Principal characteristics of transformations in hydrological and ecological conditions of minor rivers within the affected area of mining facilities (on the example of the rivers Karagayly and Khudolaz in the Ural river basin)

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Abstract. The article reveals the specific features of the influence posed by mining facilities towards morphometric and hydrological characteristics as well as the environmental condition of small rivers. Given the characteristic features of the impact experienced by the environment (incl. water bodies), the article seeks to identify the peculiarities of the influence caused by a large set of industries involved in the extraction of minerals and their primary treatment leading to production of semi-finished products of non-ferrous metallurgy. The objects of investigation cover the rivers Karagayly and Khudolaz, which are located within the upper reaches of the river Ural and are undergoing an excessively high impact caused by the facilities of the latter industry and the housing and public utilities.

1. Introduction

During the comprehensive research conducted by the authors in 2020, the characteristic properties of changes in the hydrological and ecological characteristics of the given rivers were studied taking into consideration the influence of a combination of natural and anthropogenic factors. In terms of the natural factors analysis was exercised as to the impact of long-term dynamics of changes in hydrometeorological conditions and climate towards the characteristics of the annual, maximum, minimum summer-autumn and winter runoff. It was identified that the basins of the rivers Karagayly and Khudolaz are located at the junction of the forest-steppe and steppe zones, where the effect of growing climate aridity observed since 2001-2007 to date is especially pronounced.

Among the anthropogenic factors, the peculiarities of the impact produced by numerous technogenic items occupying vast areas were investigated. Special attention was paid to analysing the peculiarities of the influence posed by quarries, rock dumps, tailings dumps, waste water discharge of industrial enterprises, housing and public utilities, city dumps, etc. Detailed hydrochemical and hydrobiological surveys of the analysed rivers, as well as the identifying of dynamic processes...
reflecting the changes in the researched parameters in the long-term context have provided the grounds for justifying the measures needed for restoring their morphometric, hydrological and ecological characteristics.

2. Materials and methods
The research methodology and methods are premised on the geosystem approach and the basin principle. It is herein implied that natural and anthropogenic factors pertaining both to the catchments and the watercourses per se as to any estimated (analysed) section should be taken into consideration from the standpoint that "a catchment and a water body are treated as a single natural (natural-economic) system" [1]. This calls for conducting comprehensive surveys and research resulting in the identification of the major factors to be considered while justifying the necessary measures aimed at substantial improvement of the hydrological and ecological situation of the watercourses. In this article they are substantiated on the example of the basins of the rivers Karagayly and Khudolaz that are subject to a continuous and concentrated impact of such processes and facilities as polluted wastewater discharge conducted by the Sibay ore mining and processing plant (also referred to as Sibayskiy GOK) and other enterprises located in the adjacent area, as well as the leaching, dissolution and migration of characterizing pollutants in rock dumps, their subsequent afflux into watercourses, the emergence of a cone of depression, the absorption of river runoff by quarries, the growing proximity of the old and new tailings dumps posing a substantial risk of an emergency situation, etc.

In the course of investigating the spatial and temporal variability of the studied natural and anthropogenic factors, as well as the traced hydrological and ecological changes, various methods of analysing multiannual time-series of hydrometeorological observations, hydrochemical and hydrobiological surveys, mapping the results obtained using GIS technologies, etc. were adopted.

3. Results and discussion
It’s known that a significant territory found along the eastern slope of the Middle and South Urals, as well as along the adjacent hills, is characterized by the occurrence of long-term mining activities in the production of non-ferrous metal ores, their processing and beneficiation at the mining and refining facilities, which results in the predominant deterioration of the quantitative, qualitative characteristics of water in water bodies, and a consequent drastic impairment of their environmental condition [2, 3]. Among the most indicative in this aspect we should mention the location of non-ferrous metal ore extraction sites within the basins of small rivers, while their processing facilities are mainly found in the towns Karabash (the Chelyabinsk region), Uchalı, Sibay and the village Buribay (the Republic of Bashkortostan), as well as Mednogorsk (the Orenburg region). Their locations are to be found in figure 1.

As can be seen from the figure given above, within the affected area of the Karabash copper plant we can find the upper part of the Sak-Elga river basin. This territory featured an emergency situation following the breakthrough of the tailings dump in the 1970s, wherein plant communities and fauna were virtually devastated throughout the area corresponding to the path of the breakthrough wave along the given river. Extremely high concentrations of conservative pollutants in the watercourse have led to the rivers being lifeless for decades. An extremely unfavourable situation now persists in the influence area of the Uchalinskiy mining and processing plant, its wastewater being discharged into the rivers Buyda and Kidysh belonging to the Tobol-Ob basin. A rather difficult situation has still been observed along the rivers Karagayly and Khudolaz, which have also been exposed to excessively high influence of the mining facilities of the town Sibay. The rivers Tanalyk and Blyava, their basins being located to the south, display unfavourable hydrological and ecological condition arising from the influence of the Buribaevskiy and Mednogorskiy mining and processing plants respectively.

Based on the generalization and analysis of a substantial amount of published sources and our own research findings, it can be emphasized that within the above-mentioned areas of adverse effect posed by mining facilities towards natural complexes, typical factors and mechanisms of influence are revealed and may be further generalized and taken into account in studying the on-going changes, as
well as in substantiating the water-protection measures (hydrological-and ecological) in view of the peculiarities of influence exercised by a combination of natural and anthropogenic factors.

![Figure 1. Locations of mining and processing works within the South Urals and Trans-Urals.](image)

Among the principal natural factors exerting influence on the conditions of river runoff formation and ecological characteristics of watercourses found within the affected area of Sibay industrial facilities the following should be briefly reflected. In terms of geology the studied area belongs to the West Magnitogorsk zone of the Magnitogorsk megazone (megasynclinorium), located on the eastern slope of the South Urals. It consists of numerous overlapping overthrust-folding plates and scutes formed by Paleozoic igneous-sedimentary formations and a mass of allochthonous ultrabasites [4].

The climatic conditions of the territory are formed in relation to its geographical position, which is characterized by being located in the temperate climatic zone and within the vast Eurasian continent, quite far from the oceans. Thus, heat and moisture availability are determined by the correlation of the radiation balance and the heat generated on the earth surface, as well as by the general circulation of air masses and atmospheric precipitation. They are characterized by the following: long and harsh winters, warm and incidentally hot summers, large amplitude fluctuations in the air temperature throughout the year, rapid weather changes during mid-seasons, especially in spring, frequent cold spells, significant deviations from the average norms of the thermal regime for individual years, precipitation amounts, etc.

Based on the graphic analysis of the materials obtained during long-term observations over the yearly average values of air temperatures at the meteorological stations, a trend towards constant increasing was revealed for at all river stations. The figures reflecting the increase in values of the mid-annual air temperature for the observation periods including 1) since the beginning to the 1980s
and 2) since 1981 to date reach 1.0-1.5 degrees on average. The dynamics of changes in the annual sums of atmospheric precipitation in the long-term context, as well as the sums of precipitation for the summer-autumn and winter seasons, indicate that they are distributed in different directions. However, there is ample evidence to the fact that throughout the river basins located in the steppe zone growing aridity has been observed over the previous decade. This is reflected in the corresponding transformation of the river runoff. Minor rivers are characterized by the fact that spring accounts for the major amount of water resources, wherein up to 90-96% of the annual runoff flows down. Most of these rivers dry up in summer and freeze in winter [1].

It should be noted that a full-fledged reconstruction of the hydrographic network of the rivers Karagayly and Kamysh-Uzyak was carried out as early as at the beginning of ore mining at the quarry and storing rock dumps. With a view to full-scale reclamation of land eligible for rock dumps, the Karagayly river bed was blocked above the dump area, the river flow was directed along an artificially burrowed streambed (canal) into the river Kamysh-Uzyak. Further restoration of the Karagayly river flow occurs 2 km below the old streambed due to the river being fed by constantly flowing smaller streams originating at the springs to be found on the right slope of the river valley.

Currently, geographic information analysis functions as one of the additional tools widely applied in assessing environmental condition and in forecasting further changes. In analysing the territory of the urban district Sibay the following geoformation data was used: Landsat satellite images (survey date: April 26, 2020), Shuttle Radar Topography Mission (SRTM) 1 Arc-Second Global data (survey date: February 11, 2000, at a 30-meter resolution).

A schematic map of the territory of the urban district Sibay was drawn, featuring designated objects of the technogenic landscape (figure 2). The figure indicates that the territory adjacent to the city of Sibay is characterized by an extraordinary density of disturbed, polluted and littered and otherwise adversely affected areas, which is a consequence of prolonged extensive mining exercised without proper attention to solving environmental problems.

![Schematic map of the study area](image)

**Figure 2.** Schematic map of the study area.

The Sibay quarry and dumps (figure 3) are located in the southwestern part of the city, on the northern and western sides adjacent to residential settlements (Gorny and Zoloto) [3]. The dumps are
composed of spilites, rhyolites, quartz rhyolites, tuffs and tuff breccias of spilites and quartz rhyolites, chlorite-sericite-quartz as well as sericite-quartz and chlorite-quartz metasomatites, clays. The rocks contain sulphide mineral admixtures: pyrite, sphalerite, chalcopyrite, etc. Dumps function as complex geochemical filters containing successively operating evaporative, cryogenic, redox, acid-base, and thermal geochemical barriers [2, 3].

The dumps are virtually non-insulated from water systems, which accounts for the inflow of chemical elements into watercourses. The subsoil waters of the northern dumps at the Sibay minery enter the quarry and, alongside with the mine waters, are pumped out to the surface and are subsequently discharged into the river Karagayly through the sewer.

![Figure 3. Three-dimensional model of the Sibay quarry area.](image)

Wastes from the southern dumps are received without purification. The subsoil waters are highly mineralized – up to 515 g/l, pH varying from 2.1 to 2.6, sulphate ion concentrations reaching 29500 mg/l, copper content being from 330 to 645 mg/l, zinc – 718-890 mg/l, iron – 188-731 mg/l, magnesium – 190 mg/l, incl. high concentrations of manganese, nickel, cobalt, cadmium, mercury, etc. The volume of the subsoil waters of the Sibay minery amounts to 650 thousand m³ per year.

Thus, overburden rock dumps act as a source of formation of aggressive acidic subsoil waters, their high concentrations of chalcophytic elements accounting for high toxicity. Low volatility and low freezing points predetermine their high mobility throughout all seasons.
It is known that in the bottom sediments of watercourses in mining areas technogenic geochemical anomalies that are intense, complex in composition and extended along the streambed are formed. The bottom sediments of the Khudolaz, Karagayly and Kamys-Uzyak rivers feature the content of heavy metals up to tens and hundreds of times higher than the background concentrations: Cu of 20-125 MPC (75-500 background values), Zn of 30-59 MPC (100-200 background values), As of 50-90 MPC (18-60 background values), Cd of 4-30 MPC (40-300 background values), Sb of 4 MPC (20 background values), Hq of 2-18 background values, Pb of 1-3 MPC (3-10 background values), Co of 2-7 background values, Mo of 2-4 background values. The greatest degree of contamination is observed in the rivers Karagayly and Khudolaz below the confluence point of the river Karagayly [2,3].

The characteristic features of transformations in the hydrological regime and environmental conditions in respect to the influence of mining facilities located within the urban district of Sibay were studied in the course of our comprehensive research conducted in 2017-2020 on the level of comparative analysis of variability in the species composition and population characteristics of aquatic life communities: in terms of phytoplankton and phytothems, zoobenthos and ichthyofauna. Consequently, the biodiversity of cyanobacteria and algae of the phototrophic plankton and benthos, as well as their being affected by various factors were investigated with an assessment of the state of ecosystems of various sections of the Karagayly and Khudolaz rivers. Phytoplankton and zoobenthos samples were collected simultaneously with the samples for hydrochemical analysis. With a view to identify regular patterns reflecting the ongoing hydrological and ecological modifications occurring at watercourses subject to the influence of natural and anthropogenic factors, the results of a vast number of research activities have been studied and consolidated [5-14].

It is common knowledge that following an increase in anthropogenic load a sharp decrease in the stability of benthic communities and their species diversity is clearly observed against the background of the dominance of certain species. A situation of this kind was observed along the river Karagayly – while moving downstream of the river in the dumps’ area of influence, a sharp decrease in the species diversity of zoobenthos and its quantitative abundance was traced.

On account of comparing the observation data for the rivers Karagayly and Khudolaz the following was revealed. The largest scale of adverse effects of mining facilities is experienced by the river Karagayly, its lower part being characterized by radical changes in the morphometric characteristics of the streambed and severe contamination. Being the right tributary of the river Khudolaz, it is responsible for significant changes in the ecological condition and, consequently, in the species composition of the river’s ichthyofauna. This effect is especially clear-cut at the river stations located below the confluence of the river Karagayly. Thus, while 15 species were identified in the river Khudolaz above the city of Sibay, only 4 fish species have been identified below the mouth of the river Karagayly.

Unlike the river Khudolaz, the ichthyofauna of the river Karagayly is represented by a single species – the Prussian carp belonging to the eurybiontic species that can exist in a wide range of ecological conditions. The fact that, except for this fish, other fish species are absent, testifies to an extremely unfavorable ecological situation, which tends to aggravate in the areas completely lacking ichthyofauna.

In terms of assessing the damage experienced by the natural environment and its components as a result of the large-scale negative impact of mining facilities and due to the need of justifying environmental protection measures, it is of great importance to perform calculations and assessments so as to determine the indicators of accumulated damage. The latter have been calculated during our research: taking into account the economic damage inflicted by the destruction of soil invertebrates; the damage of soils, natural vegetation; the detriment caused by ecology-related morbidity of the population; as well as the damage caused to the aquatic life of the rivers Karagayly and Khudolaz.

On the whole, the total amount of damage inflicted towards the natural environment and health of the population within the affected area of industrial enterprises of the urban district Sibay is estimated at more than 110 billion rubles. This should be taken into account in the course of substantiating the
measures aimed at restoring the morphometric characteristics, the hydrological regime of the rivers Karagayly and Khudolaz, as well as their ecological condition in respect to the magnitude of the influence caused by the anthropogenic load and experienced by their catchments as well as in respect to the concentrated impact experienced by the watercourses exclusively.

4. Conclusions
Having summarized the research data, the following can be inferred. In the area of direct influence caused by the mining industry facilities within the urban district of Sibay the rivers Karagayly and Khudolaz have undergone fundamental changes, including those in their streambeds, water protection areas, inundation-floodplain complexes and a part of the catchments degraded by the facilities of the given industry. This is primarily characteristic of the river Karagayly, which, in fact, turned into a watercourse receiving wastewater of various origins and qualities.

With regard to the implementation of a set of activities aimed at restoring the hydrological and ecological characteristics of the rivers Karagayly and Khudolaz the following provisions should be considered:

1. The Karagayly River basin within its lower part is covered by large areas of disturbed territories. In the course of extraction and sales of a large volume of products obtained, huge amounts of profit were allegedly received by the owners of the enterprises without further redistribution towards the required reclamation and water protection measures. This happened in contradiction to the stipulations of the environmental legislative acts of the Russian Federation;

2. Objects of technogenic nature, characterized by a huge scale of negative impact towards the components of the natural environment, incl. the rivers Karagayly and Khudolaz, are located in the area characterized by lack of full-scale compliance with the requirements to prevent negative impact towards water bodies and their ecosystems. It resulted in a complete degradation of the Karagayly river bed, its water protection zones within the urban district of Sibay, which has led to adverse environmental and economic consequences;

3. Continuous operation of the mining facilities, which have repeatedly changed their company names and owners, has affected the natural environment and the local population suffering from the accumulated environmental and economic damage estimated as exceeding 110 billion rubles. This necessitates adequate attraction of funds so as to eliminate (minimize) the violations committed;

4. The vast areas designated for quarries, rock dumps in the basins of the rivers Karagayly and Khudolaz are associated with extremely hazardous facilities in terms of ecology: the old and the new tailings dumps, the city dump and other degraded areas requiring urgent activities in the direction of environmental resolving the situation;

5. Under the conditions of the low-water phase formation in terms of the water content of the rivers and owing to the growing climate aridity observed since the beginning of the 2000s, an aggravation of environmental and economic problems in the urban district of Sibay has been detected. The municipal authorities of the city lack necessary funds to eliminate the interference committed.

On the whole, solving the accumulated problems, including the restoration of the morphometric characteristics of the river Karagayly, its water protection areas, as well as landscape and ecological improvement of the disturbed territories, requires attracting huge financial and material resources, which can be implemented only on the basis of targeted attraction of funds on the Federal, regional and municipal tiers.

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