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ГЕОЭКОЛОГИЯ ПОВЕРХНОСТНЫХ И ПОДЗЕМНЫХ ВОД НА СРЕДНЕМ УРАЛЕ: НА ПРИМЕРЕ ПОЛЕВСКОГО И КАЧКАНАРСКОГО ГОРНЫХ РАЙОНОВ СВЕРДЛОВСКОЙ ОБЛАСТИ

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Аннотация: Представлена оценка состояния поверхностных и подземных вод на территории некоторых горнодобывающих районов Свердловской области. Основным методом исследования является мониторинг, под которым понимается система наблюдений, направленных на прогностические и экологические мероприятия. Сеть мониторинга и расследований, развернутая на шахтах, предоставляет исчерпывающую информацию о состоянии поверхностных и подземных вод и позволяет проводить прогнозную оценку и снижать воздействие на окружающую среду. Оценка поверхностных и подземных вод была проведена с использованием данных о предельно допустимых концентрациях в водных объектах рыбохозяйственного значения, поскольку как подземные, так и поверхностные водные ресурсы в значительной степени питаются из искусственных водоемов. Оценка поверхностных вод проводится на примере Северского водохранилища в Полевском районе Свердловской области и показывает, что водоем находится в критическом состоянии. Оценка подземных вод проводится в районе Качканарского горнорудного кластера. Выявлена нерегулярная тенденция изменения состояния подземных вод в этом районе.

Ключевые слова: водные объекты, подземные воды, мониторинг, сточные воды, хранилища отходов, химический анализ проб, хвостохранилища, мониторинговые скважины.

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Surface and groundwater geoecology in the Middle Urals: a case-study of Polevskoy and Kachkanar mining districts, Sverdlovsk region

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Abstract: The article presents the appraisal of surface water and groundwater in the territory of some mining districts in the Sverdlovsk Region. The main method of research is monitoring, which is understood as a system of observations aimed at predictive and environmental measures. The monitoring investigation network deployed at mines provides comprehensive information on the condition of surface and groundwater, and enables predictive appraisal and environmental impact reduction. The appraisal of surface and underground water was carried out using the data on maximum permissible concentrations in water bodies of fishery value as both underground and surface water resources are largely fed from man-made water bodies. The surface water appraisal is implemented as a case-study of Seversk Reservoir in the Polevskoy district, Sverdlovsk Region and shows that the water body is in critical condition. The groundwater appraisal is undertaken in the area of Kachkanar mining cluster. An irregular trend change in the condition of groundwater in this area is revealed.

Key words: water bodies, groundwater, monitoring, waste water, waste storage facilities, chemical analysis of samples, tailings dumps, monitoring wells.

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Introduction

The sound regional environmental policy and effective public control of environmentally friendly and sustainable development activities call for the environmental impact assessment and ecosystem valuation [1–7], which is presented in this article as a case-study of a mining area in the Middle Urals.

Materials and methods

This study used the proprietary field research and analysis results, and the available literary sources. The work is based on the surface and groundwater monitoring data. Regarding groundwater monitoring, the test area has a system of monitoring wells with the layout governed by the local hydrodynamic network between the impact sources and the effluent discharge outlets.

The purpose of the monitoring in terms of water sampling is to obtain a discrete sample representative of the test water quality. Therefore, the surface and groundwater monitoring followed some rules and requirements. According to the GIDEK guidelines, before sampling, all existing wells were pumped through within minimum 0.5 hours. The volume of one sample was 3 l minimum. Water sampling, storage and transportation were carried out as per RF State Standard GOST R 51592-2000.

Results and discussion

Over the past ten years (2008–2017, the Ural Federal District is Russia's fourth region in terms of ecological quality. As a whole, during this period, polluted waste water discharge in the Ural Federal District has increased by 19.5% and amounted to 2231 Mm^3 in 2017 [8].

For example, the chemical analysis of 154 water samples taken from 7 sections in Seversk Reservoir, located in the Polevskoy district of the Sverdlovsk Region and affected by intense effluents of local mining and metallurgical plants, showed an excess of MAC over the standard values for the following components: sulfate ion — 1,16, copper — 100, zinc — 5, manganese — 1,9. In 76 samples taken from 3 effluent outlets at Seversk Reservoir, the excess of toxic elements over the standard values is: 2140 MAC for copper and 4604 MAC for zinc [9, 10].

Table 1
Chemical composition of recirculated water in tailings dump

No.	Parameter	Units	Value	MAC of fishery-value water bodies
1.	Sulphates	mg/dm^3	45	100
2.	Nitrite ions	mg/dm^3	1,42	0,08
3.	Nitrite ions	mg/dm^3	79,9	40
4.	Ammonium ions	mg/dm^3	1,5	0,5
5.	BOI full	mgO$_2$/dm^3	6,5	3,0
6.	Total iron	mg/dm^3	0,43	0,1
7.	Copper	mg/dm^3	0,004	0,01
8.	Vanadium	mg/dm^3	0,0066	0,001
9.	Petroleum products	mg/dm^3	0,08	0,05
10.	Suspended matter	mg/dm^3	10	25+background
11.	Dry residue	mg/dm^3	344	1000

The data obtained make it possible to conclude that Seversk Reservoir is actually a man-made water body, and its water quality is governed by the localized man-made effluents.

Another potentially hazardous object affecting the surface and underground hydrosphere is waste storage facilities [11,12]. Let us consider the degree of impact exerted by a tailing dump located in the Kachkanar district, Sverdlovsk Region on the underground hydrosphere.

The tailing dump consists of three sections separated by dams. Currently the total area of the tailing dump is about 1695 hectares.

The liquid phase chemistry of the waste accumulated in the tailing dump is given as the composition of recirculated water. The recirculated water composition fully characterizes the tailing dump as a source of impact on ground water (Table 1). Parameters of the recirculated water chemistry include 11 items and, in general, illustrate the chemical specifics of iron ore processing aimed to produce iron–vanadium concentrate.

It is evident from Table 1 that the chemical composition of the recirculated water in the tailings dump is a potential source of pollution of surface and groundwater: nitrogen group — from 2–3 to 17 MAC at high BOD total up to 2–3 MAC as a result of nitrogen pollution, iron — up to 4 MAC and vanadium — up to 6 MAC. Oil products in the recirculated water also exceed MAC.

Therefore, to evaluate quality of groundwater under the influence of the tailing dump, a monitoring network of wells was arranged in 2016. The layout and design of observation wells were determined based on the main task, namely, monitoring of negative impact of liquid tailings in the tailings dump on the groundwater quality (pollution) [13, 14]. The background well is located outside the influence area of influence of seepage flows at the boundaries of the tailing dump (Fig. 1).

All observation wells in the area of the tailing dump should be divided into three groups. The first group adjoins the groundwater drainage base — the Rogalevka river valley, which exerts the highest impact and occurs at the longest boundaries of the tailing dump. This group comprises the most of the observation wells — Nos. 1, 2, 3, 4, 5 and 6.

The second group of wells is oriented along the Vyia river valley, which is the

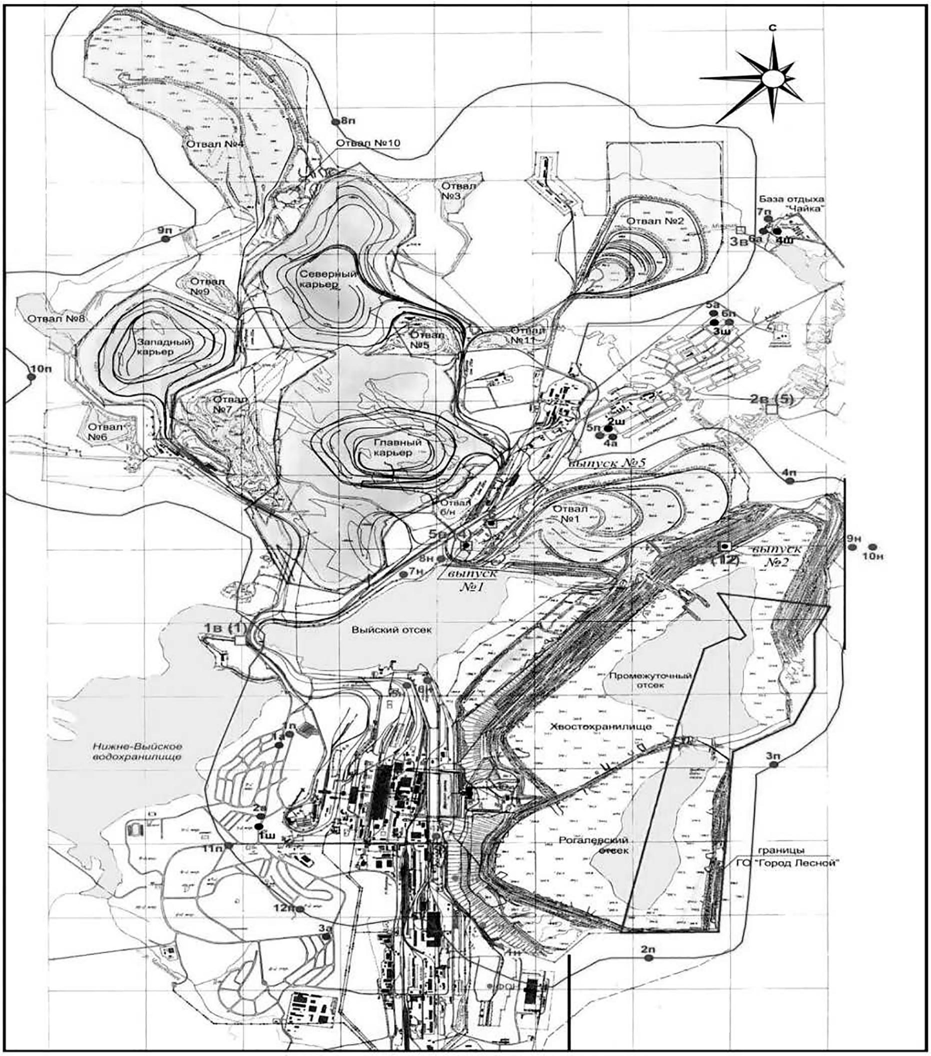

Figure 1. Layout of observation wells for groundwater condition in the impact zone of the tailing dump (1n–11n—observation wells colored in green)

second higher order basis of groundwater drainage in this area. This group includes observation wells Nos. 7, 8, 9 and 10.

The third group is the background well located outside the influence area of seepage at the boundaries of the tailing dump.

Structurally, all operational wells are equipped identically; their depth varies from 20–25 m to 35–40 m since they are drilled down to the first unconfined aquifer adjoined to the zone of exogenous fracturing of bedrocks.

The groundwater level measured through the mouth of an observation well informs on the underground hydroregime in space and time. The depth of groundwater shows during drilling is reflective of the groundwater depth level in a certain place and at a certain time.

Table 2

Measurement data of ground water level in observation wells of monitoring network at tailing dump

No.	Well No.	Groundwater level as of November 2016 (depth to water, m)	Groundwater level as of November 2017 (depth to water, m)	Groundwater level as of November 2018 (depth to water, m)	Groundwater level as of November 2019 (depth to water, m)	Groundwater level as of November 2020 (depth to water, m)
1.	Background well	0	6,5	7	8,6	7,76
2.	Well 1	3,2	0	0,5	0	-
3.	Well 2	8,3	0	0	0	1,12
4.	Well 3	1,3	0	0	0	0
5.	Well 4	2,0	2,2	1,5	1,6	1,54
6.	Well 5	1,3	4,8	4,5	1,7	2,78
7.	Well 6	Well spring	Well spring	Well spring	Well spring	Well spring
8.	Well 7	6,6	4	4	4,9	5,02
9.	Well 8	1,7	5,5	4,5	6,1	6,32
10.	Well 9	5,9	2,0	6	3,1	2,75
11.	Well 10	7,8	16,5	18	19,1	19,57

Table 3

Ground water monitoring results in 2019, mg/dm^3

1st Quarter											
Well / Parameter	**Background**	**MAC**	**Well 1**	**Well 2**	**Well 3**	**Well 4**	**Well 5**	**Well 6**	**Well 7**	**Well 8**	**Well 9**	**Well 10**
Ammonium ions	0,21	1,5	**0,7**	**0,7**	0,1	0,1	**1,4**	**1,2**	0,11	0,19	0,11	**1,48**
Manganese	0,03	0,1	**0,08**	**0,05**	**0,08**	**0,05**	**0,05**	**0,07**	**0,08**	0,03	**0,05**	**0,04**
Iron	0,2	0,3	0,1	**0,2**	**0,2**	**0,1**	**0,2**	0,08	**0,23**	0,1	0,2	0,08
Nitrite ions	0,03	45	**0,04**	0,03	0,03	0,03	**0,13**	**0,15**	0,023	**0,09**	0,03	0,023
Nitrate ions	1,5	3,3	1,4	1,3	0,9	0,9	1,9	0,9	1,1	0,8	1,1	1,1
Sulphate ions	31,2	1000	10	26,4	60	11,3	**45,6**	**36**	**26,4**	**88,8**	**40,8**	**36**
Dry residue	234	–	59	170	196	159	180	177	220	160	204	198
2nd Quarter											
Well / Parameter	**Background**	**MAC**	**Well 1**	**Well 2**	**Well 3**	**Well 4**	**Well 5**	**Well 6**	**Well 7**	**Well 8**	**Well 9**	**Well 10**
Ammonium ions	0,1	1,5	**0,7**	**0,7**	**0,7**	**0,9**	**0,25**	**0,4**	**0,6**	**1,2**	**0,8**	**0,13**
Manganese	0,07	0,1	0,05	0,01	0,01	0,07	0,05	0,05	0,08	0,08	0,06	0,04
Iron	0,25	0,3	0,1	0,2	0,2	0,07	0,06	0,1	0,2	0,07	0,08	0,1
Nitrite ions	0,02	45	0,03	0,03	0,03	0,03	0,023	**0,08**	0,016	**0,04**	**0,03**	**0,03**
Nitrate ions	0,21	3,3	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21	0,21

End of the table

2nd Quarter

Well / Parameter	Back-ground	MAC	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Sulphate ions	60	1000	**78**	34	34	48	46	46	24	**92**	29	58
Dry residue	281	–	123	223	223	192	166	182	185	196	180	178

3rd Quarter

Well / Parameter	Back-ground	MAC	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9	Well 10
Ammonium ions	0,1	1,5	**1,2**	**0,8**	0,1	**0,5**	0,1	**0,4**	**0,9**	0,1	**0,13**	**0,17**
Manganese	0,045	0,1	**0,05**	**0,07**	**0,8**	**0,5**	**0,07**	**0,08**	**0,06**	**0,08**	**0,06**	**0,07**
Iron	0,2	0,3	0,1	**0,21**	**0,21**	0,15	0,2	0,16	0,2	0,17	0,2	0,15
Nitrite ions	0,007	45	**0,07**	**0,036**	**0,025**	**0,029**	**0,14**	**0,1**	**0,032**	**0,21**	**0,1**	**0,039**
Nitrate ions	5,3	3,3	5,2	5,3	**5,5**	**5,6**	**5,6**	4,3	4,8	**5,6**	4,8	4,3
Sulphate ions	35	1000	10	24,2	**36**	10	10	24	14,5	**62**	29	34
Dry residue	290	–	73	181	199	151	78	106	160	244	180	91

4th Quarter

Well / Parameter	Back-ground	MAC	Well 1	Well 2	Well 3	Well 4	Well 5	Well 6	Well 7	Well 8	Well 9
Ammonium ions	0,1	1,5	**0,8**	**0,8**	**0,4**	**0,4**	**0,4**	**0,3**	**0,4**	**0,9**	**0,4**
Manganese	0,045	0,1	**0,07**	**0,07**	**0,08**	**0,05**	**0,05**	**0,06**	**0,08**	**0,04**	**0,07**
Iron	0,2	0,3	**0,21**	**0,21**	**0,21**	0,15	0,18	**0,28**	0,07	**0,024**	**0,28**
Nitrite ions	0,007	45	**0,036**	**0,036**	**0,03**	**0,034**	**0,071**	**0,097**	**0,023**	**0,16**	**0,054**
Nitrate ions	5,3	3,3	0,7	0,7	2,6	0,7	3,4	0,9	1,8	1,2	0,4
Sulphate ions	59	1000	10	10	28	25	13,2	13,2	22,8	**92**	47

The time history of the groundwater level illustrates the impact of various natural and man-made processes such as backwater, depletion of the reserves, etc.

In case of close-spaced location of a surface storage of liquid effluents, which is a tailing dump, there is a rise in the level of groundwater as it is fed by seepage the tailings dam bottom and flood wall (Table 2).

As a criterion of groundwater pollution, we assume the MAC of water bodies of fishery value, due to the fact that groundwater in the area of the tailing dump supplies surface water bodies and watercourses of fishery value, as well as the value from background well 4-n, as some pollutants (for example, copper, manganese, vanadium, iron) are typical of the area of the tailing dump, which is associated with numerous ore deposits in the territory under consideration, and a large number of operating and abandoned underground openings at various depths and of different size, as well as waste storages and wastewater outlets.

Table 3 presents the results of quarterly groundwater sampling throughout the year. The analysis of these data shows that a number of pollutants stably exceed the background value, and some toxic components overrun the background value randomly ore once.

However, in general, the evidence of monitoring over a five-year period (2016–2020) points at some regular patterns. In groundwater accessed by observation wells 1–4, there is a chaotic change in the chemical composition, without visible variability in the components. In groundwater stricken by well 3, dry residue decreases from 120–140 mg/dm^3 to 80–100 mg/dm^3; in well 2, NO_3 decreases from 2.5–3 mg/dm^3 to 1.5–2 mg/dm^3; in well 4 there is an increase in manganese, NH_4 and in dry residue from 100 to 200 mg/dm^3. Thus, the groundwater chemistry features both irregular variability and stationary directional (trend) variability. Accordingly, it can be predicted that some chemical components will remain at the same level (with irregular variability), while the other will decrease. The amount of reduction can be found from simple extrapolation.

The same trend is observed in groundwater accessed by wells 5 and 6; namely, almost all components show irregular variability except for NH_4 in well 5, which increases from 0.1 mg/dm^3 to 0.6 mg/dm^3; in turn, NO_3 decreases in well 6 from 4–5 mg/dm^3 to 2–3 mg/dm^3.

In groundwater stricken by wells 7 and8, there is no regular variability in the chemical composition, except for NO_3 in well 7h, where this component increases from 1 mg/dm^3 to 3 mg/dm^3.

In groundwater accessed by wells 9 and 10, the content of such components as NO_2, HNO_3, as well as the dry residue decreases. The other indicators vary irregularly.

The background well located on the south of the waste storage facility shows stationary variability in terms of all components [10].

Conclusions

The ecological analysis of surface water and groundwater subjected to waste water impact shows that such water resources are, in fact, man-made bodies and need effective environmental measures to be developed and implemented. The created monitoring network allows water quality evaluation and analysis, prediction of changes in the surface and groundwater quality and prompt implementation of preventive environmental measures to reduce the impact of man-made objects.

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