Geoecological assessment of water bodies in Novosibirsk using cluster methods

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Abstract. Currently, there are practically no water bodies left on the territory of the Russian Federation that are not affected by anthropogenic activity under the influence of which the water quality ceases to comply with the regulatory requirements. The most sensitive water bodies to the anthropogenic load are small water bodies and watercourses since the self-purification processes are very limited in comparison with larger water bodies. The article presents the results of cluster analysis of morphometric and hydrochemical parameters using the example of water bodies in the city of Novosibirsk. The analysis was carried out by complete link method with the development of dendrogram to identify the most optimal number of groups of water bodies and their further hydroecological assessment. When comparing dendrograms for a number of morphometric and hydrochemical parameters, it can be concluded that morphometric parameters do not affect the development of the component composition of water bodies within an urbanized territory. In general, the cluster analysis indicates the dependence of the water composition on the reservoir origin, which makes it possible to identify some features of the quality of water bodies; however, as a result of the analysis, it was revealed that the studied water bodies are not differentiated by the territory. This trend indicates the absence of large point stationary sources of pollution and confirms the presence of diffuse pollution.

1. Introduction
Currently, there are practically no water bodies left on the territory of the Russian Federation that are not affected by anthropogenic activity under the influence of which the water quality ceases to comply with the regulatory requirements. The most sensitive water bodies to anthropogenic load are small water bodies and watercourses, since the self-purification processes are very limited, in comparison with larger water bodies. Large quantities of oil products, heavy metals, surfactants, chlorides, sulfates and other pollutants get into their waters with surface runoff and air fallouts. Urbanization creates certain conditions that have a powerful negative impact on water bodies that are the receivers of pollutants from wastewater and surface runoff.

Surface water bodies of the state water fund of the Novosibirsk Oblast are represented on the territory of the city of Novosibirsk by the Ob River with the large tributaries, i.e. the Inya and Tula Rivers; small rivers, i.e. Yeltsovka-1, Yeltsovka-2, Kamenka, Nizhnyaya Yeltsovka, Kamyschenka,
Plyushchikha and the reservoirs, i.e. part of the Novosibirsk reservoir, ponds, flood bypass conduits, natural lakes and swamps [1]. Small water bodies of Novosibirsk can be divided into three groups by the genesis:

- Natural origin, which include natural lakes (six reservoirs, five of which are located in the floodplain of the Ob River).
- Artificial origin (31 reservoirs can be attributed to ponds, 16 refer to water bypass conduits).
- Mixed origin (two reservoirs).

The hydrological conditions and ecological state of the city’s water bodies are influenced by a combination of natural and anthropogenic factors: the presence of surface inversions leading to a greater accumulation of impurities in the surface air layer, with their further air fallout, the local ecological situation, which causes the accumulation of heavy metals such as copper, iron, etc. manganese in the soil cover and water bodies, water pollution by stationary and mobile sources [2, 3]. Pollutants accumulate on geochemical barriers primarily in the bottom sediments of water bodies where the transformation of chemical elements and their avalanche accumulation take place. The most important geochemical barrier zones are the “river-sea” and “bottom-water” systems [4].

Particularly vulnerable objects of the urban landscape from the point of view of anthropogenic impact are small water bodies [5–8]. The lack of flow of water bodies in a large city causes their shallowing, an increase in the mass of bottom sediments, debris and intensive weediness. The accumulation of free organic matter in reservoirs leads to a slowdown in self-purification processes, a decrease in the content of dissolved oxygen in the water, water blooming, unpleasant odors, and ecosystem depletion [9]. Even slight changes in their water quality can significantly change the ecological situation [1]. The processes of self-purification of water proceed more intensively in flowing reservoirs, i.e. rivers, while low-flow reservoirs (ponds, lakes, reservoirs) undergo self-purification much less since the flow of water is slowed down and suspended particles settle to the bottom. As a result of these processes, the reservoir becomes silted up and the water quality deteriorates [10–12]. In addition, the rate of self-purification depends on the waves and currents that cause mixing of water in the reservoir, as well as on the water content of the water body [13]. In closed reservoirs, the more intensively the sources themselves are, the more intensively the water is purified, therefore, small reservoirs have extremely weak self-purification processes.

At present, systematic work is being carried out aimed at improving the state of water bodies, which includes clearing river beds, bank strengthening, eliminating unauthorized dumps in water protection zones, stopping the discharge of untreated wastewater, snow removal, recreational zones setting up in the areas adjacent to rivers [14]. However, an important component necessary to maintain the condition of water bodies in an urbanized area is the study of the quantitative composition of pollutants in water, their spatial and temporal distribution and assessment of their contribution to the total water pollution.

2. Research Methods

The study of the component composition of rivers and reservoirs of the city of Novosibirsk made it possible to reveal the main pollutants regarding the exceeding MAC of waters of fishery significance among which are as follows: oxidizable organic compounds determined by the value of biological oxygen consumption BOD₅ and chemical oxygen consumption COD, oil products, ammonium nitrogen, nitrites, fluorides, phenols, nickel, copper, iron, manganese, zinc and aluminum. It was also found that the concentration of these and other components varies in a fairly wide range of values from one water body to another, and the components themselves are unevenly distributed in them. To identify the pollutant distribution patterns in the water bodies throughout the city, a cluster analysis was carried out by the method of complete link method with the development of dendrogram to identify the most optimal number of groups of water bodies. The Euclidean distance is used as a measure of the distance between the objects. Cluster analysis was carried out using sets of morphometric and hydrochemical indicators, which were previously standardized in Excel by minimum-maximum normalizing [15]:

2
where \( X \) is normalized value; 
\( \min \) and \( \max \) are minimum and maximum coordinates over the entire set \( x \).

3. Research Results

The article presents the results of the analysis on the example of reservoirs in Novosibirsk. Cluster analysis was performed for water bodies by a set of morphometric indicators describing water bodies (7 variables): length, width, length of the coastline, maximum and average depth, mirror area. As a result of statistical analysis by the method of clustering according to a set of selected morphometric parameters it was revealed that all the studied water bodies can be combined into 3 groups of clusters (Figure 1).

The first group (cluster I) includes one water body, i.e. the Reservoir 29 located near the South-West residential area, which stands out from all the objects since its water volume is 2810.79 thousand m³, which exceeds the total volume of all other surveyed water bodies.

The second group (cluster II) includes 6 elongated reservoirs characterized by a water volume of 279 thousand m³ on average and an average depth of 7 m.

The rest of the objects united into cluster III, within which 3 subclusters (a, b, c) can be distinguished. Sub-cluster “a” included 2 objects, i.e. Reservoirs 27 and 40 with an average depth of 0.5 m and a water volume of 20 thousand m³. In sub-cluster “b” 8 water bodies can be distinguished with an average depth of up to 0.7 m and a volume of 14 thousand m³. The remaining reservoirs with an average depth of 1.8 m and a water volume of 120 thousand m³ can be attributed to the “c” subcluster.

Figure 1. Dendrogram of distribution of small reservoirs in Novosibirsk by morphometric indicators
According to a set of 26 hydrochemical indicators (pH, dry residue, BOD₅, COD, dissolved oxygen, oil products, phosphate ion, ammonium ion, nitrite ion, nitrate ion, chloride ion, sulfate ion, fluoride ion, phenol, surfactant, lead, cadmium, chromium, nickel, copper, iron, manganese, zinc, aluminum, arsenic, and tin), 3 clusters of water bodies have been identified (Figure 2). The results of cluster analysis by hydrochemical indicators show the typological differentiation of water bodies by their origin. The first group (cluster I) included 2 objects which belong to flood bypass conduits according to the presented classification, as well as water bodies that fell into cluster II (with the exception of the Lake Spartak), however, in the water bodies of the first cluster, an extremely high content of oil products was observed, which explains this association. Cluster III (with the exception of Reservoir 20) united water bodies, which are ponds. The objects of cluster III are distinguished by significantly lower content of most pollutants, including iron and manganese, which probably indicates different types of food for water bodies.

In general, the cluster analysis carried out by hydrochemical parameters indicates the dependence of the water composition on the origin of the reservoir, which makes it possible to reveal some features of the quality of water bodies, but the results of analysis indicate the absence of territorial differentiation of water bodies. The reservoirs of cluster I are located in the left-bank part of the city on the territory of the Kirovsky district, the reservoirs of cluster II are scattered over six districts of the city, as are the objects included in cluster III. This trend indicates the absence of large point stationary sources of pollution and confirms the presence of diffuse pollution.

![Figure 2. Dendrogram of small reservoirs in Novosibirsk by hydrochemical indicators](image)

4. Conclusion
When comparing dendrograms for a number of morphometric and hydrochemical parameters, it can be concluded that morphometric parameters do not affect the development of component composition of water bodies within an urbanized territory. It should be noted that the clustering did not include geographic coordinates of objects in order to avoid combining water bodies by location.
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