ameliorative problem of water supply after the most optimal terms of irrigation of agricultural crops. Water reservoirs are ubiquitous objects for organization of fishery. Commercial fish species (bream, pikeperch, etc.) are often reared in artificial reservoirs. In addition, initiatives are taken to acclimatize such valuable fish species as fathead carp, white amur, rainbow trout and others in this reservoir.

In addition to their economic importance, water bodies are also important for the biosphere. For example, their water areas provide favorable conditions for nesting, breeding and wintering of waterfowl. The same applies to mammals, whose life is directly connected with water. Water bodies influence the level and balance of groundwater in the area. In addition to animal life, both the water body itself and the areas immediately adjacent to it contribute to the development of aquatic vegetation, as well as various mollusks and insects [2, 3].

Since reservoirs mainly receive water from river networks, which, passing through large industrial and urbanized centers, carry a significant amount of pollutants [4-8], the assessment of the ecological state of artificial reservoirs is an urgent task of modern hydroecology. At the same time, more informative criteria for such assessment are often not only properties of the hydrochemical regime [9-12], but also hydrobiological indicators [13, 14].

In particular, the dynamics of phytoplankton, zooplankton and benthos are traditionally considered as criteria that can serve as an indicator of the ecological state of a water body [15, 16].

Human-induced changes in climate, land use and land cover have significantly altered rainfall patterns [11]. River training and water management, which may include the construction of single and cascading reservoirs and intake tunnels, have further altered river

hydrology and water quality. After several decades of development, hydropower has recently become an important part of China's energy mix [16]. The construction of large hydropower plants has caused serious environmental problems, including eutrophication of retaining zones as in the Three Gorges Reservoir, reduction of fish stocks such as Chinese carp along the Yangtze River [14], and reduction of fish habitats such as Yangtze sturgeon [14].

Due to the irregular location of rivers, lakes and other hydrological objects on the Earth's surface, artificial reservoirs have become a common planetary phenomenon. They include various ponds, canals, reservoirs, filtration ponds and other objects of unique economic and/or biospheric importance. The main purpose of creating reservoirs is to accumulate water for its subsequent use. In addition, the reservoir as an artificially created water object has a strategically significant function in the sectors of national economy and ecological biosphere [17].

Kozlov et al. revealed that despite the presence of certain anthropogenic impact on the water area of the Cheboksary Reservoir, its hydrobiological condition remains satisfactory, which is determined, on the one hand, by a wide buffer limit of up to 240 Level of ecological and hydrobiological indicators in the water body pollution level of the Cheboksary Reservoir and, on the other hand, by chronic anthropogenic load on the chemical composition of all watercourses of the reservoir [3].

Geographic information systems (GIS) are used to determine the change in usable volume, area of gyroko reservoirs. Evrem, 2019 a digital elevation model (DEM) was created using a topographic map of the Buyuk-Karachay basin. This map was used to characterize the basin, stream network, reservoir volume and reservoir area. In his study, the Buyuk-Karacay dam, which is still under construction in Hatay province in Turkey, was selected as a case study. The reservoir volume of the dam was estimated using the Ripple method. Procedures for determining the storage volume from the crest height are described. The GIS application provides useful information for water managers and planners. Water storage capacity and water surface area can be analyzed for different dam locations, which is easier than the reservoir survey method to find the most appropriate dam location [7].

2 Materials and methods

2.1 Classification of reservoirs

Reservoirs can be subdivided into types according to the morphological structure of the bed (a natural depression of the earth's surface occupied by water), the method of water filling, geographical location, place in the river basin, and the nature of flow regulation.

Valley (river), basin (lake) and basin-valley reservoirs are distinguished by morphological structure of the bed.

- Classification by nature of nutrition.

Most of the reservoirs in the region are confined to lake-like extensions of river valleys or drainless closed basins. The reservoirs are filled either by the river or by supply canals [12].

According to the condition (nature) of feeding, reservoirs can be classified as channel, flood and mixed feeding.

Table 1 presents classification of Central Asian reservoirs by feeding character [9].

Table 1. Classification of Central Asian reservoirs by feeding character.

	Riverbed	Bulk	Mixed meals	Total

Kyrgyzstan	17	16	1	44
Uzbekistan	25	28	2	55
Tajikistan	9	2		11
Turkmenistan	6	10		16
Total for the region	57	56	5	126

The largest channel reservoirs in the Syrdarya basin are Toktogul, Kayrakkum, Andijan, Charvak, and Nurek in the Amudarya basin. Talimardjan, Kattakurgan, Khauzkhan in the Amudarya river basin are the largest of the bulk reservoirs. The Karkidan reservoir is a mixed-feeding reservoir.

Thus, 48% of operated reservoirs are channel reservoirs, 49% are filled reservoirs, and 3% are mixed-flow reservoirs.

According to the **method of water filling**, reservoirs are subdivided into impoundment reservoirs, which are filled with water from a watercourse, and filling reservoirs, to which water is supplied through a canal or pipe from a neighboring water body (e.g., reservoirs of pumped-storage power plants) [1].

According to **geographical location**, there are mountain reservoirs (altitude from sea level more than 1000 meters), foothill reservoirs (altitude from sea level from 500 to 1000 meters), plain reservoirs (altitude from sea level 500 meters) and seaside reservoirs (a few meters). Examples of mountain reservoirs are the Charvak reservoir, foothill reservoirs - the Kapchagai reservoir in Kazakhstan, and plain reservoirs - the Shurtan and Talimardjan reservoirs in Uzbekistan Depending on their location in the river basin, reservoirs are upstream and downstream [1, 12].

By temperature. Reservoir temperature has a significant impact on vegetation for the following reasons:

Photosynthesis processes: Water temperature directly affects the rate of photosynthesis in aquatic plants. Optimal temperatures promote more efficient absorption of light and carbon dioxide, which increases plant growth. Temperatures that are too low or too high can slow these processes and even damage plants.

Thus, reservoir temperature is one of the key factors determining the growth and diversity of aquatic vegetation, as well as the health and balance of the ecosystem as a whole [12, 17].

- **Classification by configuration**

The configuration of reservoirs in Central Asia is not characterized by great diversity. Channel reservoirs are mainly elongated along the riverbed, while fill reservoirs are shaped depending on local topographic conditions.

According to the shape of water surface, round-shaped and oval-oval reservoirs belong to the round-shaped and oval-oval reservoirs, which have bowl elongation index l /vsr from 1.5 to 5.4.

Valley channel reservoirs belong to the group of oval-elongated and elongated reservoirs (l /vsr=5... 10).

The most elongated reservoirs include large foothill valley reservoirs: Nurek (l/vsr=46.7), Toktogul (l/vsr=14.8), Charvak (l/vsr=8.1). Analysis of the shape of the water surface of the reservoirs at the elevation of the NPA allows classifying the reservoirs of Central Asia as: valley simple, which include Yuzhnosurkhan, Chimkurgan, Kairakkumgan, Kassansai, Akhangaran, Saryyazinsk and others [16];

Complex valley - Pachkamar, Tashkent, Charvak, etc.; basin-valley: Kattakurgan, Karkidan, Kattasay, Ortotokoy.

Basin-valley: Uchkyzyl, Kuyumazar, Djizak.

2.2 Object of study

The Shurtan reservoir (Figure 1), located in the southern part of the Republic of Uzbekistan, was chosen as the objects of the study. The Shurtan reservoir was constructed in 1998-2000. The reservoir is an embankment reservoir and has a full volume of 11.5 million m3 and a usable volume of 11 million m3 with water intake from the Karshi main canal located in the territory of Guzar district of Kashkadarya province at the mouth of Davrazakam sai 3. km northeast of the production zone of the Shurtan gas chemical complex [18].

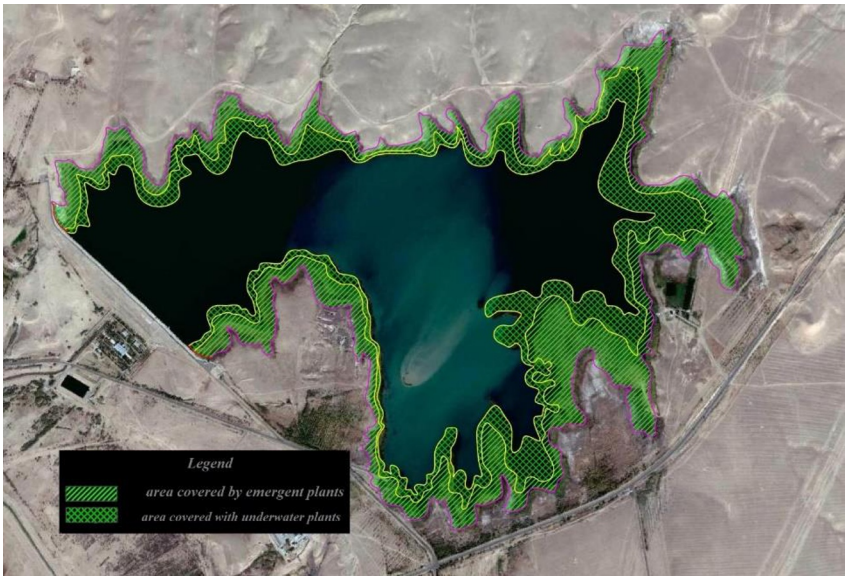

Fig. 1. Map of the Shurtan reservoir.

Charvak Reservoir is a hydraulic structure built in the upper reaches of the Chirchik River (1963-1970). It was built for water supply to agriculture, flood prevention and other purposes. The Charvak reservoir seasonally regulates river water consumption (Figure 2). The reservoir is built between the Chatkal and Ugam ridges. The stone-fill dam is 768 m long, 168 m high and 12 m wide at the top. The dam has two tunnels 800 m long and 11 m in diameter to supply water to the Charvak HPP. Total capacity of Charvak reservoir 2006 million m3, of which usable water volume 1580 million m3, water surface level 40.1 km2, width in places 10 km, length 19 km, maximum depth 131 m, average depth. 55 м. The Piskem, Koksuv and Chatkal rivers flow into the reservoir. The reservoir is equipped with shaft (1200 m3/s) and two-stage (450 m3/s and 500 m3/s) releases, which release water when the dangerous flow level is reached (19). The Charvak reservoir provides stable water supply to the Chirchik and Bozsuv rivers. Construction of the reservoir provided stable water supply to more than 355,000 ha of lands in the Tashkent oasis and South-Kazakhstan oblast of RK in dry years (including 150,000 ha of newly developed lands), as well as elimination of floods in the upper reaches of the Chirchik River [1, 19-21].

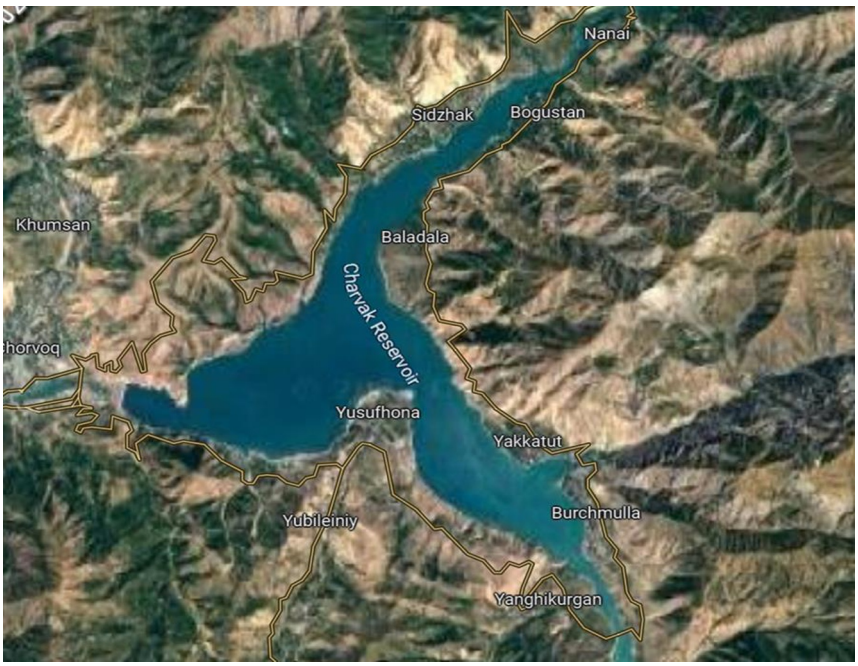

Fig. 2. Map of Charvak Reservoir.

Kapchagai Reservoir is one of the largest reservoirs in Kazakhstan. It is 180 km long and 22 km wide. The reservoir was created to regulate the flow of the Ili River. In 1965-1980, a dam and the Kapchagai hydroelectric power station were built in the narrow Kapchagai gorge formed by rocks. Filling with water began in 1970 (Kapchagai reservoir // Kazakhstan. National Encyclopedia. - Almaty: Kazak Encyclopedia, 2005. - VOL. III. - ISBN 9965-9746-4-0. (CC BY-SA 3.0)

The Kapchagai reservoir is located in the Iliysk valley in Almaty oblast (Figure 3). It has many channels and arms, rolls and shoals. Gentle slopes are interspersed with rocky coastal landscapes. The coastal zone of the Kapchagai reservoir runs along the gently sloping accumulative plain and along the foothill spurs of the Dzungarian Alatau.

Thanks to the reservoir, the climate in the neighboring regions, up to Alma-Ata, has softened.

The natural zone is semi-desert. The usual landscape of the Kapchagai reservoir shores are turang groves, hills covered with shrubby white saxaul, riparian jungles with thickets of lianas and blackberries. In some places the desert comes right up to the water. In other places, the coastline is covered with stunted willows, tamarisk, steppe plant communities with predominantly xerophytic (Artemisia serozem) and halophytic (saltwort) forms [2, 22-24].

On the eastern shore of the reservoir there is the Almaty Reserve. The Altyn-Emel National Nature Park is located on the northern shore.

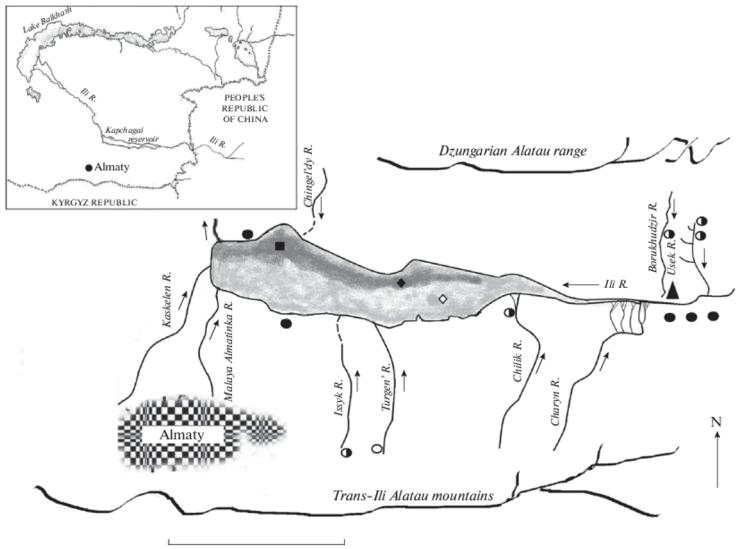

Fig. 3. Map of Kapchagai Reservoir.

3 Research methods

This vegetation area was determined remotely using satellites. Landsat OLI satellite images were used for this purpose. This high-resolution satellite captures objects at a resolution of 30 m/pixel and has 11 spectral layers. These layers and resolutions allow large objects to be analyzed at high resolution [1, 19-23]. This satellite was launched by NASA in 2013. The satellite images were downloaded from the agency's website https://earthexplorer.usgs.gov/. The downloaded images were categorized in ArcMap 10.1 and divided into water, vegetation, and soil regions. The fields of each region are defined and displayed in the ArcMap attribute table [1]. The NDWI ArcMap model was used to delineate the reservoir area. The water surface is delineated from the reservoir banks. The normalized difference water index (NDWI) is calculated based on near infrared (NIR) and green (G) channels.

$$NDWI = ((Band\ 3 - Band\ 5))/((Band\ 3 + Band\ 5)) = (NIR\text{-}SWIR)/(NIR+SWIR)$$

This formula shows the amount of water in a body of water. The following calculation formula was used: here, near infrared (NIR) wavelengths are slightly longer than red wavelengths and are outside the range visible to the human eye. The blue wavelengths, which are part of the natural color film, are filtered out of the CIR.

Shortwave infrared imaging (SWIR) is an advanced imaging technique based on radiation in a region of the electromagnetic spectrum invisible to the naked eye.

Also utilized was the Copernicus Sentinel-2 mission based on a constellation of two identical satellites in the same orbit. Each satellite is equipped with an innovative high-resolution multispectral imager with a wide swath and 13 spectral bands, providing new insights into our earth and vegetation (https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-2).

4 Results

A chart was created based on the results of the in-situ data.

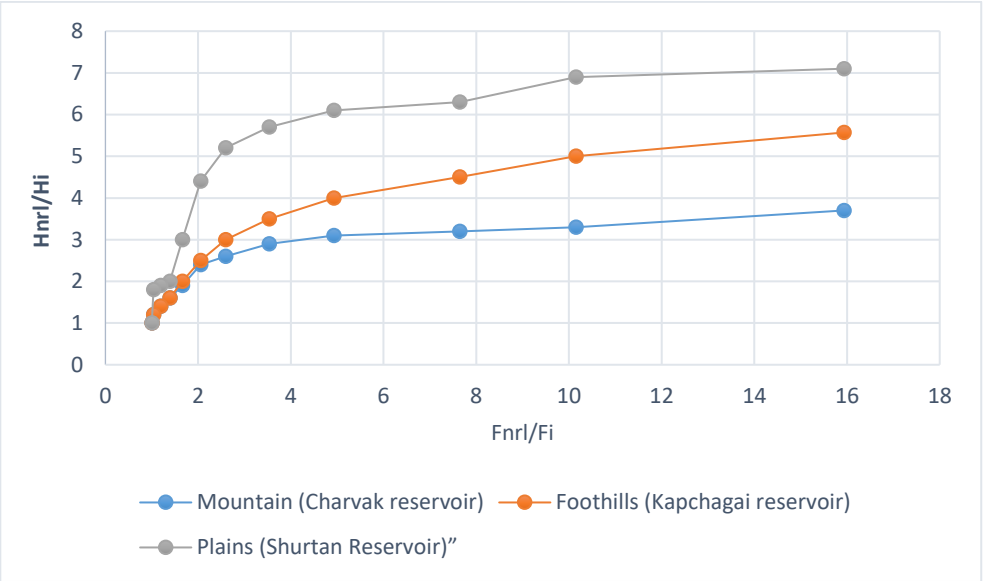

Fig. 4. Graph of dependence of relative water surface of a water body on relative depth.

The diagram (Figure 4) shows that the level to area ratio due to geographical location, reservoirs located in mountainous areas will change sharply and more than foothill and plain ones.

As a result of the study, it was revealed that vegetation coverage of reservoirs depends on location, water temperature, reservoir shape, composition of silt fractions, etc.

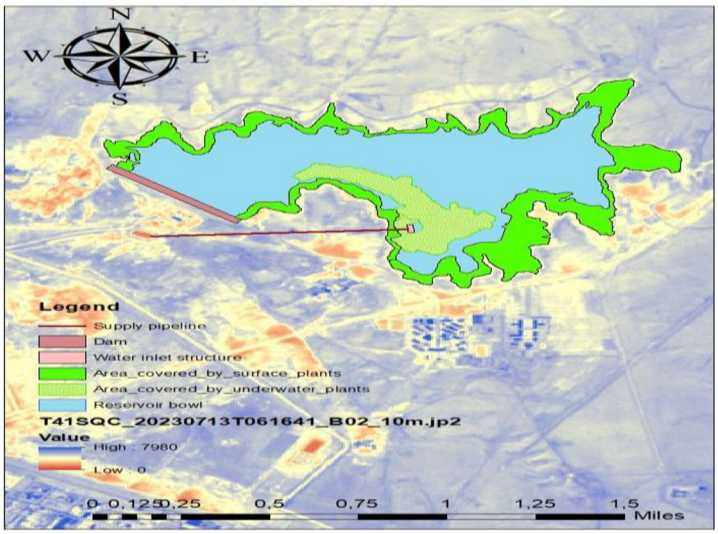

Fig. 5. Map of aquatic plant coverage in the Shurtan reservoir.

The large area covered by emergent and submergent vegetation in the Shurtan Reservoir (Figure 5) may be due to the following factors:

- Changes in the morphometry of the reservoir:

Siltation. The process of siltation of the reservoir leads to the formation of shallow areas that are favorable for the growth of aquatic vegetation. The silt layer creates a good environment for plant establishment and enriches the water with nutrients.

- Stable water level:

Constant water level. The absence of significant fluctuations in water level allows plants to grow steadily and not be stressed by changing conditions. This is especially important for aquatic vegetation that requires constant access to water.

- Temperature:

High water temperatures. Warm water promotes vigorous growth and reproduction of aquatic plants because it accelerates photosynthesis and metabolism. The warm climate of the region can keep water temperatures high for long periods of time.

- Nutrient-rich conditions:

High nutrient content. Water can be nutrient rich due to runoff from surrounding farmland or due to the accumulation of organic materials. This favors vigorous growth of both emergent and submergent vegetation.

- Geologic and soil conditions:

Favorable substrate. Reservoir bottom soil may be suitable for plant rooting, which favors plant propagation.

- Climatic conditions:

Good light exposure. A large amount of sunlight, especially penetrating up to 2 meters, promotes photosynthesis, which is especially important for submerged vegetation.

Thus, the changing morphometry of the reservoir, siltation process, stable water level, warm water and favorable conditions rich in nutrients create ideal conditions for active growth of above-water and underwater vegetation in the Shurtan reservoir.

Charvak reservoir was chosen as the second object of the study.

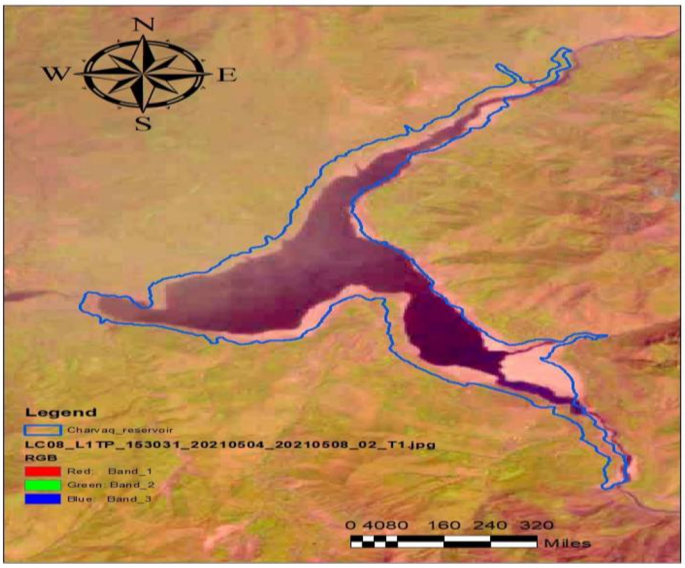

Fig. 6. Absence of aquatic vegetation in Charvak reservoir.

Charvak reservoir in its entirety

The lack of significant vegetation on the Charvak reservoir (Figure 6) is due to several factors:

- Water level fluctuations:

Since the water level in the Charvak Reservoir changes frequently and significantly, this creates unstable conditions for the growth of aquatic vegetation. Plants do not have time to adapt to the changes and die.

- Deep and steep banks:

Deep areas of the reservoir with steep banks do not provide adequate shallow water for aquatic and riparian vegetation growth. It is difficult for plants to get established and receive the necessary amount of light.

- Temperature conditions:

Cold Water. Because the water in the reservoir remains cold for most of the year, this limits the growth of many aquatic plant species that prefer warmer conditions.

- Water Composition:

Low nutrient content. The water in the Charvak Reservoir is poor in nutrients necessary for plant growth, which can limit plant development.

High water clarity. Excessive transparency may indicate low nutrient content, which also inhibits plant growth.

- Geologic and soil conditions:

Unsuitable soil. Because the soil at the bottom and along the banks of the reservoir is rocky and gravelly, it may not be suitable for aquatic plant establishment.

- Human activity:

Recreational Use. The reservoir may be actively used for recreational purposes such as swimming, fishing and water sports. This may result in the destruction of aquatic vegetation.

The perpendicular position of the Charvak Reservoir to stormwater runoff means that the direction of stormwater runoff intersects with the direction of the reservoir at right angles, forming a cruciform shape on the map.

The Charvak Reservoir is located in the Tashkent region of Uzbekistan on the Chirchik River. It serves as an important source of water for irrigation, water supply and hydropower, as well as a popular destination for recreation and tourism.

The perpendicular position of stormwater runoff to the reservoir can affect the distribution and intensity of water flows entering the reservoir. In the event of intense rainfall events, stormwater crossing the direction of the reservoir can create additional flows directed into the reservoir at an angle. This can result in rapidly rising water levels and the need to regulate water flows to prevent flooding and shoreline erosion.

In addition, this location may require special engineering solutions for stormwater management such as the construction of drainage systems, diversion channels, or dams to minimize potential adverse impacts to the reservoir and surrounding areas.

Thus, a combination of factors such as large fluctuations in water levels, deep and steep banks, cold water, low nutrient content, unsuitable substrate and active human activity may explain the lack of significant vegetation on the Charvak reservoir.

The third site is the Kapchagas Reservoir, located in a mountainous area. The parallel position of the Kapchagai Reservoir to the storm drains implies that the reservoir and the storm drains are at the same or close geographic coordinates, allowing the drains to flow easily into the reservoir.

The Kapchagai Reservoir, located on the Ili River in Kazakhstan, plays an important role in water regulation and is used for a variety of purposes including irrigation, water supply and recreation. Stormwater runoff, which is rainwater flowing over the land surface, can affect water levels in the reservoir, especially during periods of intense precipitation.

The parallel positioning of the reservoir and storm drains promotes efficient collection and storage of rainwater, which helps to maintain stable water levels and prevent potential

flooding of adjacent areas. It is also important for preventing soil erosion and preserving the region's ecosystem.

The following map was obtained based on the results of the study.

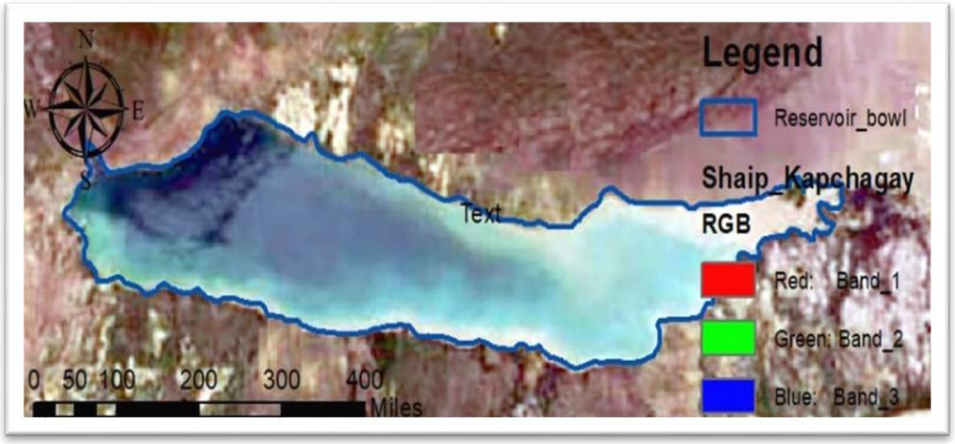

Fig. 7. Absence of aquatic vegetation in the Kapchagai reservoir.

As can be seen from the images, the Kapchagai reservoir also lacks aquatic vegetation (Figure 7), this is due to the fact that:

- Water level fluctuations. Frequent and significant changes in water level in the reservoir make it difficult for aquatic plants to develop and take root. During periods of declining water levels, plants may denude and dry out, and when water levels rise, they may become flooded again, creating unfavorable conditions for their growth.

- Bottom type: The bottom type of the reservoir also plays an important role. The bottom of Kapchagai reservoir is mainly composed of rocky clayey soil. This type of soil includes mixtures of stones, pebbles, sand and clay, which creates a strong and stable base for the reservoir. A rocky clay bottom makes it difficult for aquatic plants to take root and grow, as it is difficult for plants to establish themselves in such a dense and inhospitable substrate.

- Human activity: Active use of the reservoir for recreational purposes such as swimming, fishing and navigation can also inhibit the development of aquatic vegetation as the mechanical impact of people and machinery destroys plant growth sites.

As a result, a combination of these factors may result in an absence or minimal amount of aquatic vegetation in Kapchagai Reservoir.

5 Conclusion

This paper assessed the change in vegetation cover of reservoir banks using GIS technologies. The analysis showed that the conditions for aquatic vegetation growth vary significantly depending on the characteristics of each reservoir.

The Shurtan reservoir has an abundance of aquatic vegetation. This is due to the high water temperature, favorable sediment composition and standing water, which creates ideal conditions for the growth and development of aquatic plants.

In the Charvak reservoir, on the other hand, aquatic vegetation is virtually absent. This is due to the cold water and stony terrain, which do not favor the establishment and development of aquatic plants.

As for the Kapchagai reservoir, there is also a lack of aquatic vegetation. This is due to several factors: frequent water level fluctuations, strong currents and waves, the bottom type of stony-clay soil, as well as water quality and active human activity.

Thus, GIS technologies can effectively assess and analyze the impact of various factors on the change of vegetation cover of reservoir banks, which is important for water resources management and environmental monitoring.

According to the results of the study, it became known that with the help of field data and modern GIS technologies there is a possibility to assess changes in hydrobiological regime.

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