



Current State of Lands Affected by Mining Activities in Ural Region

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Abstract. This study includes research and analysis of the current state of lands in the Ural Region. It is highly affected by mining activities. Nowadays, the lands affected by mining activities are disturbed lands, which include the combination of natural and man-made landscapes. The development of mineral deposits and the primary processing of raw minerals negatively impact the environment. In particular, water-engineering structures, industrial waters accumulated in abandoned open-pits, flooded open-pits, slag dumps, and other man-made objects formed after the development of mineral deposits have many negative aspects and heavily pollute the environment. This study is based on the authors' longstanding (over 20 years) monitoring of the environmental elements in the territory greatly affected by mining activities in the Middle Urals. The study presents the analysis of geochemical surveys of environmental elements conducted during the monitoring. The impact of various man-made objects—slag dumps, tailing ponds, as well as an industrial site, on these elements is shown. The research conducted is a prerequisite for the development of a methodology for a comprehensive geoecological assessment of the impact mining activities have on the environment.

Keywords: Mine · Mineral resources · Industrial area · Waste · Ural region · Landscape · Sludge storage

1 Introduction

The development of mineral deposits (MD further) has a significant anthropogenic effect on the subsoils. This causes major anthropization with the formation of artificial post-mining landscapes and converted lands—the results of the negative impact of the mining activities (hereinafter referred to as MA) on the environment [1, 2].

Consequently, the lands affected by mining activities (hereinafter referred to as LMA) can be defined as territories exposed to the environmental impact of MA [3]. The area of LMA is defined by the number of objects related to MA, as well as the impact of MA on the environment. It should be noted that LMA include areas with territories of various types used for certain special purposes, as well as polluting different environments—air (emissions into the atmosphere), water (discharges drainage and other industrial water), soil (accumulation of contaminants due to air emissions and water discharges) [4].

The total volume of man-made mineral waste located in the territory of the Ural Region exceeds 8.5 billion tons with about 2 km³ of all types of production waste added annually. The contribution of the Ural Economic Region to the atmospheric pollution by stationary sources in the 1990s amounted to 23–26% of the All-Russian emissions [5, 6]. A significant portion of converted lands was formed by the mining industry.

During over 300 years of mining history in the Ural Region, more than 1,670 mining companies were active (or stopped their activities) including gold mines—1002, underground mines—566; open-pit mines—105. Currently, more than 40 gold mines, 48 underground mines, 100 open-pit mines are operating here, notably, 40 of them are large [7]. Still, the Ural Region permits developing unallocated subsoil reserves in the future.

A detailed analysis of the current state of lands affected by mining activities is required to reduce the negative impact of MA on the environment, to have a more effective subsoil resource management, as well as to re-integrate objects remaining after MD depletion into the national economy or to support the population needs.

2 Materials and Research Methods

The study applies a systematic approach, which uses abstract-logical, geographical and morphological methods, as well as a retrospective method. The study is based on the results of field observations and the analysis of a large number of documents, map data, as well as remote sensing data.

3 Results and Discussion

The considered territory, the Ural Region, is located on the border of Europe and Asia covering a mountainous country—the Urals, as well as parts of the East European and West Siberian Plains [7]. The total area of the region is 270,421.7 thousand hectares or 16.1% of the Russian Federation.

Spanning over a common location, certain lands affected by mining activities form a mining district. Mining districts united by a physiographic region or a physiographic country form mining regions. By the type of mineral resources, the territory of the Ural Region is divided into three mining regions associated with oil and gas production, solid minerals, and peat [8–10]. This study analyzes the current state of the Ural mining region associated with the extraction of solid minerals (UMR SME). The studied mining region unites the Sverdlovsk Oblast, the eastern parts of the Republic of Bashkortostan, the Perm Krai, and the Orenburg Oblast, as well as the western part of the Chelyabinsk Oblast with the total area of approximately 29,655.1 thousand hectares (11% of the Ural Region area).

A complete transformation of natural landscapes usually takes place at MD development locations, which in turn create new objects of subsoil use. These include natural and man-made objects—such man-made landscape shapes as excavations (open-pits, strip-pits), piles (waste rock dumps, spoil tips), etc., as well as various facilities (industrial buildings and structures, including water-engineering facilities) [11]. MA objects are formed and operated during the construction and production of MA, as well as primary

processing of MD, partially remaining in a form of mining landscapes after the MD are depleted [3]. Furthermore, MD mining creates new artificial geological provinces. MA disturb the geochemical conditions for the formation of surface runoff and underground flow, as well as runoff parameters, which in turn changes the hydrochemical and hydrological conditions of water objects.

Arranging dumps, landfills, and tailing ponds in drainage basins without proper sealing essentially creates new geological provinces affecting the formation of surface runoff different from runoff in non-disturbed lands in purity, and this is already pollution. The development of residential areas without proper environmental protection measures is actually a full-scale pollution of drainage basins by man-made products. It imminently results in land quality degradation. Affected by anthropogenic activities, water bodies accumulate bottom sediments, which often include ingredients not common to discharged wastewater. For instance, deposited organic matter can be a source of toxic gases, toxic organics, as well as nitrogen- and phosphorus-containing mineral and organic substances. Accumulated sulfide minerals are often a source of metals, acids, arsenic compounds. In certain regions, such secondary pollution is currently starting to prevail, posing a significant threat to water ecosystems. The use of unsustainable technologies increased water consumption. In its turn, it required change in the hydrological conditions of surface waters. Reservoir cascades were built on many rivers of the Middle Urals, which radically changed the conditions affecting surface water quality. These conditions result in intra-basin processes starting to have a significant impact, which, alongside with anthropogenic load, leads to the occurrence of large amounts of substances present in river systems at the ambient level. Water engineering structures on rivers alter their hydrological conditions, as well as hydrochemical conditions, in turn, changing the living conditions of river flora and fauna, sometimes along the entire river length. Almost in all cases, the disruption of hydrological conditions below the control structure reduces the water level, deteriorates habitats of flora and fauna, causing deterioration of water quality, as well as sanitary and epidemiological conditions even against the minimum anthropogenic load.

The main MA objects in case of open-pit mining are open-pits (strip-pits) and waste rock dumps. In case of underground mining these are industrial sites of underground mines and allotted territories, as well as industrial sites of processing plants with dry and liquid waste dumps. The distribution of areas occupied by the MA objects for open-pit mining of MD varies within the following limits: from 20 to 60% of the MA area is occupied by open-pits (strip-pits), from 30 to 70%—waste rock dumps, from 5 to 40%—processing plants. In the case of underground mining of MD, the occupied territories generally include industrial sites with a system of buildings for transportation of rocks and ores from underlying aquifers to the surface, lifting people and equipment down to underground workings, as well as the other industrial structures and waste rock dumps (spoil tips). Industrial sites occupy areas ranging from 4 to 60 ha., while the areas of allotted territories on the surface depend on the MD volume and their subsurface formation specifics.

The areas of several large operating mining facilities are shown in Table 1.

To determine the impact of slag dumps on surface waters, the dynamics of their pollution with metals were evaluated (on the example of a slag dump of Rezh Nickel Plant).

Table 1 Areas occupied by large operating mining facilities

Mining facilities	Area, ha			
	Pit(s)	Waste rock dumps	Industrial area (including processing plant and tailing ponds)	Total
Sverdlovsk Oblast				
Uralasbest JSC	1898.0	1056.2	1635.8	4590.0
Kachkanarsk mining and processing plant	931.0	2793.5	2316.0	6040.5
Republic of Bashkortostan				
Uchalinsk mining and processing plant	252.9	334.5	457.7	1042.1
Sibay mining and processing plant	182.6	711.7	399.2	1292.5
Orenburg Oblast				
Gai mining and processing plant	309.4	717.0	718.4	1744.8
Kiembay mining and processing plant	252.1	568.2	539.4	1360.0

The observation results allowed calculating the geochemical mobility of chemical elements for various water exchange conditions. The dependence of metal concentration in waters on the season has been detected for almost all metals. The highest content of Ni reaching $1006 \mu\text{g}/\text{dm}^3$ is observed in autumn. This is caused by increased precipitation and relatively long excessive moistening of waste rock dumps. The second period of elevated contents of Ni, Cd, Fe, and partly Mn happens to be in February–March. Apparently, this is caused by a migration environment with a higher reduction potential associated with the maximum soil freezing. Acid-alkaline migration conditions exhibit a changing pH from 8.17 in winter to 7.16 in summer. Furthermore, the Eh value varies from +185 to +326 mV. The deviations into the alkaline and reducing regions are due to the composition of the water-bearing medium. The migration ability of elements is determined, for one part, by their content in slag dumps, and for the other—by the natural water circulation conditions in the “slag dump—environment” system. The following amount of substances are carried away from the dump into surface water on average per year: Ni—25.8 kg; Cr—14.4 kg; Fe—5 kg; Mn—0.8 kg; Cd—82 g. The water migration intensity row has the form: Ni > Cd > Cr > Mn > Fe.

Also, we studied the impact of part of the drainage basin in the OJSC Svyatogor diversion channel on the surface runoff contents. The studied area of the drainage basin has acidified soils (pH = 3.6–4.5) containing a significant amount of pollutants. The following concentrations were detected (mg/kg of air-dry weight): sulfur—21,177.6–116,281.94, iron—15,412.46–116,281.94, copper—436,27–10,009.61, zinc—309.93–575.01, manganese—190.07–324.14, lead—214.12–324.36. Surface runoff in this

drainage basin is over acidified ($\text{pH} = 2.3\text{--}2.6$) and contains a significant amount of pollutants: sulfates— $15,807.6\text{--}56,724.2 \text{ mg/dm}^3$, iron— $370.52\text{--}1128.776 \text{ mg/dm}^3$, copper— $19.16\text{--}119.094 \text{ mg/dm}^3$, zinc— $44.425\text{--}45.6 \text{ mg/dm}^3$, manganese— $11.85\text{--}50.797 \text{ mg/dm}^3$. The surface runoff has the following contents of nickel, cadmium, lead and cobalt (mg/dm^3): nickel— $0.78\text{--}1.41$, cadmium— $1.3\text{--}2.53$, lead— $0.0035\text{--}0.012$; cobalt— $1.536\text{--}2.86$.

The specifics of land use for the extraction and processing of MD in UMR SME is that many settlements were formed due to the establishment of mining facilities, while 34 cities are considered as industry-based towns [12]. For example, 38–40% of settlements in the Chelyabinsk Oblast are closely connected to mining. This value is about 35% in the Sverdlovsk Oblast. Among these settlements, 49% of settlements on the UMR SME territory are associated with underground mining of MD, and 51% of settlements—with open-pit mining [13]. Also, the lands associated with underground mining are impacted by underground operations. For example, the north-western part of Krasnoturinsk, the southeastern part of Upper Pyshma, almost the entire territory of Berezovsky town, the central part of Bereznyaki and Solikamsk towns, and others have underlying underground workings.

In the analysis, we paid particular attention to agricultural lands of the Ural Region, which account for 28% of all land area on average. The following territorial entities of the Russian Federation in the Ural Region have more than 50% of the territory occupied by agricultural lands: Republic of Bashkortostan (50.9%), Chelyabinsk Oblast (58.4%), and Orenburg Oblast (88.4%). They include over 850 depleted and about 500 developed MD, including large (Table 1), as well as about 260 MD in the state reserve, prepared for the development or explored [14].

The analysis of over 300 years of mining history in the region conducted by the authors revealed that the following MA objects in the UMR SME territory have not yet been properly abandoned:

- Objects of former MA (prospecting pits, mine shafts, etc.).
- **Disturbed lands** with open-pits (strip-pits) and extensive land areas with waste rock dumps and other mining-related piles, including yet to be abandoned dumps of processing plants.
- **Degraded lands** having a satisfactory environmental condition due to self-regeneration (mining facilities overgrown by trees or shrubs and/or bogged, flooded mines, open-pits, etc.), reservoirs (ponds) of mining and processing facilities with water-engineering structures (dams, ditches, gateways, etc.).
- **Contaminated lands** containing toxic substances and transformed into lifeless deserts [10, 15, 16].

For instance, the territory of the Nizhny Tagil industrial hub includes the following waste dumps—slag dump of the Kuibyshev Refinery, sludge dump in the Tagil River floodplain, waste dump of a fire brick production facility, and chemical waste dump of a coke production plant.

According to our monitoring, the Kuibyshev Refinery slag dump negatively affects the atmospheric air, which is indicated by contamination of snow cover and soils. The contaminants include copper, zinc, manganese, vanadium, nickel, chrome, and iron

exceeding the maximum allowable concentration (MAC). Figure 1 shows the distribution of iron content in soils. About 2/3 of the studied area has an iron content of 0.1–0.2 mg/dm³, which exceeds the MAC by 10–20 times. This area includes locations with the maximum pollution. Such plots are located to the north, south, and southeast of the slag dump. The plot with maximum pollution has iron content ranging from 0.2 to 0.3 mg/dm³.

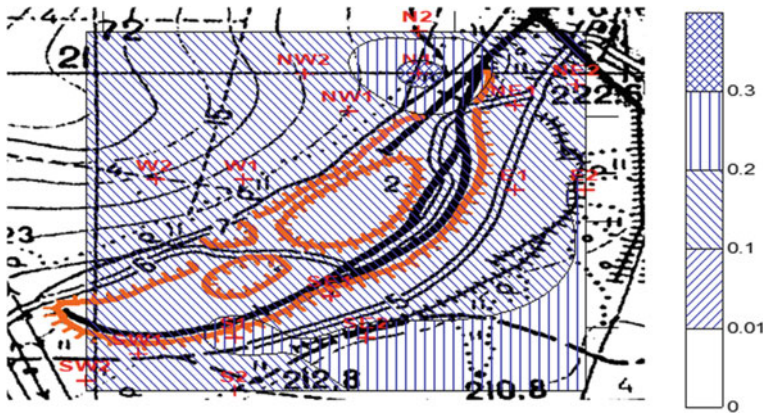


Fig. 1 Iron distribution in soils in the vicinity of the Kuibyshev Refinery slag dump (mg/dm³), and sampling sites

The sludge dump located in the secondary landscapes of the Tagil River floodplain negatively affects underground and surface water, polluting underground water with sulfates, chlorides, manganese and increasing total dissolved solids in it. The impact of the sludge dump on surface water is manifested in the increased content of suspended substances, dry solids, sulfates, fluorides, and vanadium.

The fire brick production plant dump affects the atmospheric air and groundwater. The most severe contamination of snow cover is attributed to chrome (Fig. 2), as well as vanadium and zinc. The major contaminants of groundwater are iron and manganese.

A retrospective assessment of groundwater state in wells of the coke production plant showed no significant changes in water quality near the dump area in 3 years. The increased content of phenols (Fig. 3) and nitrates was periodically detected in individual wells.

After MD depletion, the remaining open-pits are filled up with underground and surface waters to the aquifer level. After placer mines are abandoned, the sites of dredging tailings and dumps with a changed river bed are left in river valleys, as well as cascading water bodies along the river bed.

The total number of flooded open-pits remaining after the MD depletion in UMR SME exceeds 150 locations with a total area of more than 8000 ha. Major flooded open-pits are located in Sverdlovsk Oblast (about 60 locations with a total area of about 3600 ha.) and Chelyabinsk Oblast (more than 50 open-pits with a total area of approximately 2800 ha.), as well as the Republic of Bashkortostan (more than 10 open-pits with

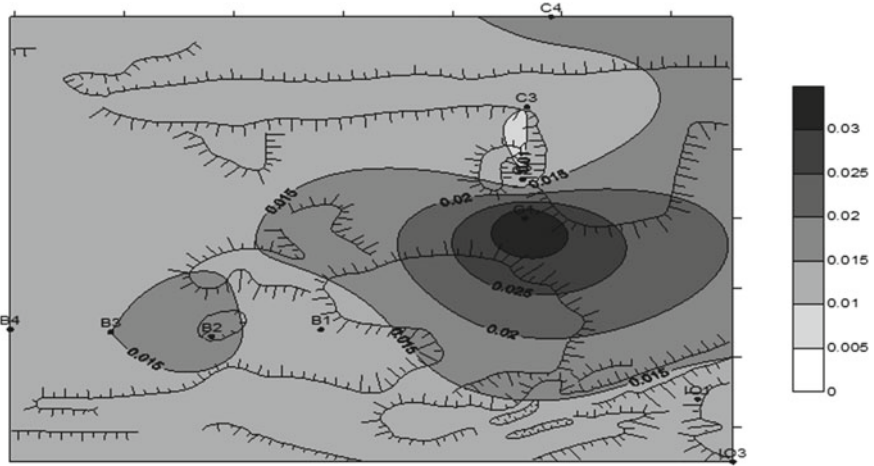


Fig. 2 Distribution of chrome from the fire brick production plant dump in snow cover (mg/dm^3), and sampling sites

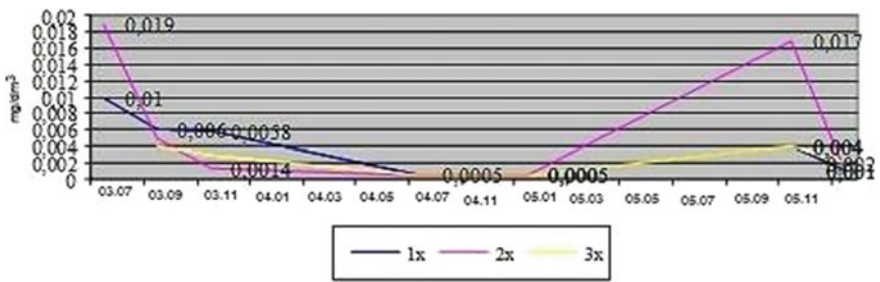


Fig. 3 Change in the content of phenols in the wells of the coke industry

a total area of approximately 1300 ha.). The areas of individual flooded open-pits range from 0.66 to 930 ha. Such open-pits are located both between and within settlements.

According to the analysis carried out by the authors using literature data [15], the placer mines affected more than 250 medium and small rivers with their tributaries, not to mention nameless streams and ravines. The scale of land conversion can be demonstrated by a couple of the following examples. Close to the Kytlym settlement, the depleted MD area is 730 ha. with the placer mine length of 13.6 km along the Lobve River, while the depleted MD area is 7140 ha. along the Is River (in the main part of the river from Shumikha settlement to Is settlement) without tributaries and ravines at a place mine length of 33.8 km and a width of the developed valley ranging from 300 to 900 m. Taking into account that landscapes of former placer mines may self-regenerate, the total area can be estimated only approximately.

The areas flooded due to overflow of mine waters reach up to 170 hectares, due to runoff from dumps—up to 1.5–6 ha., while flooded sinkhole over underground workings—up to 20 ha. For instance, the acidic mine waters of the Kizelov coal basin negatively affected the water quality of 20 small and medium rivers located in the Kama River basin, which can be traced for a long distance [17]. Other examples are mining landscapes—sources of negative impact, formed during the development of MD in the Kirovgrad orefield. The total area of the conversed (disturbed, degraded, and contaminated) lands remaining after the abandonment of 30 mines is 1165 ha. These lands include flooded open-pits, overflowing flooded mine shafts, dumps exposing host rocks and low-grad ores, sinkholes over underground working, as well as objects of Kirovgrad Hard Alloys Plant OJSC.

Both existing and mothballed or abandoned mining-related water-engineering structures [18] were constructed on the territory of more than 30 mining facilities and metallurgical plants.

For instance, one of the noteworthy facilities in the Middle Urals is a tailing pond located in the Kachkanar industrial hub. Analyze in more detail the formation of wastewater from this man-made object and its impact on the surface and underground water.

Located in the Kachkanar industrial hub, this tailing pond has raised hill-type dams and is located in the valley of the Viya River and its right-bank tributary—Rogalevka River. The tailing pond consists of three sections—Rogalevsky, Intermediate, and Viysky. Every section has a dedicated pond and drainage structures. Numerous surveys of the tailing pond territory conducted in different seasons revealed the following sources of wastewater formation (Fig. 4).

Industrial wastewater and storm waters from the overflowing Viysky section of the tailing pond form discharge point 1 releasing water to the Viya River. Discharges occur periodically during high-water periods (as a rule, in spring). Water goes through the discharge point 1 via two siphons with a diameter of 1 m directly into the bottom pool of the Viysky section, located 28.2 km from the mouth of the Viya River. Discharge point 3 is formed by seepage waters from dam 2 of the Intermediate section of the tailing pond. Currently, dam 2 of the Intermediate section of the tailing pond passes through a depression between the Lukovaya mountain and a hill with an elevation of 271 m over a meridional intra-basin drainage dividing ridge between the Viya River and its right-bank tributary—Rogalevka River. The dam body has several locations where filtrated water seeps through entering a ravine directed to the east from the drainage divide to the Viya River. The straight distance from the dam foot to the Viya River is 1.7 km (with the ravine turns included—2.3 km).

The filtrated water proceeds in several streams through the forest in the direction of the Viya River. Discharge point 4 is formed by water filtering through the dam 3 of the Rogalevsky section of the tailing pond. Water is filtered through the dam in several locations and forms several beds (up to 3–4 filtration passages), partially joining at the dam foot, which carry the filtered water across the landscape to the bogged forest. The wastewater has flooded the western side of the anticline between hills of a drainage divide with elevations 413.0 and 312.0 m and formed a small pond with a depth not exceeding 1.5 m. A gradual water level decrease is observed along the water flow due to

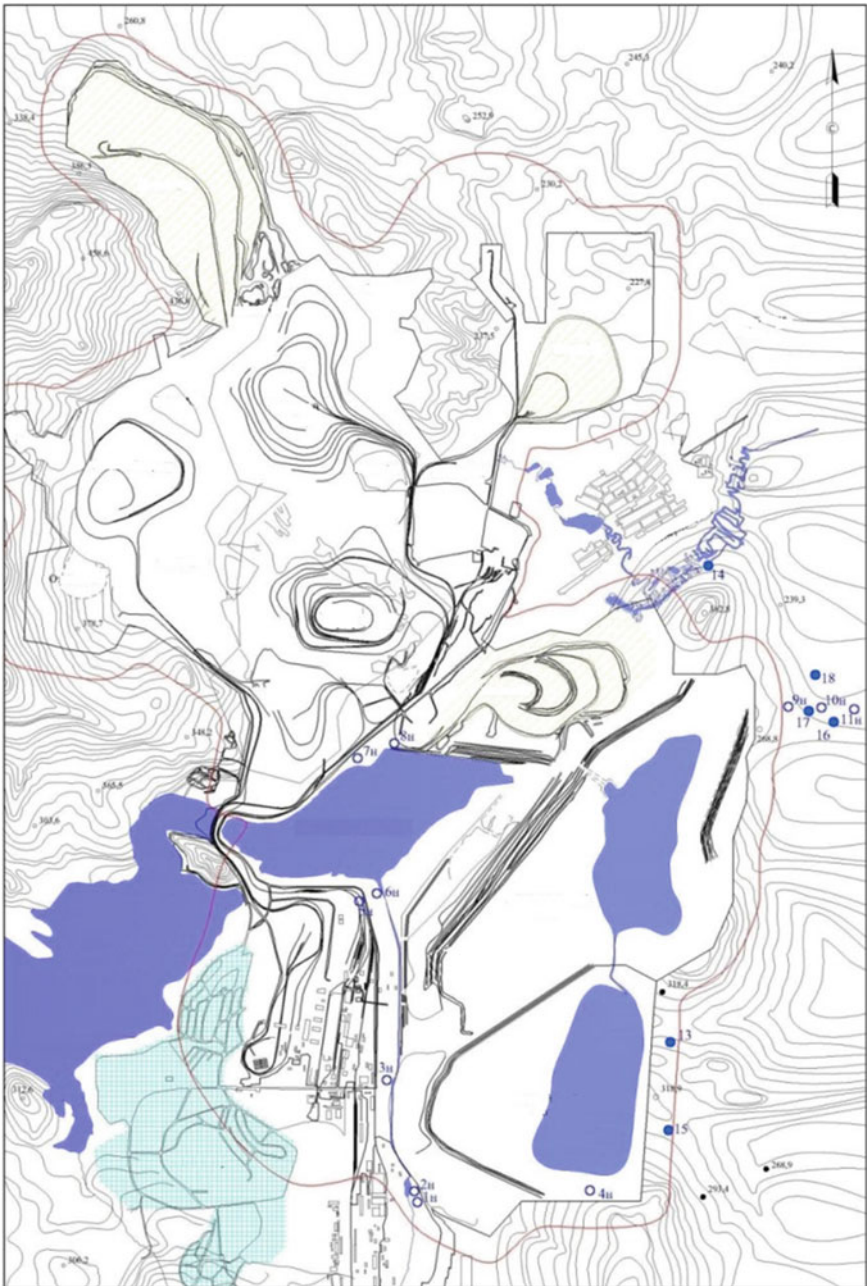


Fig. 4 Locations of points of wastewater discharge from the tailing pond into water bodies located in the Kachkanar industrial hub territory

water moving into the underflow up to a confluence with the southern river bed receiving filtrated waters from discharge point 10. In the limiting conditions of low-water periods, the upper part of the B. Medvedvka River hydrographic structure. A significant part of the wastewater goes into underlying aquifers or forms flood ice (during the winter period). Thus, most of the wastewater discharge via discharge point 4 can be considered to go into underlying aquifers. Waters filtered through the eastern dam of the Intermediate section of the tailing pond form discharge point 9. At the dam foot, wastewater forms two streams over the ridge of the anticline on the drainage divide between the Malaya Lukovaya town and a hill with an elevation of 271 m. The flow moves further along the hill slope gradually accumulating in a valley line expanding towards the Viya River near a bogged ravine. The wastewater going through discharge point 9 reaches the Viya River, draining the groundwaters, having a significant transformation during the filtering process and additional aeration on the site. Flood ice is formed during the winter period accumulating a significant amount of wastewater. It can be assumed that most of the wastewater passing through discharge point 9 goes into the underlying aquifers. Discharge point 10 is formed by water filtering through dam 4 of the Rogalevsky section of the tailing pond. Water filtered through the dam flows in several beds over the landscape to the bogged forest. Filtered water formed a pond without much growth between the dam and the anticline of drainage basin ridge between hills with elevations of 313.0 and 374.0 m. The following pollutants are brought with wastewater into the water bodies: suspended solids, sulfates, nitrogen compounds, iron, vanadium, copper, petroleum products.

On average, the areas of tailing ponds and sludge dumps range from 2.3 to 1252.25 ha., containment ponds—from 3.69 to 711.27 ha., settling ponds—from 1.67 to 45.82 ha. The total area occupied by the 69 facilities is 8283.20 ha. Their number, as well as the large volume of accumulated waste, create an environmental problem. While valuable components contained in enrichment and secondary processing tailings are secondary mineral resources that can be extracted, which is another engineering task [5, 19].

The analysis of the territories of developed and depleted MD using open-pit mining (except for certain metallurgical companies) showed that the area of land occupied by the existing mining facilities is 28,620 ha., including the area of open-pits of 9972 ha., dumps—10,593 ha., processing plants and industrial sites—8055 ha. The land area occupied by the objects of depleted MD is 30,890 ha., including the area of open-pits—9833 ha., dumps—20,127 ha., the area of waste landfills of enrichment plants and the remaining objects of industrial sites—881 ha.

4 Findings

The studies have revealed multiple types of objects of the developed and depleted MD using open-pit mining, as well as the need for remote sensing to obtain full and actual data on the state of the studied objects. The obtained data allows developing a methodology for the assessment of accumulated environmental damage to the territories and, ultimately, to propose methods for the rehabilitation of territories of depleted MD.

References

1. Milkov FN (1986) Physical geography: landscape knowledge and geographical zoning. VGU Publishing House, Voronezh, p 328
2. Isachenko AG (1991) Landscape study and physic-geographical zoning: textbook. Higher School, Moscow, p 366
3. Semyachkov AI, Pochechun VA, Konovalov VE, Ganin EV (2020) Ecological concept of mining landscape rehabilitation. Institution of economics of UrB RSA, Yekaterinburg, p 190
4. Panfilov EI (2008) Assessment of impact on the mineral resources and possible consequences while developing a mineral deposit. *Min Indus* 2:26
5. Mormil SI, Salnikov VL, Amosov LA et al (2002) Man-caused deposits of the middle Ural and assessment of their environmental impact SSA—Nature, Moscow, p 206
6. Slavikovskaya YO (2012) Ecological and economical aspects of developing the mineral resources on the ur-ban territories. IMA UR RAS, Yekaterinburg, p 208
7. Kolchina M, Konovalov V, Kolchina N (2019) Analyzing the state of mining towns in the Ural region. *E3S web of conferences* 135:04015
8. Morozova TG, Pobedina MP, Polyak GB et al (2001) Regional economy: textbook for universities. Moscow, p 472
9. Oil and gas province, basin <https://neftegaz.ru/tech-library/ngk/147608-neftegazonosnaya-provintsiya/>
10. Effort of the Ural into the mining of Russia during 300 years: Ural mining encyclopedia, vol. 1/ eds. Prof. Khokhryakov. VS p.h. UGGA, Yekaterinburg, 2000, p 500
11. Komashchenko VI, Golik VI, Drebenshtedt K (2010) Impact of exploration and mining activities on the environment: monograph / V.I.Komashchenko. KDU, Moscow, p 356
12. Government executive order of 29.07.2014 #1398-p (rev. of 21.01.2020) On the approval of the list of single-industry municipalities in the Russian Federation (mono-cities)
13. Konovalov VY, Koltchina ME (2016) Creating and functioning of industrial landscapes in the conditions of the Ural mining region. Environmental and technosphere safety of the mining regions. Works of IV international training conference 4 April 2016, Ural State Mining University, Yekaterinburg, pp 143–149
14. Konovalov VE, Pochechun VA, Semyachkov AI (2020) Influence of mining complexes on agricultural lands of the ural region. *IOP Conf Ser Mater Sci Eng* 962(4):042061
15. Albreht VG, Antufyev AA (2004) Ural precious metals: ural mining encyclopedia “Mountain Ural on the turn of the century, vol. three, part 1, p.h. USMA, Yekaterinburg, p 857
16. Ural coal and black dirt: Ural mining encyclopedia “Ural on the turn of the century”, vol. five; p.h. USMA, Yekaterinburg, 2007, p 705
17. Maksimovich NG, Pyankov SV (2018) Kizelovskii coal basin: environmental problems and ways of solving them: monograph. Perm State Research University, Perm, p 288
18. Yevdokimov PD, Sazonov GT (1978) Design and exploiting of tailing facilities of the processing factories. Nedra, Moscow
19. Anisimov VN (2009) Zero-waste reworking of natural-and-technogenic deposits with mobile technological complexes “Mining industry” 4(86), p 42