Hydrogeochemical Assessment of Groundwater Conditions and Delineation of the Influence Zone of a Waste Disposal Facility in the Kirovo-Chepetskiy Industrial Area

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Abstract. The data was analyzed to identify the influence zone of the waste disposal facility and to reveal the current level of pollution. Element-by-element maps of pollutant distribution were built on the basis of groundwater chemical analysis. Strontium, ammonium nitrogen, nitrate nitrogen were selected as marking elements to identify the influence zone of the waste disposal facility. Analysis of the pollution dynamics was carried out on the basis of multi-temporal maps comparison.

Cartographic analysis revealed that over a five-year period the boundary of nitrogen pollution moved the Vyatka River to 200 m.

The impact of the tailing dump on ground waters was determined by the occurrence of ammonium nitrogen, nitrate nitrogen, strontium ion. To determine the influence zone, we used the method of spatial comparison of contamination halos with individual components. Geostatistical calculations were carried out by the method of interpolation of "natural vicinity" for each element. As a result, it was revealed that the areole of strontium distribution in groundwater was slightly less than that of other pollutants, despite the fact that the migration capacity of all the studied elements was approximately equal.

Thus, the influence zone of the studied object is 4.7 km^2 and is limited by isolines of minimum concentrations of strontium-ions.

Keywords: Waste Disposal Facilities · Hydrogeochemical Assessment · Groundwater

1 Introduction

The absence of a unified terminological base in state documents regarding the "zone of influence of negative impact" was the reason that the authors consider various options to determine and calculate the influence zone, including the use of modern hydrodynamic modeling software [5–9].

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Under the influence zone of the waste disposal facility on the environment, the authors understand the spatial area within which changes in the state of the components of the natural environment induced by the pollution source are observed.

The object of research is the territory of the Kirovo-Chepetskiy industrial hub. We studied the groundwater and its geochemical characteristics. Special attention is given to the task of identifying the influence zone of the waste disposal facility on groundwater.

2 Region of Interest

Region of interest is a technogenically loaded area situated to the west of the Kirovo-Chepetsk, 20 km from the Kirov city (Russia). It is a large industrial center of the Kirov region where a large number of technogenic objects is concentrated (see Fig. 1).

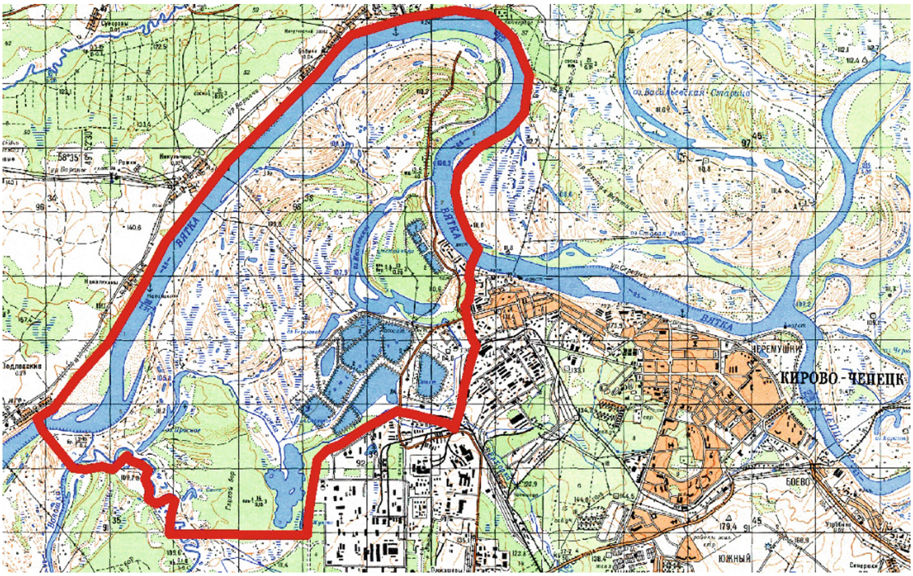

Fig. 1. Overview map-scheme of the studied area.

Nitrogen compounds are the main chemical pollutants in the studied area. Due to the high concentration of technogenic objects on the territory and the specifics of objects activities, nitrogen compounds enter the environment in various ways: into groundwater through infiltration, into surface water with water outlets and various uncontrolled drains, into the atmospheric air with emissions, into the soil with polluted waters surface runoff and with precipitation from the atmosphere, vegetation and wildlife perceive pollution indirectly through the other components of the environment. Therefore, a special attention is given to nitrogen pollution in the article, and on its basis, the influence zone is determined [1–3].

The allocation of the influence zone of the waste disposal facility on the environment is complicated by the fact that the waste disposal facility is located at the site of the Kirovo-Chepetskiy industrial hub, where the sources of environmental pollution characterized by the release of pollutants similar to those characterized studied object [2, 3].

To determine the changes induced by the waste disposal facility, the authors considered it is appropriate to take the background values of pollutants, the deviation of them makes it possible to quantify the impact of the facility on the environment. Background values should be considered not only those that existed before the construction of the facility, but also those that are currently observed outside the influence zone of the facility. Therefore, identifying of the boundaries of the influence zone is the most important task.

3 Objects of Negative Impact

Within the study area, surface and groundwater are affected by production facilities located on the catchment area of the Elkhovka and Vyatka Rivers. Analysis of the location of production facilities in the Kirovo-Chepetsk town and some adjacent settlements was carried out using Internet available information. At the catchment area of the Elkhovka River, there are at least 32 objects that have an impact on the natural environment.

At a distance of 7.8–8.5 km from the mouth, the effect of the oil depot and runoff from the territory of the oil depot with a flow rate of 0.5 l/s are noted. At a distance of 7.3 km, the river flows 680 m through the territory of the industrial site, below which the river receives water from the territory of the furniture enterprise. Further, at a distance of 6.4 km from the mouth, there is a wastewater outlet from the oil refinery.

Among the contaminants, it should be noted radioactive ones in the Elkhovka riverbed – plutonium, strontium, cesium, and chemical ones – sulfate (SO_4^{2-}), chloride (Cl^-), sodium (Na^+), calcium (Ca^{2+}), strontium (Sr^{2+}).

There are large wastewater treatment plants that discharge wastewater into the Vyatka River and its tributaries. In addition, there are warehouses of pesticides and mineral fertilizers on the studied area. It has been established that 50% of objects and waste disposal sites are unauthorized in the Kirov region. Improper storage and disposal of waste products from livestock farms and poultry farms causes nitrate pollution of the soil and groundwater.

4 Hydrogeological Conditions

The study area is located in the northern part of the Volga-Kama artesian basin [4].

Groundwater of the research area is confined to the Volga-Kama artesian basin [4]. The thickness of the sedimentary complex of rocks is 2500 m. The Permian gypsum-anhydrite deposits and Carboniferous limestones are the regional aquiclude.

Three hydrodynamic zones are distinguished in the section of the sedimentary cover: active water exchange, hindered water exchange and very hindered one (see Table 1).

According to the groundwater conditions of formation and circulation, common hydrogeological conditions and stratigraphic affiliation in the studied area, the seven aquifers are distinguished:

Table 1. Characteristics of the hydrodynamic zones of the study area

Hydrodynamic zone	Bottom boundary	Hydrochemical parameters
Active water exchange	Roof of the Kazanian stage, depth 200 m below surface	Fresh water (up to 1 g/dm^3) and brackish water (1–10 g/dm^3)
Hindered water exchange	Roof of halide-carbonate deposits of the Sakmarian stage of the Permian system, depth 450–500 m below surface	Salty water (10–15 g/dm^3)
Very hindered water exchange	Bottom of the sedimentary rocks	Brain water (50–200 g/dm^3 and above)

1) Quaternary aquifer (aQII-IV);
2) Tatarskiy aquifer (P_2t);
3) Kazanian aquifer (P_2kz);
4) Assel-Kashirskiy aquifer (P_1a-C_3g-C_2mc-ks);
5) Serpukhov-Oka aquifer (C_1s-ok);
6) Famennian-Franzian aquifer (D_3fm-f2-3);
7) Pashian-Givetskiy aquifer (D_3f-D_2zv).

The first from the surface and the most susceptible to pollution is the Quaternary aquifer, which is distributed throughout the study area. In the area of the Kirovo-Chepetskiy industrial hub, it is associated with alluvial sand-gravel (15 m in thickness) and marsh peat (0.5 m) deposits. The aquifer is predominantly non-pressured, in some places in the upper part of the stratum it has a local pressure of up to 1.5 m. The groundwater level lies at a depth of 1.0–2.5 m. The thickness of watered rocks in this aquifer reaches 10 m. Upper Permian clays (56 m) with a filtration coefficient of $6.7*10^{-6}$ m/day serve as an aquiclude for the groundwater horizon [4].

The mineralization of groundwater of natural chemical composition in the adjacent north and northwest areas the varies from 0.08 to 0.34 g/l.

There is a layer of gravelly and coarse-grained sands in the lower part of the Quaternary aquifer, which is considered as the main filtration route to the Vyatka River due to its filtration coefficient of 10–25 m/day.

The ubiquitous distribution of the Quaternary aquifer, the peculiarities of its supply, the layered occurrence of water-bearing rocks and their lithology determine the direct influence of pollution sources on aquifer. At the same time, the significant thickness of the aquifer and its low filtration coefficients to assume that there is no negative impact on the underlying aquifers. However, there is a risk of pollution of surface water bodies, mainly the Vyatka River.

5 Hydrogeochemical Characteristics

In 1978, it was revealed that the areola of chemical contamination of groundwater spread downstream by 1000 m and completely covered the site of the studied waste disposal facility. To the north-west of the chain of oxbow lakes, the mineralization of groundwater was 0.2–0.3 g/dm^3, the waters were predominantly hydrocarbonate-calcium-magnesium. To the south and south-east of the chain of oxbow lakes, water salinity varied from 0.2 to 14.8 g/dm^3. Thus, it can be said that at the end of the 1970s, the groundwater in the study area was affected by a number of industrial waste disposal sites, including waste from the production of electrical and thermal energy.

According to archival data, in the groundwater of the study area the concentration of ammonium ion for the period of designing the studied waste disposal facility was not significant. The content of the ammonium ion in groundwater at a depth of 0.9–1.2 m during this period reached 25 mg/dm^3.

In 1978, two types of chemical pollution were identified in the study area:

Type 1 – groundwater pollution by production wastes from existing waste disposal sites. According to the composition of water, there was mainly chloride-sodium-potassium-calcium waters (more polluted) and chloride-bicarbonate-calcium-sodium-potassium ones (less polluted);

Type 2 – groundwater pollution due to leakages from the drainage systems of an enterprise for the production of electrical and thermal energy. The composition of the water was predominantly sulfate-chloride-calcium magnesium one (more polluted) and chloride-hydrocarbonate-calcium-magnesium one (less polluted).

Thus, there were areolas of chemical pollution predominantly of the chloride and sulfate types in the studied area, and there were ammonium ions in concentrations up to 25 mg/dm^3 among the pollutants [9].

At present, the “spectrum” of the main pollution components has expanded due to the inflow of ammonium nitrate and strontium ions from the studied waste disposal facility. There is sulfate, chloride, ammonium, nitrate, sodium pollution on the territory. Additionally, radioactive elements are observed in the groundwater of the study area: strontium, uranium, cesium, plutonium, and thorium [9].

6 Determination of the Influence Zone

The authors analyzed the data to identify the influence zone of the waste disposal facility and identify the current level of pollution. Element-by-element maps of the distribution of pollutants were constructed based on the chemical analysis of water.

To identify the influence zone of the object of study, the following marking elements were selected: strontium, ammonium nitrogen, and nitrate nitrogen (see Fig. 2, 3, 4 and 5).

During constructing of isoconcentrations based on the summary annual data, it was revealed that the contours of the areolas of pollution with ammonium nitrogen have a pollution tongue distributed upstream from the waste disposal facility (see Fig. 5). The area of the tongue decreases and increases periodically. Presumably, there are several other sources of nitrogen pollution located above the studied object. This assumption is also confirmed by the observation of ammonium nitrogen in a number of observation wells (see Fig. 3). According to the results of water chemical analysis, a significant amount of ammonium ions is present here, while nitrates are practically absent.

Thus, the area of distribution of pollution with ammonium and nitrate nitrogen was formed due to the merger of at least two pollutant areolas. The northern part of the study area is subject to pollution from the studied object. The southern part of nitrogen pollution is confined to the floodplain of the Elkhovka River and has been formed since the middle of the 20th century, when the first waste disposal facilities in the study area were put into operation.

Analysis of the dynamics of pollution development was carried out on the basis of a comparison of multi-temporal maps of summary data. Thus, the areola area of nitrogen pollution has changed insignificantly over the five-year period, namely from 4.9 km^2 to 5.1 km^2.

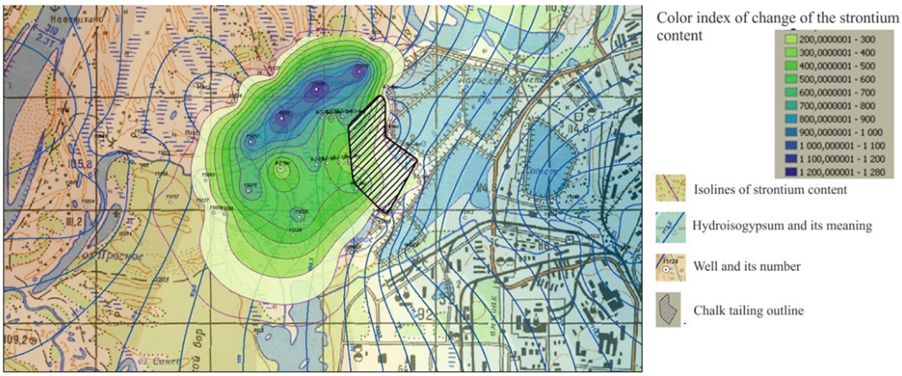

Fig. 2. Cartogram of strontium content in groundwater.

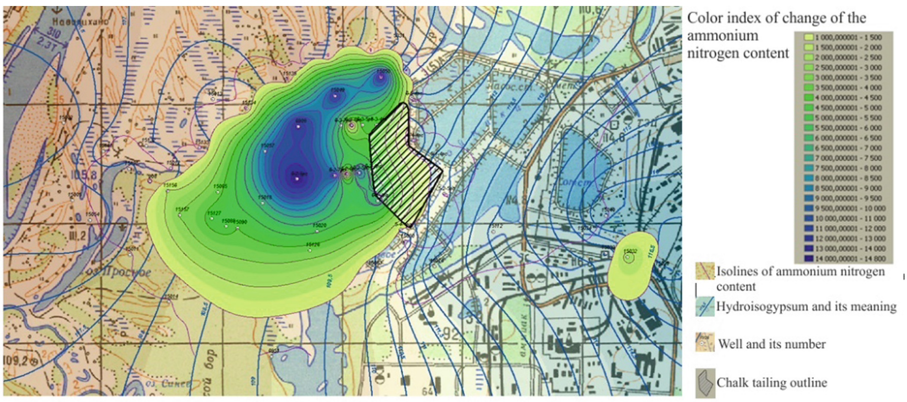

Fig. 3. Cartogram of ammonium nitrogen content in groundwater.

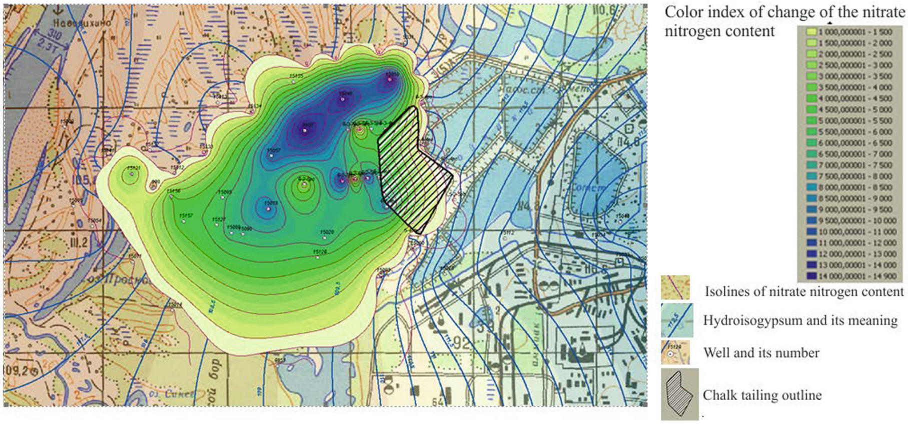

Fig. 4. Cartogram of nitrate nitrogen content in groundwater.

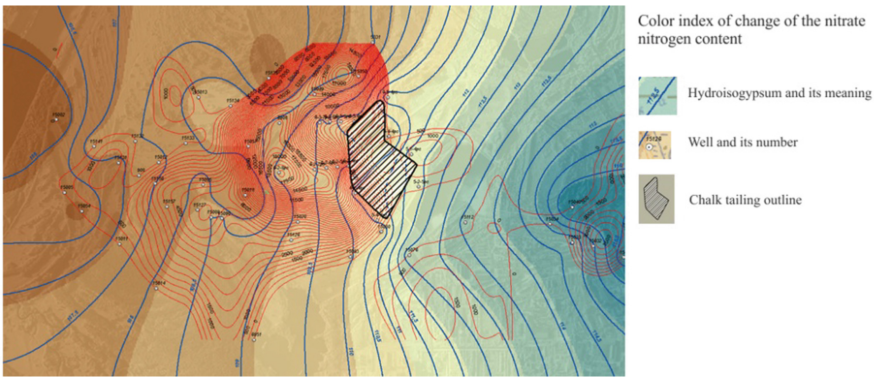

Fig. 5. Cartogram of the distribution halo of nitrogen pollution in groundwater.

Cartographic analysis revealed that over a five-year period, the border of nitrogen pollution moved the Vyatka River to 200 m and is currently located at a distance of 600 m of the river's edge.

7 Conclusion

The impact of the waste disposal facility on groundwater is determined by the presence of ammonium nitrogen, nitrate nitrogen, and strontium ion in them. Of all the listed elements, the strontium ion is characteristic only for this object and is not originated from other technogenic sources located in the study area. The presence of strontium ion in groundwater can be considered as an identifier of groundwater pollution formed under the influence of the studied object.

To determine the influence zone, the method of spatial comparison of pollution halos of individual components was used. Geostatistical calculations were carried out using the "natural neighborhood" interpolation method for each element. As a result of comparison of spatial areas, it was revealed that the areola of strontium distribution in groundwater is slightly smaller than that of other pollutants, despite the fact that the migration ability of all studied elements is approximately equal [10].

Thus, the influence zone of the object is limited by the isolines of the minimum concentrations of strontium ion as shown in Fig. 6.

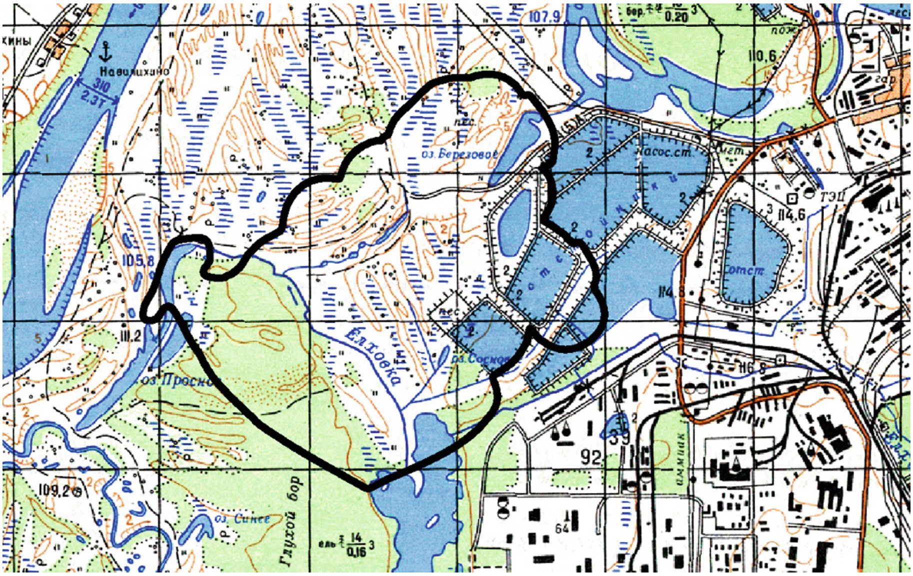

Fig. 6. The influence zone of the object under study on groundwater.

The area of the influence zone is 4.7 km^2. The thickness of the influence zone on groundwater corresponds to the difference between the absolute marks of the groundwater level and the top of the Upper Permian clays and is 10 m on average. Taking into account the porosity of water-bearing soils, the volume of groundwater affected by the object is 14,1 million m^3.

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