Geo-ecological problems of artificial reservoirs of Kalmykia (case study of the Tsagan-Nur reservoir)

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Abstract. The article presents results of six-year research on the Tsagan-Nur reservoir located on the Caspian lowland. Quantitative values of several indicators were obtained: hydrological (level and area of the reservoir), hydro-chemical (mineralization, chemical elements), environmental (ecotone water-land system). The methodological basis is the ecotone concept according to which there are blocks (areas) experiencing effects of the water body. Analysis of space information showed a significant reduction in the water surface area from 55.4 km² (1978) to 6 km² in 2018. Mineralization of the reservoir water increased 7 times compared to the average long-term data (10-12 g/l) and amounted to 70.24 g/l in 2018. Drying and deterioration of the water quality increase the saline area and decrease biological diversity of the flora and fauna, make it impossible to use waters of the reservoir for economic purposes.

1. Introduction

Intensification of the anthropogenic impact on natural ecosystems, especially on aquatic ecosystems, contributes to the development of a number of geoecological problems that are extremely acute for arid and sub-arid regions. The most important one for Kalmykia are as follows: salinization of surface waters making them unsuitable for use; pollution of natural waters by toxic elements, waterlogging of lands making it impossible for them to use for economic needs, reduction of the water surface, a decrease in the level of groundwater, drying of lakes, formation of takyrs and new saline areas. An important feature of geo-ecological problems is their slow development, the cumulative nature of destructive phenomena and latent manifestation.

Many geo-ecological problems remain unresolved due to the lack of field data. Identification of features of natural systems on the banks of reservoirs in the conditions of arid Kalmykia seems very relevant; it can establish mechanisms and patterns of their development, assess the degree of development and possible hazards.

2. Materials and methods

In order to assess the state of water bodies, since 2001 long-term monitoring has been carried out. Its main task is to analyze quantitative data. Monitoring helps obtain reusable quantitative values of several indicators during the year: hydrological (level and area of the reservoir), hydrochemical (mineralization, chemical composition), environmental (ecotone water-land system). Hydrological indicators (water
surface area) were determined using multi-time satellite imagery materials. Generalized requirements for remote sensing information used in solving hydrological problems include: spectral ranges: 0.6, 0.3–0.9 μm, 10–12 μm; spatial resolution of 30–60 m, the image scale 1: 100000:1: 250000 [1]. For processing and analyzing data obtained from space images, MapInfo 12.0, MultiSpek W32, Ilwis 3.6 were used. Interpretation was performed by the visual-instrumental method using black-and-white, color spectrum-zone, color-synthesized materials of space information obtained from artificial earth satellites (Resource O1 No. 3, Cosmos, Landsat, Spot) in different seasons (spring-summer-autumn) from 1975 to 2018.

The methodological basis of this study is the ecotone concept according to which there are blocks (areas) experiencing impacts of the water body on the reservoir shore. According to [2], there are six main blocks: aqual – a water area with depths of more than 1.5-2.5 m (devoid of macrophytes); amphibian – a littoral area with periodic drying during the period of water drawdown of reservoirs, fluctuation – an annually flooded coastal area; dynamic – a non-annually flooded area; distant – a non-flooded area affected by shallow (up to 3-5 m) underlying groundwater, and marginal – an area affected by the water body transmitted through the microclimate of the previous blocks (transitional to zonal). Ecotone “water-land” systems of coastal reservoirs were studied by the method of topo-ecological profiling. Topo-ecological profiles were laid perpendicular to the water edge, from the reservoir into the coast to the zonal vegetation. Topo-ecological instrumental coast profiling involved location of test plots with a detailed study of the soil, vegetation, groundwater and elevations. All descriptions were accompanied by sampling for studying water salinity in water bodies and groundwater; morphological structures and salt composition; species composition and biological productivity of plant communities.

Analysis of samples for mineralization and water composition of reservoirs was performed in the Kalmyk branch of the Russian Agricultural Academy n.a. A.N. Kostyakova in accordance with GOST 26449.1-85: the cation-anionic composition was determined by by the titrimetric method, dry residue – by the gravimetric method, pH – by the potentiometric method. Latin names of plant species were given according to S.K. Cherepanov [3]. The analysis of plant life forms is based on the approaches by I.G. Serebryakova [4]; ecological types of plants were identified by the method suggested by T.K. Goryshina [5]. When describing and classifying vegetation, the dominant method in the name of communities was used.

3. Research object
The research object is the Tsagan-Nur reservoir which was the largest in a chain of lakes located in the southern part of the Sarpinskaya depression created by the ancient riverbed of the Volga River in the Caspian lowland. The bed of the channel reservoir elongated from the north to the southeast; it has a length of 45 km and a width of 0.7 to 1.5 km. The average depth is 1.15 m. At the normal water level (NWLI), the reservoir volume is 90.0 million m³, the mirror area is 61.5 km². The main power of the reservoir is irregular water supply from the Volga river through the BP-1 channel. The main function of the reservoir is a drainage-waste water receiver whose waters were used for two administrative districts and commercial fishing. From 2008 to 2014, the maximum catch yield was recorded in 2012 (46.4 tons), and the minimum one – in 2013 (21.3 tons). According to V.G. Poznyak [6] and D.S. Petrushkivka [7], there were 34 fish species in the Tsagan-Nur reservoir. However, due to a decrease in the water surface area, the commercial catch is not carried out. In addition, since 1982, the Tsagan-Nur reservoir has been a core of the Sarpinsk regional wildlife sanctuary, a concentration site for many rare bird species (deer crane, bustard, little bastard, steppe eagle, white-tailed eagle, long-legged buzzard, etc.). The list of birds included 145 species [8].

4. Results and discussion
The study of the current ecological state of the Tsagan-Nur reservoir was carried out at three sites: in the upper part of the reservoir, in the central part and at the dam. According to the results of monitoring of remote sensing data, the maximum filling was observed in 1978 (55.4 km²) [8]. Since 2012, the water surface area has been steadily decreasing. According to the data of space imagery in 2012, its area was
31.63 km², in 2015 – 20.2 km², and in August 2018 – only 6 km². A decrease in the water surface area of the reservoir is due to a decrease in the flow of drainage-waste water through the BP-1 channel caused by a reduced area of irrigated rice fields. Annual monitoring of water mineralization revealed a significant increase. The dam zone of the Tsagan-Nur reservoir is a salt reservoir, as the Volga river water flows through the BP-1 channel into the northern part of the reservoir; water reaching the southern dam part increases its mineralization. In this part of the reservoir, mineralization has significantly increased. In 2015, it reached maximum values (in April – 22.13 g/l, in September – 73.18 g/l), in spring of 2018, salinity was 70.24 g/l (Fig. 1) exceeding the average annual values (10–12 g/l) 7 times. In 2017, it was not possible to take samples in this part of the reservoir due to its transformation into a salt marsh. Since 2015, the reservoir has been divided into small two arms separated by islets; it continues to dry out.

In the central part of the reservoir and in the transient region, it was not possible to select surface waters due to strong desiccation.

In order to study the effect of the reservoir on adjacent (ecotone) territories, monitoring studies of the composition of the water-land ecotone system were carried out from 2008 to 2012. This article presents results of the 2017 autumn field research on the composition and structural-functional organization of the key section located on the left coast of the Tsagan-Nur reservoir at a distance of 1.5 km from the dam (47°22'37"N, 45°11'37"E). Four blocks of the ecotone system were studied and described: fluctuation, dynamic, distant, and marginal [9].

![Figure 1. Changes in surface water salinity in the dam of the Tsagan-Nur reservoir.](image)

The length of the fluctuation block was 250 m from the water's edge; the drying line was 110 m. The soil surface freed from water was gray, clayey, damp, takyr-like, devoid of vegetation. In the dehydration zone, the depth of groundwater (GW) was 0.7 m. Salinity of humic substances was 14.28 g/l, salinity was of sulphate-sodium-chloride type. Behind the strip of drying inland, the salt-bass community (Bassia hirsuta + Salicornia perennis) increased. The groundwater lay at a depth of 1.3 m. The total projective coverage was 15 %. There are only two of the above listed species with a projective cover of more than 7 %. These are annual species that carry a high level of soil salinization. The air-dry weight of phytomass was 95 g/m².

The dynamic block, 150 m long, comprised two vegetation lanes. In the first lane, 65 m long, there were Salicornia perennis + Bassia hirsuta with a total projective cover of 95 %. The depth of groundwater was 1.6 m. HW mineralization was 16.02 g/l, the type of salinity was sodium sulphate-chloride. The community dominant was Salicornia perennis (PP 40 %), the subdominant was Bassia hirsuta (PP 35 %), other annual halophytes are Suaeda salsa and Salsola soda. The maximum height of
the main mass of herbage is 40 cm. Biological productivity was 426 g/m². In the second lane of this unit, there was a petrosymonium-winch plant community (Atriplex tatarica + Petrosimonia oppositifolia) with a total projective cover of 65 %. Groundwater was deposited at a depth of 2.3 m. Salinity of humic substances was 12.36 g/l, the type of salinization was sulphate-sodium-chloride. The number of plant species was 13. The community dominant was Atriplex tatarica, the subdominant was Petrosimonia oppositifolia with an abundance sp1.2. The remaining species were less numerous: Bassia hyssopifolia, Atriplex prostrata, Salsola soda, Suaeda salsa and perennial herbs Argusia sibirica, Vincetoxicum sibiricum. Artemisia santonica grew from semi-shrubs; woody plant forms were represented by Tamarix laxa 20 cm in height. The air-dry weight of plant phytomass was 307 g/m².

The distant block began at a distance of 400 m from the water edge. In the first lane of vegetation, 80 m in length, the groundwater was located at a depth of more than 2.5 m. Petrosymonium-prosperous (Suaeda salsa – Petrosimonia oppositifolia + P. brachiata) communities grew here. The number of species was 11, the RPF of the community was 60 %. The dominant was Suaeda salsa whose abundance makes up half of the total projective cover of the grass stand (cop1). Community subdominants were Petrosimonia species. Salicornia perennis, Atriplex tatarica, Bassia hirsuta, Senecio vernalis, Polygonum aviculare, Suaeda acuminata were observed. Perennial species were represented by Aeluropus littoralis, shrubs – by Tamarix laxa up to 40 cm in height. The biological productivity of the community was 92 g/m². In the second lane which was more than 50 m long, there were petrosymonium-santonin-full-tamarisk communities (Tamarix laxa – Artemisia santonica + Petrosimonia brachiata). Groundwater was deposited at a depth of more than 3 m. The number of species was 10, OPP was 60 %. The community was two-tier: the first tier was up to 3 m in height with a crowns density of 0.6. It was represented by Tamarix laxa shrubs. The second tier, up to 50 cm in height, was represented by Petrosimonia brachiata with an abundance of cop2.3 and Artemisia santonica with an abundance of sp2. The abundance of other species is insignificant. Most of them are perennial herbaceous plants: Puccinellia dolicholepis, Limonium caspium, Alhagi pseudalhagi, and the long-rhizome xerophyte Argusia sibirica. Among the annual species, there were Atriplex prostrata, Polygonum novoascanicum, Lepidium ruderale. The air-dry weight of plant phytomass was 125 g/m².

The marginal block starts at 520 m from the water edge. Forb-red-wormwood communities (Artemisia lerchiana + A.santonica + A.pauciflora – Poaceta – Mixteherbosa) grew here. The RPF of the community was 50 %, the number of plant species was 20. Soils and vegetation are of zonal nature: meadow soils are replaced by brown desert-steppe light loamy soils in combination with solonet, there are more xerophilous species: Arthmisia lerchiana, A. pauciflora, A. santonica, Potentilla bifurca grow from semi-shrubs, Alhagi pseudalhagi, Agropyron cristatatum, A.desertorum, Koeleria glauca, and APEMA, Apteratorum, aptortorum, A.desertorum, airoporhumi, and atiortorum. Annual cereals were as follows: Anisantha tectorum, Eremopyrum triticeum. Herbs were represented by perennial species: Achillea leptophylla, A.nobilis, Dianthus polymorphus, Kochia prostrata, Phlomis pungens. The air-dry weight of plant phytomass was 58 g/m².

Floristic analysis of the ecotonic vegetation of the Tsagan-Nur reservoir showed that the species composition is represented by 135 species belonging to 26 families and 91 genera. The most numerous of them are Chenopodiaceae (31), Asteraceae (20), Poaceae (20) and Brassicaceae (13). Most of the plants are monocarpic herbs (54.3 %). Among annual monocarpic grasses, there are Alyssum desertorum, Eremopyrum orientale, E. triticeum, Atriplex (Atriplex aucherii, A.micrantha, A.prostrata, etc.), Chenopodium album, Berteroa incana, Crepis tectorum, Lappula squarrosa, Lepidium perfoliatum. Perennial herbs make up 33.3 % of the total number of plant species: Achillea (A. leptophylla, A.nobilis), Bolboschoenus maritimus, Convolvulus arvensis, Dianthus polymorphus, Leymus ramosus, Carex stenophylla, Limonium (L. caspium, L. gmelinii , L.meyeri), etc. There are 12 species of half-shrubs (8.9 %): Artemisia austriaca, A.lerchiana, A.pauciflora, A.santonica, A.taurica, Camphorosma monspeliaca, Frankenia hirsuta, Halimione verrucifera, Kochia prostrata, Limonium suffruticosum, Halocnemum strobilaceum. Trees are represented by shrubs; in this area, 2 species (1.5%) of Tamarix were observed – T.laxa and T.ramosissima. The vegetation of the ecotonic territory of the Tsagan-Nur reservoir is represented by 10 ecological types, of which euxerophytes predominate – 32.6
% (Artemisia lerchiana, A. taurica, Atriplex aucheri, etc.). Eumeophytes and transient xeromesophytes account for 19.3 % and 18.5 %, respectively. 11.1 % is accounted for by mesoxerophytes, 7.4 % – by egalophites, 5.2 % – by haloxerophytes. Halomesophytes make up 2.2 %, hygrophytes and halomesophytes account for 1.5 %, hydrophytes – 0.7 %.

5. Conclusion
Studies have revealed a significant increase in the degree of mineralization of surface waters of the Tsagan-Nur reservoir – up to 70.24 g/l which is seven times higher than average long-term data (10–12 g/l). Deterioration of water quality making water unsuitable for economic use was identified. Most of the reservoir (the central and transient zones) turned into a salt marsh bog. Salinization of groundwater in the conditions of the effusion type of the water regime increases the area of saline lands. Drying of reservoirs decreases biological diversity of flora and fauna, since in dry conditions, reservoirs are landscape reserves for conservation of natural biodiversity of vegetation, soil, animals and birds. It is necessary to eliminate reservoir regimes that contribute to the salinization of waters and adjacent territories, and replace them with more rational, non-adverse regimes.

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