



Scientific article

MULTICOMPONENT ASSESSMENT OF POLLUTION AND ECOLOGICAL STATUS OF SURFACE WATERS OF THE BRAZHINSKY STREAM (EASTERN KAZAKHSTAN)

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KEYWORDS

Brazhinsky Stream, surface water quality, heavy metals, Water Pollution Index (WPI), water turbidity, anthropogenic impact, hydrochemical analysis

ABSTRACT

This study presents a multicomponent assessment of pollution and the ecological status of surface waters in the Brazhinsky Stream, located within the city of Ust-Kamenogorsk (Eastern Kazakhstan). The assessment is based on the analysis of water turbidity and hydrochemical composition. The results show that turbidity values range from 47.7 to 54.3 NTU, indicating a high content of suspended solids and their significant role in the transport of pollutants. Hydrochemical analysis revealed persistent exceedances of maximum permissible concentrations for several elements, with copper, zinc, aluminum, and iron making the greatest contribution to overall contamination. Copper concentrations reach up to 44.2 times the permissible limit, while zinc concentrations are as high as 9.8 times the allowable level, indicating pronounced anthropogenic impact. An integrated assessment of water quality was carried out using the Water Pollution Index (WPI), with values of 2.27, 2.75, and 3.68 recorded for the upper, middle, and lower sections of the stream, respectively. According to the classification scheme, these values correspond to the category of “polluted water,” with a clear trend of increasing contamination downstream. It is shown that the Brazhinsky Stream, despite not directly discharging into the Irtysh River, plays an important role in the redistribution of pollutants within the system of surface and groundwater. The findings indicate a significant anthropogenic load on the watercourse and highlight the need for regular hydrochemical monitoring of small streams in urbanized areas.

1. INTRODUCTION

Under conditions of intensive industrial development, the issue of surface water quality is becoming increasingly important, particularly in urbanized regions with a well-developed mining and metallurgical sector [1...3]. The city of Ust-Kamenogorsk is one of the largest industrial centers in Kazakhstan, where non-ferrous metallurgy, energy production, and mechanical engineering enterprises are concentrated. Long-term anthropogenic impact has led to the release of substantial amounts of pollutants into the environment, including heavy metals, which are capable of accumulating in ecosystem components and exerting prolonged adverse effects on the hydrosphere [4...6].

Small watercourses play a particularly important role in shaping the ecological status of aquatic systems, yet they are often excluded from regular monitoring programs [7, 8]. At the same time, they act as primary accumulators of pollutants and as pathways for their transfer into larger water systems [9]. The Brazhinsky Stream is one such watercourse – a small stream flowing within the urban area of Ust-Kamenogorsk and subjected to complex anthropogenic pressures. Despite the absence of direct discharge into the Irtysh River, this stream may exert an

indirect influence on both surface and groundwater systems through infiltration processes and the redistribution of contaminants.

An important aspect in the assessment of surface water quality is the comparison of obtained data with regulatory standards, in particular maximum permissible concentrations (MPCs), which allows for the evaluation of anthropogenic pressure on a watercourse. At the same time, it should be taken into account that elevated concentrations of certain elements may be associated with the natural geochemical features of a region. For example, studies of the Olgokhta River have shown that concentrations of several elements (e.g., Fe and Mn) may exceed regulatory levels without a direct link to anthropogenic impact [10]. In this regard, the use of regulatory criteria in combination with consideration of natural background conditions enables a more accurate interpretation of hydrochemical data and the identification of components of anthropogenic origin.

Results of studies on small watercourses show that elevated concentrations of heavy metals may form not only under the influence of anthropogenic factors, but also under conditions of minimal human impact due to the natural geochemical characteristics of a territory. For example, in small rivers on the western slope of the Irandek Ridge, exceedances of MPCs have been recorded for elements such as Cu, Fe, Pb, Zn, and Cd, which is attributed to the leaching of ore-bearing and bedrock formations and the specific geological structure of the area [11]. These findings indicate that, when assessing surface water quality based on regulatory standards, it is necessary to consider the potential influence of natural factors, which enables a more substantiated interpretation of results and the differentiation between natural and anthropogenic components of pollution.

Thus, the integrated consideration of regulatory indicators and natural factors is a necessary condition for an objective assessment of the water quality of small watercourses. Contemporary approaches to water quality assessment are based on a comprehensive analysis of hydrochemical parameters and the application of integrated indices that allow for the generalization of multicomponent information on pollution [12, 13]. Particular attention is given to heavy metals such as copper, zinc, iron, and aluminum, which are characterized by high toxicity, persistence in the natural environment, and the ability to bioaccumulate [14...16]. In addition, turbidity is an important indicator of the ecological status of aquatic systems, reflecting the content of suspended solids and their role in the transport of pollutants [17].

The Brazhinsky Stream is a small watercourse located within the city of Ust-Kamenogorsk, flowing from north to southwest through an urbanized area. It originates in the northern foothills of the Uba Ridge and belongs to the Irtysh River Basin. The total length of the stream is approximately 14.3 km, with a catchment area of 36 km². The width of the riverbed between the banks reaches about 10 m, while the actual width of the water flow during the low-flow period is significantly smaller. The water depth during the low-flow period does not exceed 0.3 m.. The bed is predominantly sandy-silty with inclusions of fine gravel. The hydrological regime is characterized by a predominance of snowmelt feeding; peak discharges occur in spring, whereas during the low-water period the flow decreases significantly and may be intermittently disrupted by rainfall-driven flood events.

Thus, the studied watercourse is characterized by pronounced seasonal variability in runoff and increased sensitivity to external, including anthropogenic, impacts. According to design and environmental documentation, the Brazhinsky Stream serves as a recipient of stormwater and industrial wastewater, which determines its vulnerability to pollution [18].

It should be noted that the Brazhinsky Stream is not among the water bodies subject to regular state hydrological monitoring with publicly available observation data. Therefore, information on its hydrological regime and individual extreme hydrological events is limited and is available mainly from open-access published sources.

In regional media publications, cases of anthropogenic impact on the watercourse have been reported, including the discharge of contaminated waters from energy infrastructure facilities. An incident of pollution of the Brazhinsky Stream associated with an accidental release

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of clarified water from the territory of the Ust-Kamenogorsk CHP Plant used for the transport of ash-and-slag waste has been documented [19]. A sudden deterioration in water quality has also been reported, accompanied by changes in water color and signs of severe contamination [20]. Additional sources of pollution include organic waste, such as grain residues entering the stream, as well as littering of the riparian zone, indicating a persistent nature of anthropogenic impact [21]. According to publicly published sources, the stream is characterized by pronounced flood activity and is considered a potentially hazardous element of the urban drainage system, as evidenced by flooding events during the snowmelt period [22]. In this regard, regular hydraulic engineering works are carried out on the Brazhinsky Stream, including dredging of bottom sediments and channel deepening, aimed at preventing flooding and maintaining the drainage function of the watercourse.

The presented data indicate the complex nature of anthropogenic impacts on the Brazhinsky Stream and highlight its significant role in shaping the ecological condition of the urban aquatic system.

Despite the existence of individual studies devoted to the hydrochemistry of large rivers in Eastern Kazakhstan [23, 24], small watercourses in urbanized areas remain insufficiently investigated, which limits the ability to provide an objective assessment of environmental risks and to develop effective environmental protection measures. In this regard, there is a need for detailed multicomponent studies aimed at identifying spatial patterns of pollution and assessing the ecological status of such aquatic systems. The aim of the present study is a comprehensive assessment of pollution and the ecological condition of surface waters in the Brazhinsky Stream based on the analysis of turbidity, hydrochemical composition, and the calculation of the integrated Water Pollution Index (WPI), as well as the identification of the role of this watercourse in the redistribution of pollutants within the urban area. The scientific novelty of this study lies in obtaining new data on the spatial distribution of pollutants in the Brazhinsky Stream, identifying priority pollutants, comprehensively assessing the ecological status of a small urbanized watercourse using the Water Pollution Index and visualizing the spatial distribution of pollutants through a heat map.

2. MATERIALS AND METHODS

2.1 Study area and sampling

The object of the present study was the Brazhinsky Stream (Figure 1), located within the city of Ust-Kamenogorsk (Eastern Kazakhstan) (Figure 2).

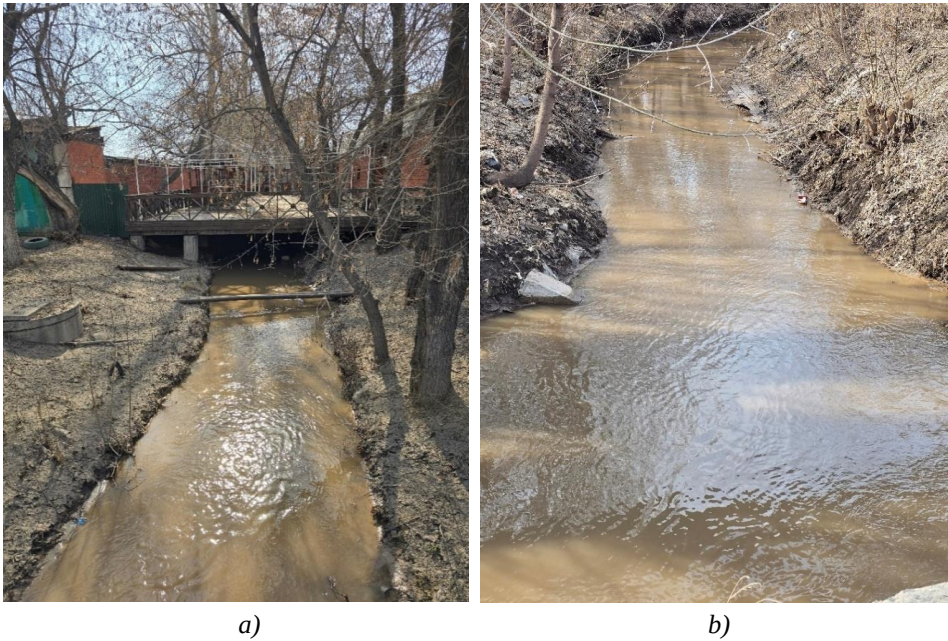


Figure 1. Surface waters of the Brazhinsky Stream within the urban area of Ust-Kamenogorsk. (a - 61a Nursultan Nazarbayev Street (the actual width of the water flow during the sampling period: 2.9 m); b - 1/5 Mostovaya Street (the actual width of the water flow during the sampling period: 2.6 m).)

The watercourse flows through an area of intensive industrial development and is subject to significant anthropogenic impact (Figure 3). Water sampling was carried out at three sites representing different sections of the stream: the upper reach (Brazh 1), the middle reach (Brazh 2), and the lower reach (Brazh 3). The sampling points were selected taking into account the hydrological regime and the location of potential pollution sources. Surface water sampling was conducted in August–September 2025 in accordance with the hydrochemical monitoring program (Table 1, Figures 2...3).

Table 1
Actual sampling sites

No.	Site	Sampling date	Coordinates of sampling point	Remarks
1	Brazh 1	26.08.2025	50°02'21.27" N, 82°35'09.11" E	Brazhinsky Stream tributary, headwaters
2	Brazh 2	24.09.2025	49°59'03.52" N, 82°35'44.52" E	Middle reach of the Brazhinsky Stream
3	Brazh 3	24.09.2025	49°59'04.24" N, 82°33'27.93" E	Lower (outlet) reach of the Brazhinsky Stream

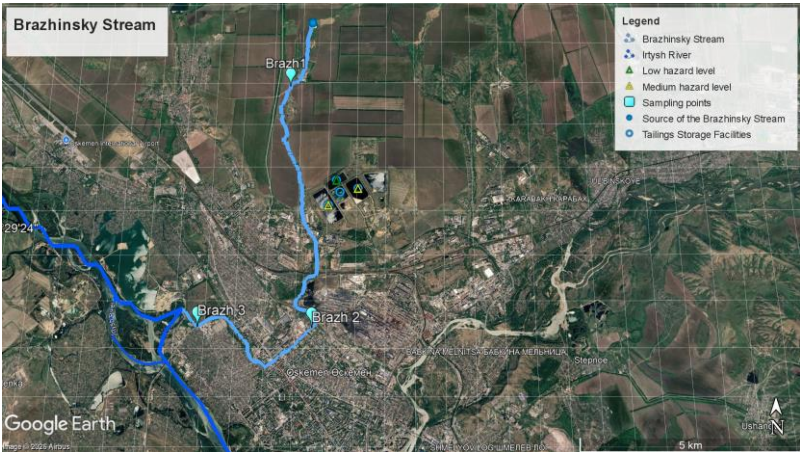


Figure 2. Overview map of the Brazhinsky Stream and locations of sampling sites

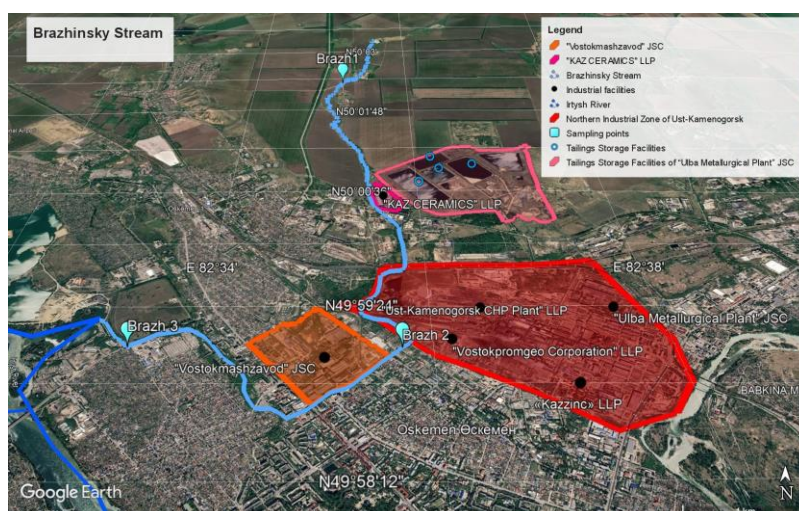


Figure 3. Scheme of the distribution of anthropogenic impact sources within the Brazhinsky Stream catchment area

According to the information bulletins of RSE "Kazhydromet" [25], the study was conducted within the same summer–autumn hydrological season, which is characterized by a unified hydrochemical monitoring regime for surface waters. The obtained results were interpreted to assess the spatial distribution of hydrochemical parameters along the Brazhinsky Stream.

Surface water samples were collected in accordance with ST RK ISO 5667-6-2017 [26] and GOST 59024-2020 [27]. At each sampling site, three point samples were collected from different parts of the cross-section of the watercourse, namely from both banks and the central part of the channel. Sampling was carried out in flowing water, avoiding areas of stagnant water, accumulated bottom sediments, and dense aquatic or riparian vegetation. Samples were collected at a depth of 20...30 cm below the water surface to avoid collecting the surface film and disturbing bottom sediments.

The volume of each point sample was 0.5 dm³. The three point samples were then combined in equal proportions to obtain one composite sample with a total volume of 1.5 dm³, representing the water composition at each sampling site.

Pre-cleaned polyethylene containers with tightly sealed lids were used for sample collection. During transportation, the samples were stored in a thermal container and protected from direct sunlight. Since the Brazhinsky Stream is located within the city of Ust-Kamenogorsk, all samples were delivered to the laboratory within one hour after collection, and the analyses began immediately upon their arrival. For metal analysis, a separate aliquot of each sample was acidified with nitric acid to pH < 2 and stored at a temperature of 2...5 °C.

2.2 Methods

Within the framework of this study, stream discharge was not measured. Therefore, the interpretation of the spatial distribution of pollutants is based on the analysis of the hydrochemical composition and turbidity of the surface waters.

Water turbidity was measured in field conditions using a Hanna HI 93414-02 turbidimeter with an accuracy of ±0.1 NTU. At each sampling site, three replicate measurements were taken, and the results were averaged [28]. Turbidity of surface waters was considered as an integral indicator of suspended solids content and was used to assess their role in the migration of pollutants. All measurements were carried out prior to chemical analysis.

Chemical analyses were performed at the Laboratory of Analytical Research of the VERITAS Center of Excellence, D. Serikbayev East Kazakhstan Technical University. Chemical element analysis was performed using inductively coupled plasma mass spectrometry

(ICP-MS) after sample filtration through 0.45 µm membrane filters and acidification for preservation (HNO₃, pH < 2) [29]. Macro- and microelements, including heavy metals, were determined. Quality control of the analytical measurements was performed using standard calibration solutions, and the reported results represent the mean values of parallel determinations [30]. The combined analysis of turbidity and the chemical composition of the Brazhinsky Stream water was used to identify spatial patterns in the distribution of pollutants and to assess the influence of natural and anthropogenic factors.

In the present study, the assessment of surface water quality in the Brazhinsky Stream was carried out using the Water Pollution Index (WPI) to process and integrate information on the chemical composition of surface waters, with the aim of obtaining a comprehensive evaluation of their pollution level. According to the methodology, the degree of water pollution in a water body can be assessed based on a set of pollutants at any sampling site, over any defined time period, and using any set of hydrochemical parameters [31]. In this study, maximum permissible concentrations (MPCs) of harmful substances for fisheries water bodies were used as reference standards [32], as these standards are the most stringent among the existing surface water quality standards and are widely applied in the environmental assessment of natural water body pollution. The use of fishery MPCs makes it possible to assess the potential impact of pollutants on aquatic ecosystems and ensures the comparability of the obtained results with those of both domestic and international studies.

The exceedance factor of the maximum permissible concentration (MPC) was calculated for each chemical element as the ratio of the measured concentration of the substance to the corresponding regulatory limit value:

$$\frac{C_i}{MPC_i} \quad (1)$$

where C_i - is the measured concentration of the i -th element in water (mg/dm³);

MPC_i - is the maximum permissible concentration of the corresponding element (mg/dm³).

For the integrated assessment of water pollution in the Brazhinsky Stream, the Water Pollution Index (WPI) was calculated as the arithmetic mean of the MPC exceedance factors for all considered components:

$$WPI = \frac{1}{n} \sum_{i=1}^n \frac{C_i}{MPC_i} \quad (2)$$

where C_i - is the measured concentration of the element; MPC_i - is the maximum permissible concentration; n - is the number of considered parameters.

This index is an integrated dimensionless indicator of water pollution level and is used for comparative assessment of water quality at different sampling sites. Only regulated substances with established MPC values were included in the calculation. Exceedance factors below unity (in cases where MPCs were not exceeded) were also included in the WPI calculation, which allows for consideration of the overall chemical load on the water body. Based on the obtained results, the pollution level was assessed (Table 2) and priority pollutants were identified.

Table 2

Water classification according to WPI

No.	WPI	Water quality
1	<0,3	very clean
2	0,3 ... 1,0	clean
3	1,0 ... 2,5	moderately polluted
4	2,5 ... 4,0	polluted
5	4,0 ... 6,0	dirty
6	> 6,0	very dirty

3. RESULTS AND DISCUSSION

The cartographic scheme of the Brazhinsky Stream (Figure 1) illustrates its spatial location within the city of Ust-Kamenogorsk, as well as its relationship with the main natural and anthropogenic components of the environment. The watercourse is situated within the right-bank part of the valley of the Irtysh River and has a total length of approximately 14.3 km. The stream originates in the northern part of the study area (approximately 49.99° N, 82.63° E) and flows predominantly from north to southwest, passing through agricultural lands and further across the urbanized territory of the city. In the middle reach (site “Brazh 1”), the watercourse retains a relatively natural character; however, downstream (site “Brazh 2”) it intersects an area of intensive industrial development. In the lower reach (site “Brazh 3”), the stream loses a well-defined channel and, according to cartographic data, has no direct surface connection to the Irtysh River, partially discharging into topographic depressions and the groundwater system.

Morphologically, the Brazhinsky Stream belongs to gully–ravine type watercourses. The channel is meandering and unbranched, with steep banks 2...3 m high. The stream width within the main banks is about 10 m, while the actual width of the flowing water during the autumn sampling period was significantly smaller, ranging from 2.6 to 2.9 m at the study sites (Figure 1). The banks are steep and unstable with respect to erosion, which promotes the active transport of suspended matter, especially during rainfall-induced flood events. The average water depth is approximately 0.1 m, the flow velocity is 0.25 m/s, the channel roughness coefficient is 0.04, and the mean monthly discharge (95% exceedance probability) is 0.01 m³/s. The channel bed is predominantly sandy–silty with inclusions of fine gravel and vegetation. The watercourse is perennial, with a pronounced increase in discharge during periods of intensive precipitation [18].

The hydrological regime of the stream is characterized by pronounced seasonal variability. During the spring flood period (late March to early April), increases in water levels and discharge are observed due to snowmelt, and rainfall-induced flood events may also occur. The low-water (baseflow) period, which typically establishes in May under conditions of no precipitation, is marked by a substantial decrease in runoff, which may be intermittently interrupted by rainfall events. The highest discharges and water levels are recorded during the spring flood. Thus, the Brazhinsky Stream is a small watercourse with predominantly snowmelt-fed hydrology and a significant contribution of short-term rainfall-driven flood events to runoff formation. In combination with the morphological characteristics of the channel, this promotes the active transport of suspended solids.

Within the Brazhinsky Stream catchment area, the main sources of anthropogenic impact are localized. In the middle reach, along the left bank over a distance of approximately 0.9 km, the industrial site of KAZ CERAMICS is located, from which stormwater and meltwater runoff is discharged directly into the stream channel. The buffer zone between the facility fence and the stream bank is partially occupied by tree plantations; however, further upstream, approximately 70 m from the channel, the tailings storage facility of the Ulba Metallurgical Plant (Figure 2) is situated, the influence of which may be manifested through surface runoff formed along the fence and entering the watercourse. In the lower reach, the stream flows through the northern industrial zone of the city, which includes large enterprises such as Kazchrome (Kazzinc) LLP and Vostokmashzavod, corresponding to the area of maximum anthropogenic pressure.

Thus, the Brazhinsky Stream is a small urban watercourse flowing through the city of Ust-Kamenogorsk, which is characterized by a high degree of industrial development. Its morphological features, hydrological regime, and spatial location relative to industrial facilities create favorable conditions for the formation and transport of pollutants. At the same time, the absence of a direct surface connection to the Irtysh River indicates its important role in the redistribution of contaminants between surface and groundwater systems within the studied basin.

Under these conditions, the assessment of factors controlling the mechanisms of pollutant transport within the watercourse becomes particularly important. One such factor is the content of suspended particles, which can participate in the migration of contaminant compounds. In this

regard, to provide a more comprehensive characterization of pollutant redistribution processes in the Brazhinsky Stream, an analysis of water turbidity was carried out as an indicator reflecting the development of the suspended phase and its role in transport processes. Elevated turbidity values recorded at all studied sites of the Brazhinsky Stream (Table 3) indicate a high content of suspended matter in the watercourse. The maximum turbidity was observed in the headwaters (Brazh 1), reaching 54.3 NTU, while in the middle and lower reaches (Brazh 2 and Brazh 3), values were 47.7 NTU. Such a distribution may be attributed to the input of suspended material from the catchment area and active channel erosion processes in the upper part of the stream.

Table 3*Mean turbidity values (NTU) by sampling sites*

No.	Site code	Mean turbidity (NTU)	Site description
1	Brazh 1	54.3	Tributary, headwaters of the stream
2	Brazh 2	47.7	Middle reach of the Brazhinsky Stream
3	Brazh 3	47.7	Lower (outlet) reach of the Brazhinsky Stream

Heavy metals are capable of adsorbing onto the surface of suspended particles, which facilitates their transport in association with the solid phase. Under the conditions of the Brazhinsky Stream, this creates prerequisites for the migration of pollutants along the channel, as well as for their accumulation in bottom sediments and in zones of reduced flow velocity. Given the absence of a direct surface connection between the stream and the Irtysh River, increased water turbidity may promote the involvement of pollutants in infiltration processes and their subsequent transport within the groundwater flow system.

The obtained results are consistent with current understanding of the role of suspended solids in the migration of heavy metals in small urbanized watercourses. According to previous studies, an increase in the concentration of suspended particles promotes the adsorption of cadmium, zinc, lead, and other metals onto the surface of the solid phase, thereby increasing their transport capacity and facilitating their subsequent accumulation in bottom sediments. These processes are particularly pronounced in small watercourses with unstable banks and active channel erosion, where suspended matter becomes one of the main carriers of pollutants [33].

A hydrochemical study of the Brazhinsky Stream waters was conducted at three cross-sections representing different parts of the watercourse: the headwaters (Brazh 1), the middle reach (Brazh 2), and the mouth section (Brazh 3). The obtained results of chemical element concentration analyses (Table 4) made it possible to perform a comprehensive assessment of the water pollution level. The analysis showed that the chemical composition of the Brazhinsky Stream waters is characterized by significant spatial variability. For most elements, an increasing trend in concentrations is observed downstream, indicating the accumulation of pollutants as the stream flows through the urbanized area of Ust-Kamenogorsk. The most pronounced changes are observed for alkali and alkaline earth elements. In particular, the sodium concentration increases from 4.79 mg/dm³ in the headwaters to 42.84 mg/dm³ in the middle reach, followed by a slight decrease to 28.31 mg/dm³ in the mouth section. A similar trend is observed for magnesium, whose concentration rises from 3.65 mg/dm³ to 31.48 mg/dm³, which may be associated with the input of mineral salts from surface runoff and anthropogenic sources.

Calcium concentrations range from 10.30 to 31.23 mg/dm³, remaining well below the maximum permissible concentrations, which indicates the predominantly natural origin of this element.

The Eastern Kazakhstan region is characterized by a complex geological structure and a widespread occurrence of ore deposits, which determines the presence of a natural geochemical background of a number of elements in natural waters. In this regard, elevated concentrations of certain components may be partly associated with natural factors. In particular, the increased concentrations of iron and aluminum (Table 4) may be attributed to the leaching of rock-forming minerals, as well as to the transport of fine-dispersed particles within suspended matter. At the same time, the identified exceedances of maximum permissible concentrations, which are of a persistent nature, indicate that natural factors are not the sole source of these elements. This

suggests a significant role of anthropogenic impact in the formation of the chemical composition of the Brazhinsky Stream waters.

In this context, particular attention should be paid to the distribution of heavy metals, which serve as key indicators of anthropogenic pollution in aquatic systems. The concentration of aluminum exceeds the maximum permissible concentration (MPC) at all sampling sites. In the upstream section, the concentration reaches 0.147 mg/dm³, corresponding to 3.7 MPC. In the middle reach, the aluminum level decreases to 2.4 MPC; however, in the mouth section, it increases again to 4.8 MPC, which may indicate an additional input of this element in the lower part of the stream. Iron concentrations also exceed regulatory limits at all studied sites. The highest exceedance is observed in the headwaters of the stream, reaching 3.2 MPC, whereas in the middle reach the level decreases to 1.2 MPC. In the mouth section, the concentration increases again to 2.2 MPC. Elevated iron content may be associated with both the natural geochemical characteristics of the area and anthropogenic pollution sources.

It should be noted that, in areas with well-developed mining and metallurgical industries, distinguishing between the natural and anthropogenic sources of pollution is a challenging task. Under such conditions, elevated aluminum concentrations are often associated with a combination of natural rock weathering and additional inputs from industrial emissions and surface runoff, as has been repeatedly reported in studies of mining regions [34]. The review by [35] showed that, in mining areas, Fe is among the elements that most frequently exceed background levels and water quality standards, together with Cu, Zn, Mn, and Pb.

Table 4

Mean turbidity values (NTU) by sampling sites

Element	MPC _i , mg/dm ³	Brazh 1			Brazh 2			Brazh 3		
		C _i , mg/dm ³	$\frac{C_i}{MPC_i}$	$\sum_{i=1}^n \frac{C_i}{MPC_i}$	C _i , mg/dm ³	$\frac{C_i}{MPC_i}$	$\sum_{i=1}^n \frac{C_i}{MPC_i}$	C _i , mg/dm ³	$\frac{C_i}{MPC_i}$	$\sum_{i=1}^n \frac{C_i}{MPC_i}$
Be	0.0001	0.00007	0.70		0.00002	0.20		0.00003	0.30	
B	≤0.5	0.24630	0.49		0.23420	0.47		0.17820	0.36	
Na	120	4.79	0.04		42.84	0.36		28.31	0.24	
Mg	≤20	3.65	0.18		31.48	1.57		20.25	1.01	
Al	0.04	0.14702	3.68		0.09557	2.39		0.19371	4.84	
P	0.1	0.11320	1.13		0.10790	1.08		0.12060	1.21	
K	50	1.07	0.02		3.27	0.07		3.14	0.06	
Ca	180	10.30	0.06		31.23	0.17		23.83	0.13	
Cr	0.1	0.00350	0.04		0.00539	0.05		0.00601	0.06	
Mn	0.01	0.00760	0.76	43.22	0.00488	0.49	52.21	0.00659	0.66	69.97
Fe	0.1	0.32093	3.21		0.12453	1.25		0.22242	2.22	
Co	0.005	0.00108	0.22		0.00062	0.12		0.00077	0.15	
Ni	0.008	0.00334	0.42		0.00388	0.49		0.00462	0.58	
Cu	0.001	0.02422	24.22		0.03257	32.57		0.04424	44.24	
Zn	0.01	0.05846	5.85		0.07026	7.03		0.09821	9.82	
As	0.002	0.00243	1.22		0.00286	1.43		0.00394	1.97	
Mo	0.001	0.00066	0.66		0.00222	2.22		0.00153	1.53	
Cd	0.001	0.00014	0.14		0.00014	0.14		0.00019	0.19	
Pb	0.006	0.00109	0.18		0.00065	0.11		0.00239	0.40	
WPI			2.27			2.75			3.68	
Water quality			Moderately polluted			Polluted			Polluted	

The most significant exceedance of regulatory limits is observed for copper. Its concentration amounts to 24.2 MPC in the headwaters, 32.6 MPC in the middle reach, and 44.2 MPC in the mouth section. Thus, copper represents the principal contaminant of the Brazhinsky Stream waters. Such high concentrations may be related to industrial activities characteristic of the Ust-Kamenogorsk area. A similar pattern is observed for zinc, with concentrations of 5.8 MPC in the headwaters, 7.0 MPC in the middle reach, and 9.8 MPC in the mouth section. The increase in zinc concentration downstream also indicates its anthropogenic origin. Arsenic is present at concentrations exceeding regulatory limits by 1.2 ... 2.0 times, which likewise suggests potential anthropogenic impact (Figure 4).

The spatial increase in copper and zinc concentrations downstream is consistent with the results of studies conducted in urbanized catchments, which have shown that land use, industrial activities, and the condition of riparian zones have a significant impact on heavy metal concentrations in small watercourses. In industrial catchments, a significant proportion of the heavy metal load can be directly attributed to industrial sources and surface runoff from urbanized areas [36, 37].

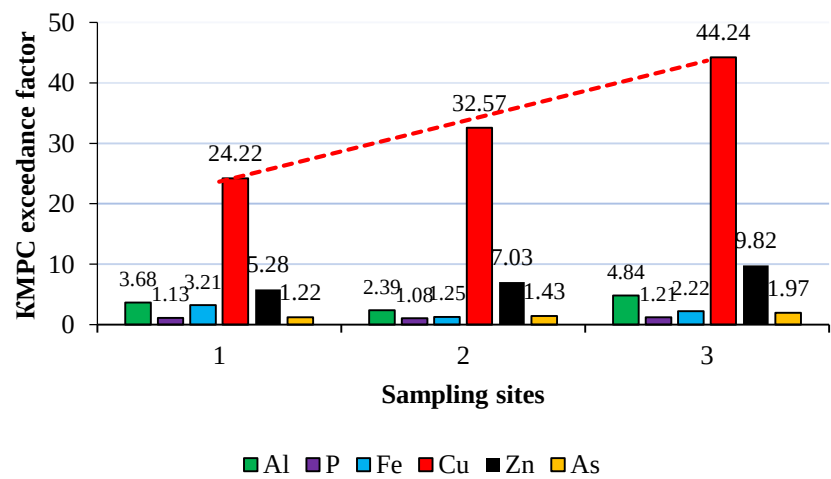


Figure 4. Multiples of maximum permissible concentration (MPC) for major pollutants at the studied sampling sites of the Brazhinsky Stream

The analysis of the heat map of maximum permissible concentration (MPC) exceedance for major elements (Figure 5) shows that copper and zinc make the greatest contribution to the overall pollution level, exhibiting the highest MPC multiples.

Element	Brazh 1	Brazh 2	Brazh 3	Scale
Cu	24.22	32.57	44,24	50.00
Zn	5.85	7.03	9.82	45.00
Al	3.68	2.39	4.84	40.00
Fe	3.21	1.25	2.22	35.00
As	1.22	1.43	1.97	30.00
Mo	0.66	2.22	1.53	25.00
Mn	0.76	0.49	0.66	20.00
Mg	0.18	1.57	1.01	15.00
P	1.13	1.08	1.21	13.00
Ni	0.42	0.49	0.58	11.00
B	0.49	0.47	0.36	9.00
Be	0.7	0.2	0.3	7.00
Co	0.22	0.12	0.15	5.00
Pb	0.18	0.11	0.4	3.00
Cd	0.14	0.14	0.19	2.00
Ca	0.06	0.17	0.13	1.00
Na	0.04	0.36	0.24	0.50

Cr	0.04	0.05	0.06	0.10
K	0.02	0.07	0.06	0.00

Figure 5. Heat map of the spatial distribution of maximum permissible concentration (MPC) exceedance factors for elements across the sampling sites of the Brazhinsky Stream

The obtained results indicate that pollution in the Brazhinsky Stream is dominated by a limited number of priority pollutants.

Elevated values are also observed for aluminum and iron, indicating their significant role in forming the overall chemical composition of the stream waters.

The spatial distribution of the indicators demonstrates an increase in the degree of pollution downstream of the stream, which is particularly pronounced for copper and zinc. A number of elements (Be, Cr, Mn, Co, Ni, Cd, Pb) occur at concentrations significantly below the maximum permissible levels. For example, beryllium concentrations range from 0.2 to 0.7 MPC, chromium from 0.04 to 0.06 MPC, and nickel from 0.42 to 0.58 MPC. This indicates that these elements do not have a substantial impact on the overall pollution level of the studied watercourse and can be considered part of the background contamination.

The identified patterns are confirmed by the results of the water pollution index (WPI) calculation, the values of which increase from 2.27 in the headwaters to 3.68 in the lower reach of the stream (Figure 6).

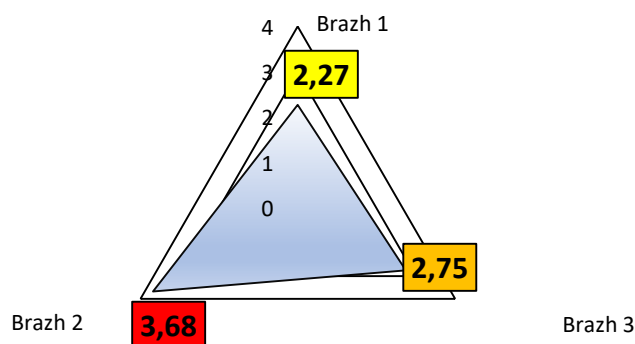


Figure 6. Spatial distribution of the water pollution index (WPI) across the sampling sites of the Brazhinsky Stream

This indicates the cumulative nature of pollution within the urbanized area. Thus, the heat map and WPI values consistently reflect the spatial differentiation of pollution, allowing the identification of priority pollutants and confirming the intensification of anthropogenic impact downstream of the Brazhinsky Stream.

According to the adopted water quality classification, WPI values in the range of 2.5...4 correspond to the “polluted water” category. The obtained index values demonstrate a clear trend of increasing pollution downstream: Brazh 1 < Brazh 2 < Brazh 3 (Figure 7). This indicates a gradual accumulation of pollutants within the stream channel and confirms the influence of anthropogenic factors on the formation of the water chemical composition. The greatest contribution to the integrated pollution index is made by the following elements: copper, zinc, aluminum, iron, and arsenic. These components determine the overall level of environmental pressure on the aquatic system.

The consistency between the results obtained from the analysis of MPC exceedance ratios and those derived from the calculation of the integrated Water Pollution Index (WPI) indicates the high informative value of an integrated approach to water quality assessment. Such an approach is widely used in contemporary surface water studies because it accounts for the

combined effects of multiple pollutants and provides a more objective assessment of the ecological status of a water body [38].

Despite its small size, the Brazhinsky Stream may serve as a significant local accumulator and transporter of anthropogenic pollutants within the urban area. Given the detected concentrations of copper and zinc exceeding regulatory limits by several tens of times, this stream should be considered a potential pathway for the migration of heavy metals within both surface and, likely, groundwater systems. According to cartographic data, the Brazhinsky Stream does not directly discharge into the Irtysh River; instead, in its lower reach it likely loses surface runoff and partially discharges into subsurface horizons. This suggests the possibility of further pollutant transport not only via surface flow but also through subsurface pathways. The obtained results confirm the need for regular monitoring of the chemical composition of small streams in urbanized areas, as even in the absence of direct inflow into major rivers, they may play a significant role in the redistribution of pollutants within a river basin.

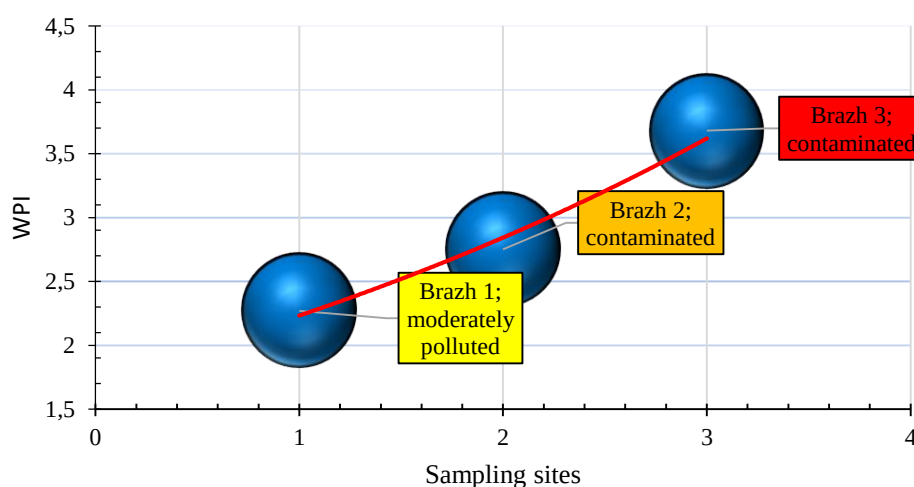


Figure 7. Variation in the level of water pollution along the flow of the Brazhinsky Stream

The obtained results emphasize that small watercourses, despite their relatively low discharge and local scale, can play an important role in the accumulation and redistribution of pollutants within urbanized areas. Such watercourses are often the most sensitive indicators of local industrial impacts and make it possible to identify pollution sources much earlier than they become evident in larger rivers. Therefore, monitoring of small watercourses should be considered an important element of the environmental monitoring system in industrial regions.

4. CONCLUSION

The conducted study made it possible to perform a comprehensive assessment of the ecological state of the waters of the Brazhinsky Stream located within the city of Ust-Kamenogorsk. It was established that the formation of the stream's chemical composition is governed by both natural and anthropogenic factors, with a predominant role of anthropogenic pressure. The spatial location of the stream within an area of intensive industrial development, as well as its morphological and hydrological characteristics, creates favorable conditions for the active input, transport, and accumulation of pollutants.

It should be noted that the identified spatial differences significantly exceed the possible seasonal variations in the measured parameters during the study period, making it possible to use the obtained data to assess the spatial distribution of pollution in the watercourse.

The turbidity analysis revealed a high content of suspended solids at all investigated sampling sites (47.7...54.3 NTU), which facilitates the migration of heavy metals in the solid phase and their accumulation in bottom sediments. Hydrochemical analysis identified persistent

exceedances of maximum permissible concentrations (MPC) for a number of elements, among which copper, zinc, aluminum, and iron make the greatest contribution to pollution. Copper concentrations reach 24.2...44.2 MPC, while zinc levels range from 5.8 to 9.8 MPC, indicating a pronounced anthropogenic origin of the contamination.

A specific feature of the Brazhinsky Stream is the absence of a direct surface inflow into the Irtysh River, which determines its role as an element in the redistribution of pollutants between surface and groundwater systems. Under these conditions, the stream may act as a local accumulator and conduit of anthropogenic contaminants, including their potential further migration into subsurface horizons.

Thus, the Brazhinsky Stream is a small urbanized watercourse subjected to significant anthropogenic impact. Its ecological condition is characterized as polluted, while the transport processes of contaminants are complex and spatially differentiated. The obtained results confirm the necessity of regular hydrochemical monitoring of small watercourses in urbanized areas as important components in the formation of the ecological state of aquatic systems.

DATA AVAILABILITY

The data used in the study were obtained as a result of an experimental analysis of surface water samples.

AUTHOR CONTRIBUTIONS

Conceptualization – NS, GD; Resources – NS, GD, OP, MK, AP, OV, ID; Formal analysis – NS, GD; Methodology – NS, GD, OP, AP; Visualization – NS, AP, OP; Writing-original draft preparation – NS, GD, MK; Writing — review and editing – NS, GD, OP, MK, AP, OV, ID.

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БРАЖИНСКИЙ БҰЛАҒЫНЫҢ (ШЫҒЫС ҚАЗАҚСТАН) БЕТКІ СУЛАРЫНЫҢ ЛАСТАНУЫ МЕН ЭКОЛОГИЯЛЫҚ ЖАҒДАЙЫНА КӨПКОМПОНЕНТТІ БАҒА БЕРУ

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ТҮЙІН СӨЗДЕР

Бражинский бұлағы, беткі сулардың сапасы, ауыр металдар, су ластану индексі (WPI), су лайлылығы, антропогендік әсер, гидрохимиялық талдау

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АБСТРАКТ

Жұмыста Бражинский бұлағының беткі суларының ластануы мен экологиялық жағдайына көпкомпонентті баға беру ұсынылған. Зерттеу су лайлылығы мен гидрохимиялық құрамын талдау негізінде жүргізілді. Су лайлылығы 47,7...54,3 ФЕ аралығында өзгеретіні анықталды, бұл қалқыма заттардың жоғары мөлшерін және олардың ластаушы компоненттердің көшуіндегі маңызды рөлін көрсетеді. Гидрохимиялық талдау бірқатар элементтер бойынша шекті рұқсат етілген концентрациялардың тұрақты артуын көрсетті, олардың ішінде ластануға ең үлкен үлес қосатындар - мыс, мырыш, алюминий және темір. Мыстың концентрациясы 44,2 ШРК-ға дейін, мырыштікі - 9,8 ШРК-ға дейін жетеді, бұл айқын техногендік әсерді білдіреді. Судың сапасын интегралды бағалау үшін су ластану индексі (WPI) қолданылды, оның мәндері жоғары, орта және төменгі учаскелер үшін тиісінше 2,27; 2,75 және 3,68 болды. Жіктеме бойынша бұл «ластанған су» санатына сәйкес келеді және ағыс бойымен төмен қарай ластану деңгейінің арту үрдісін көрсетеді. Бражинский бұлағы Ертіс өзеніне тікелей құйылмағанына қарамастан, беткі және жерасты сулары жүйесінде ластаушы заттардың қайта бөлінуінде маңызды рөл атқаратыны көрсетілді. Алынған нәтижелер су ағысына антропогендік жүктеменің жоғары екенін дәлелдейді және урбанизацияланған аумақтардағы шағын су ағындарын тұрақты гидрохимиялық мониторингтеудің қажеттілігін растайды.

МНОГОКОМПОНЕНТНАЯ ОЦЕНКА ЗАГРЯЗНЕНИЯ И ЭКОЛОГИЧЕСКОГО СОСТОЯНИЯ ПОВЕРХНОСТНЫХ ВОД БРАЖИНСКОГО РУЧЬЯ (ВОСТОЧНЫЙ КАЗАХСТАН)

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КЛЮЧЕВЫЕ СЛОВА

Бражинский ручей, качество поверхностных вод, тяжёлые металлы, индекс загрязнения воды (WPI), мутность воды, антропогенное воздействие, гидрохимический анализ

АБСТРАКТ

В работе представлена многокомпонентная оценка загрязнения и экологического состояния поверхностных вод Бражинского ручья, расположенного в пределах города Усть-Каменогорск (Восточный Казахстан). Исследование выполнено на основе анализа мутности и гидрохимического состава воды. Установлено, что мутность воды варьирует в пределах

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47,7...54,3 ФЕ, что свидетельствует о высоком содержании взвешенных веществ и их значимой роли в миграции загрязняющих компонентов. Гидрохимический анализ показал наличие устойчивых превышений предельно допустимых концентраций по ряду элементов, среди которых наибольший вклад в загрязнение вносят медь, цинк, алюминий и железо. Концентрации меди достигают 44,2 ПДК, цинка - до 9,8 ПДК, что указывает на выраженное техногенное воздействие. Для интегральной оценки качества воды использован индекс загрязнения воды (WPI), значения которого составили 2,27; 2,75 и 3,68 для верхнего, среднего и нижнего створов соответственно. Согласно классификации, это соответствует категории «загрязнённая вода» с тенденцией увеличения степени загрязнения вниз по течению. Показано, что Бразинский ручей, несмотря на отсутствие прямого впадения в реку Иртыш, играет важную роль в перераспределении загрязняющих веществ в системе поверхностных и подземных вод. Полученные результаты свидетельствуют о значительной антропогенной нагрузке на водоток и подтверждают необходимость регулярного гидрохимического мониторинга малых водотоков урбанизированных территорий.

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