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## RESEARCH ARTICLE

# CLASSIFICATION OF THE DEGREE OF ANTHROPOGENIC INFLUENCE OF WATERCOURSES IN URBANIZED AREAS (USING THE EXAMPLE OF SMALL RIVERS IN KHABAROVSK)

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## ABSTRACT

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The study evaluates anthropogenic impact on urban and suburban territories through monitoring chemical parameters of small river waters. The research encompasses 16 watercourses draining the territory of Khabarovsk and its suburbs. Water sampling and measurements were conducted during the winter low-water period using data from 2017 to 2025. Cluster analysis identified four groups of water bodies differing in the degree of alteration of hydrochemical parameters and presence of anthropogenic pollutants. The areas experiencing the highest anthropogenic impact were determined, along with potential sources of pollutants. The first cluster includes rivers flowing through the southern and northeastern parts of Khabarovsk. The second cluster comprises mainly rivers from the central part of Khabarovsk and occasionally from the eastern part. The third cluster includes both central and remote district rivers of Khabarovsk. The fourth cluster consists exclusively of rivers draining the territory of the Bolshekhkhehtsirsky Nature Reserve. Samples from this cluster exhibit the lowest chemical substance concentrations, indicating minimal anthropogenic influence. These rivers can serve as background values for chemical substance concentrations in small rivers draining Khabarovsk and its inhabited suburbs, providing a reference for assessing technogenic pollution. The possibility of using cluster analysis of small river hydrochemical research data to indicate the intensity and types of anthropogenic impact on urbanized areas has been demonstrated.

### KEYWORDS

Small rivers, Outer Manchuria, hydrochemical analysis, cluster analysis, anthropogenic influence.

## 1. INTRODUCTION

The rapid growth of industrialization is intensifying the detrimental impact on human life, wildlife, and the environment due to the pollution of surface waters (Yu et al., 2018; Melad et al., 2024). Understanding hydrochemical processes and assessing water quality are essential for implementing strategies to eliminate pollution and manage natural water resources (Li et al., 2018; Zanotti et al., 2019; Min et al., 2025; Bridgewater et al., 2025). However, isolated observations are ineffective due to the occurrence of numerous nonlinear hydrochemical processes in watercourses. Areas with variable topography, geology, and land use types are characterized by significant heterogeneity in hydrochemical indicators (Tsuchihara et al., 2020).

Measuring the physicochemical characteristics of water provides the necessary information for classifying water quality (Rahman et al., 2022). Classification systems are primarily based on the variability of

concentrations of various parameters, as well as a number of specific indicators (Aguilera et al., 2001). However, determining the extent to which water quality varies between classes using conventional classification is a challenging task (Barclay et al., 2016). For example, classical water quality assessments such as Stiff diagrams (Stiff et al., 1951) and Piper diagrams (Piper, 1944; Merino et al., 2021) are often used for classification based on visual comparison, but they are unable to provide more precise differentiation. Therefore, multidimensional methods such as cluster analysis, factor analysis, and principal component analysis are commonly used to assess temporal and spatial variations in water quality (Orak et al., 2020). Several authors agree that it is impractical to use maximum permissible concentrations for water quality assessment, as these values are uniform across the entire territory of Russia and do not take into account regional characteristics of water bodies (Lozovik et al., 2014).

The Russian Federation has over 2.5 million small rivers. Surface

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watercourses are the most important connecting element of the ecological framework of the city, which participates in the formation of bioproductivity, in increasing the biodiversity of the landscape and maintaining its ecological stability (Varenov, 2014). Currently, despite strict standards and requirements for the quality of industrial and municipal wastewater discharged into natural water bodies (Gelashvili, 2014), as well as for wastewater treatment systems from pollutants, the ecological state of watercourses is not satisfactory (Raputa et al., 2019). The reason for this is the widespread development of water-intensive industries, which generate wastewater as waste, bringing significant masses of pollutants due to large volumes of wastewater brought to the standard clean state. Wastewater treatment systems are also not effective enough (Kozlov et al., 2019). The problem of watercourse pollution with toxic elements from domestic wastewater and runoff from adjacent territories has already been highlighted in many fundamental works (Xu et al., 2020; Müller et al., 2020).

Currently, research uses a large arsenal of methods for identifying pollutants in various environments. Given the complexity of these measurements and the large time investment, it is advisable to use a screening approach to studying territories. The laboratory data obtained in this way will become a good information base for a long-term assessment of the ecological state of the territory. For this purpose, the most indicative and preferable is the chemical analysis of small river waters. There are 16 small rivers flowing through Khabarovsk and its environs (Figure 1). Draining different parts of the city, they are exposed to anthropogenic impact. Due to low water flow, any technogenic interference affects the chemical composition of water (Shesterkin et al., 2019). The analysis of water quality in high-water rivers is less informative and cannot indicate small local sources of pollution due to strong dilution of waters.

A small number of large industries are located in different parts of Khabarovsk. Its central and northern parts are characterized by high-rise buildings, while the southern and southeastern parts are dominated by the private sector. This situation allows us to consider separate areas of the city as an example of an urbanized territory with various sources of pollutant input — from domestic and agricultural to industrial pollutants.

The preferred period for measurements should be characterized by the greatest stability of measured indicators with minimal impact of weather phenomena. It is also important to distinguish between single peak emissions of pollutant concentrations and systematically recorded high levels (Shesterkin et al., 2022). These criteria make the autumn-spring period unsuitable for monitoring due to the reduction of pollutant concentrations caused by active replenishment of the watercourse with meltwater and active precipitation, rather than a decrease in their input from the pollution source. The summer period is also unsuitable for such observation, as it is characterized by both heavy downpours and periods of high temperatures causing drying up of small rivers (Shesterkin et al., 2022). Based on this, observations are preferably conducted in winter (Sinkova, 2021). For Khabarovsk, this period is from late November to early March.

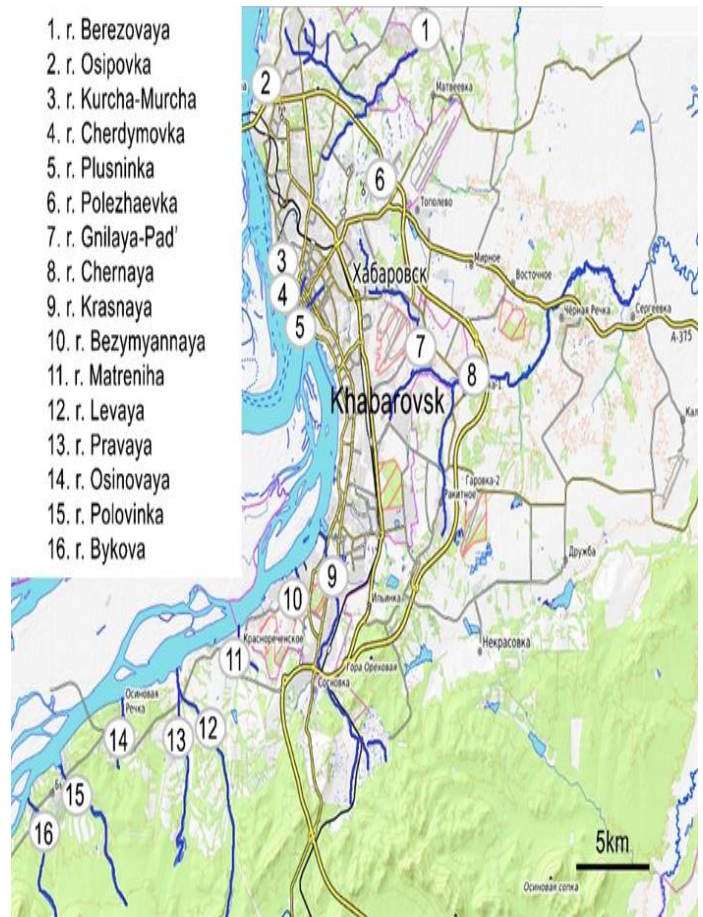
The object of the work is to assess the degree of anthropogenic impact on urbanized territories through cluster analysis of hydrochemical indicators of small rivers draining the territory of Khabarovsk and its environs, located within the Bolshekhokhtsirsky Nature Reserve.

## 2. MATERIALS AND METHODS

### 2.1. Study area

The research was conducted in the territory of Khabarovsk and its suburbs, located in the Amur River basin. Khabarovsk is the largest city in the Russian Far East, with a population of 615,600 people. Khabarovsk is situated in the monsoonal Far Eastern region of the moderate climatic zone. Winters are snowy and cold, while summers are hot and humid. The average January temperature is  $-19.2^{\circ}\text{C}$ , the average July temperature is  $+21.4^{\circ}\text{C}$ , and the annual average temperature is  $+2.7^{\circ}\text{C}$ . The annual precipitation average is 696 mm.

The territory of Khabarovsk and its surroundings are drained by 16 major small rivers (Figure 1). During the period 2017–2025, monitoring of hydrochemical parameters of waters was carried out. Sampling was conducted according to established standards (GOST 31861-2012, 2023; GOST 17.1.5.05-85, 2023). Water samples were stored in temperature-controlled containers within the temperature range of  $2-8^{\circ}\text{C}$  and were analyzed within 48 hours. To comprehensively assess the ecological status of small rivers in Khabarovsk, this study conducted a comprehensive hydrochemical analysis [RD 52.24.643-2002, 2002; RD 52.24.309-2016, 2023].



**Figure 1** : Map-scheme of the location of the studied small rivers in the territory of Khabarovsk and its environs.

### 2.2 Validation and quality control

To minimize errors in the analysis standard control measures and quality assurance procedures for conducting analyses were followed during equipment calibration and method implementation (Hasimuna et al., 2023; Nyantakyi et al., 2021). All laboratory equipment and glassware were pre-treated by soaking them overnight in 5% nitric acid ( $\text{HNO}_3$ ), after which they were thoroughly rinsed with deionized water and dried at  $60^{\circ}\text{C}$  (Khan et al., 2023, Mulwanda et al., 2025).

### 2.3 Statistical analysis

Statistical calculations were performed using the STATISTICA 10 software package. The data from the chemical analysis of small river waters were subjected to cluster analysis (using Ward's method with Euclidean distances).

## 3. RESULTS AND DISCUSSION

The data from the chemical analysis of small river waters (76 samples) were subjected to cluster analysis (using Ward's method with Euclidean distances), which revealed that the data set consists of four clusters. The median values for each hydrochemical parameter in each cluster are presented in the table. The standard deviation was used as a measure of variability (table 1).

**Table 1:** Median values of hydrochemical parameters in each cluster and average mineral content in river water (in dissolved form)

Indicator	Cluster				Clarke's content [30]
	I	II	III	IV	
pH	7,14 ± 0,18	7,33 ± 0,10	7,65 ± 0,27	6,44 ± 0,41	-
Na <sup>+</sup> , mg/l	54,00 ± 12,00	22,50 ± 3,50	48,00 ± 16,00	4,5 ± 2,5	5,00
K <sup>+</sup> , mg/l	11,50 ± 0,90	5,70 ± 1,10	7,20 ± 2,20	0,80 ± 0,50	2,00
Ca <sup>2+</sup> , mg/l	34,50 ± 7,50	30,50 ± 2,50	67,00 ± 12,00	7,50 ± 4,50	12,00
Mg <sup>2+</sup> , mg/l	10,65 ± 2,15	8,95 ± 0,85	20,25 ± 3,95	2,05 ± 1,05	2,90
HCO <sub>3</sub> <sup>-</sup> , mg/l	295,00 ± 55,00	153,00 ± 15,00	288,00 ± 68,00	26,00 ± 16,00	-
Cl <sup>-</sup> , mg/l	70,00 ± 30,00	32,50 ± 7,50	92,00 ± 47,00	4,05 ± 3,95	5,50
SO <sub>4</sub> <sup>2-</sup> , mg/l	30,00 ± 7,00	20,00 ± 2,00	25,50 ± 9,50	7,50 ± 2,50	-
NH <sub>4</sub> <sup>+</sup> , mg/l	28,40 ± 9,40	5,45 ± 1,65	4,65 ± 4,15	0,40 ± 0,40	-
NO <sub>2</sub> <sup>-</sup> , mg/l	0,18 ± 0,18	0,27 ± 0,08	0,25 ± 0,10	0,02 ± 0,01	-
NO <sub>3</sub> <sup>-</sup> , mg/l	0,90 ± 0,80	5,25 ± 0,75	5,65 ± 1,65	2,50 ± 1,10	-
HPO <sub>4</sub> <sup>3-</sup> , mg/l	5,25 ± 3,25	0,75 ± 0,25	0,35 ± 0,35	0,10 ± 0,10	-
Fe, mg/l	6,00 ± 1,30	2,95 ± 1,85	4,70 ± 3,80	0,04 ± 0,02	0,07
permanganate index (PI), mg O <sub>2</sub> /l	47,50 ± 22,50	14,50 ± 5,50	12,00 ± 5,00	3,40 ± 0,90	-
Anionic Surfactant	1,50 ± 0,40	0,25 ± 0,10	0,18 ± 0,13	0,02 ± 0,01	-
Si, mg/l	7,80 ± 1,60	6,05 ± 0,35	8,00 ± 1,60	5,35 ± 0,45	6,00

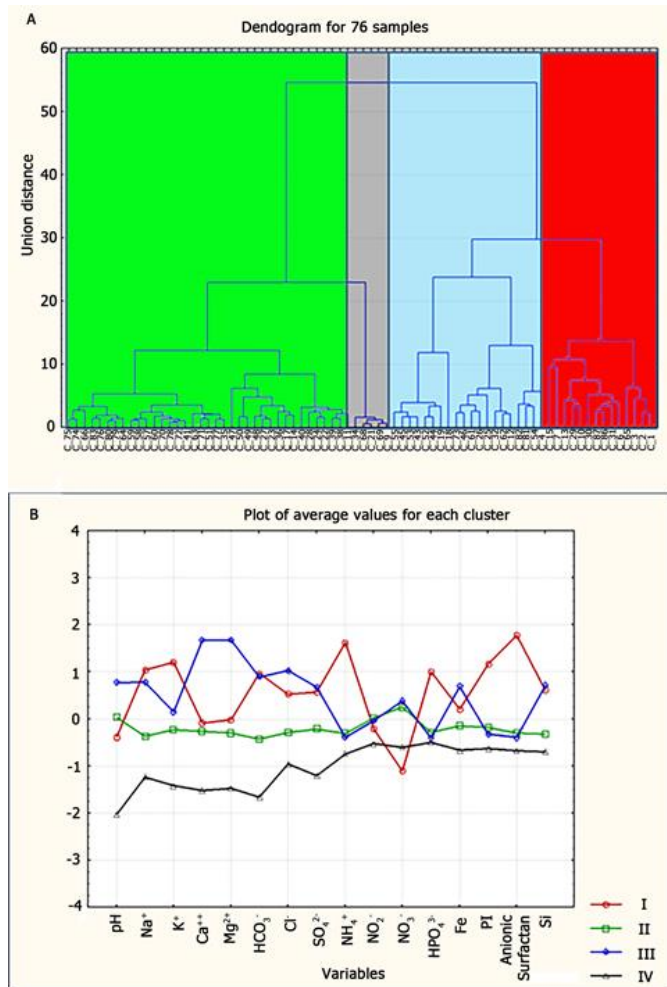
Figure 2A presents a dendrogram that was used to perform the cluster separation. Figure 2B shows a graph demonstrating which chemical parameters were used for sample clustering; the y-axis displays standardized data for all analyzed parameters across the resulting clusters (with a mean value of zero for each parameter).

The rivers of protected areas (Levaya, Pravaya, Osinovaya, Polovinka, Bykova) formed a separate cluster — the fourth one (table 2), characterized by the lowest values of hydrochemical parameters. The median pH level (6.44 ± 0.41) stands out particularly, being lower than that of other clusters (Figure 2B).

**Table 2:** Distribution of rivers into clusters

River	Cluster
r. Berezovaya	I, III
r. Osipovka	II
r. Kurcha- Murcha	III
r. Cherdymovka	II
r. Plusninka	II, III
r. Polezhaevka	II
r. Gnilaya-Pad'	I, II
r. Chernaya	I
r. Krasnaya	III
r. Bezmyannaya	I
r. Matreniha	I
r. Levaya	IV
r. Pravaya	IV
r. Osinovaya	IV
r. Polovinka	IV
r. Bykova	IV

The values of the remaining series of hydrochemical parameters of samples from the fourth cluster do not exceed background concentrations for surface waters (Arkhipov et al., 1990). This suggests that these rivers do not experience significant anthropogenic influence. Therefore, their hydrochemical parameter values can be taken as background concentrations of chemical substances in the water of small rivers in Khabarovsk and its inhabited surroundings, and can also be used for further assessment of technogenic pollution. The obtained values can serve as reference background concentrations for the region.



**Figure 2 :** Dendrogram of Cluster Analysis Results (A) and Average Values of Standardized Variables for Each Cluster (B)

### 3.1 Cluster Numbers

The second cluster is characterized by indicator values that are as close as possible to the average for all rivers. Only the nitrate ion content (4.5–6.0 mg/l) is overestimated relative to the average values. This cluster was mainly formed by rivers flowing in the central part of the city, and (less often) in the eastern part (Osipovka, Cherdymovka, Plyusninka, Polezhaevka, Gnilaya Pad'), for which high-rise buildings are characteristic. Since there are no large industrial facilities and agricultural lands in the catchment areas, the main sources of water supply in winter are domestic wastewater from housing and communal services. Such a limited number of sources of severe pollution can be traced in the graph (Figure 2B), most of the concentration values are consistently lower than the average indicator for all samples.

The third cluster (rivers Beryozovaya, Kurcha-Murcha, Cherdymovka, Krasnaya Rechka) is the most similar to the second one. The analysis of the results presented in the graph (Figure 2B) revealed a similar dynamics of substance content. Distinctive features of water samples from rivers belonging to the third cluster are elevated hardness (the average calcium content Ca<sup>2+</sup> (67 mg/l) exceeds the average background concentration value for this territory (7.5 mg/l) by 8.9 times, magnesium Mg<sup>2+</sup> (20.25 mg/l) exceeds the background (2.05 mg/l) by 9.9 times) and alkalinity (the average bicarbonate content HCO<sub>3</sub><sup>-</sup> (288 mg/l) exceeds the background (26 mg/l) by 11 times). Such a difference is probably due to the fact that the rivers of this cluster are mainly fed by groundwater flowing through alluvial deposits. These rivers are also characterized by the highest concentrations of Cl<sup>-</sup>, Fe, SO<sub>4</sub><sup>2-</sup>.

Samples assigned to cluster №1 (rivers Beryozovaya, Gnilaya Pad, Chernaya, Bezmyannaya, and Matrenikha) belong to rivers in the southern and eastern parts of the city and mainly drain private sector territories. As a rule, the majority of plots are allocated for garden and vegetable farming, which implies the use of various fertilizers. The first cluster is represented by samples showing water contamination with HPO<sub>4</sub><sup>3-</sup> (2.0–8.5 mg/l), NH<sub>4</sub><sup>+</sup> (19.0–37.8 mg/l), and anionic surfactants (1.1–1.9 mg/l). Elevated values of Na<sup>+</sup> (42–66 mg/l), K<sup>+</sup> (10.6–12.4 mg/l), and permanganate index (25–70 mg O<sub>2</sub>/l) are noted. Previously, disturbances in the nitrogen cycle in these rivers have already been noted (Shesterkin et al., 2021). This specific feature of the catchments explains the excess content of Na<sup>+</sup> (12 times), K<sup>+</sup> (14 times), and HPO<sub>4</sub><sup>3-</sup> (54 times) compared to background values for this territory. Small-scale cattle breeding and uncontrolled waste discharges lead to the highest concentrations of ammonium nitrogen (exceeding background values by 71 times) and anionic surfactants (exceeding by 43 times) in the examined samples.

It has been established that samples from the Beryozovaya River and the Gnilaya Pad River periodically fall into the first cluster, although they usually belong to the third and second clusters, respectively. The hydrochemical composition of these rivers was presumably influenced by such large anthropogenic pollution sources as poultry farms. Insufficient wastewater treatment control leads to increased phosphate and ammonium nitrogen content in water samples collected downstream from rivers that drain territories adjacent to such enterprises. These fluctuations in the hydrochemical composition are sufficient to classify some samples as belonging to the first cluster.

In addition, the Beryozovaya River flows near a construction ceramics plant located upstream from the sampling point. Insufficiently treated wastewater from this type of industry is characterized by elevated concentrations of Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Cl<sup>-</sup>. Mixing with the waters of the main channel of the Beryozovaya River causes a significant increase in total water hardness in the collected samples, which statistically move to the third cluster. Samples from the Plyusninka River periodically fall into both the second and third clusters. Although free from point anthropogenic sources of pollutants, the river remains susceptible to contamination by waters from worn-out water supply and wastewater systems, which are characterized by elevated concentrations of Ca<sup>2+</sup>, Mg<sup>2+</sup>, and Cl<sup>-</sup>.

## 4. CONCLUSION

As a result of cluster analysis of hydrochemical research data from small rivers draining the territory of Khabarovsk, three groups of areas experiencing different levels of anthropogenic load were identified (the first, second, and third clusters). A separate, fourth cluster includes areas free from significant anthropogenic interference, located within the Bolshekhekhtsirsky Nature Reserve. The areas experiencing the lowest anthropogenic load form mainly the central part of the city and are represented by the second and third clusters. The average exceedances of background values are 9 and 15 times, respectively. The areas experiencing the highest load (with an average exceedance of background values of more than 21 times) are located on the periphery of the city (the first cluster). A distinctive feature of the rivers in this group is the significant excess of ammonium nitrogen, phosphates, and anionic surfactants. Thus, the possibility of using cluster analysis of small river hydrochemical research data to indicate the intensity and types of anthropogenic impact on urbanized areas has been demonstrated.

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