Studying the Bottom Sediments of River Ecosystems within the Influence Zone of the Konder Placer Mine

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Abstract. The article presents results of studies on the influence of pollutants in bottom sediments, related to the production activity of the Konder placer mine in the Khabarovsk Territory, upon the sediment composition and water quality in the river ecosystems.

1. Introduction

In environmental studies, bottom sediments represent an indicator of the ecological state of the catchment area, a kind of integral indicator of the water pollution level.

Studying the bottom sediments is the most important aspect of investigation of the ecological conditions of water bodies. It most adequately reflects their actual state and carries an information on the pollution caused by technical and economic activities in the area. The urban construction and utilities, industry, mining, agriculture, and other human activities contribute to the accumulation of pollutants in bottom sediments of the nearby surface watercourses.

The upper section of the lithosphere (soils, rocks, and bottom sediments of surface watercourses and reservoirs) plays the role of an accumulator and transformer of anthropogenic impact and is an indicator of its intensity level. Lithogeochemical anomalies in bottom sediments are forming in almost all technogenic areas in aquatic landscapes. The specificity of these anomalies is a fine granulometric composition of the precipitations, their increased plasticity, sometimes jelly-like consistency, the presence of particles of artificial origin, oiliness, and specific (oil, hydrogen sulfide, fecal) smell.

The composition of heavy metals incoming into a landscape, as known, primarily depends on the type of anthropogenic activities.

River sediments of small fractions with a high sorption capacity accumulate the whole complex of chemical elements present in the water, during their movement and deposition in the river channel. The concentration of polluting chemical elements in sediments smaller than 0.020 mm (clayey and silty particles) is often 5-10 times higher than that in the river water. As a result of desorption processes under certain hydraulic and hydrochemical conditions, such heavily contaminated sediments can be a source of secondary pollution of the aquatic environment [1, 2, 3, 4].

Studies of bottom sediments should be given a priority in the general system of observations of the aquatic environment state, as compared to hydrochemical and hydrobiological studies, they does not require annual regime observations. This significantly reduces the cost of environmental monitoring. Results of the studies of river bottom sediments make it possible to identify the most ecologically
unfavorable parts of the river and, ultimately, to adjust the composition and scope of the river basin monitoring [5, 6, 7, 8].

2. Relevance and scientific significance of the issue

Contemporary ecological problems of river basins had been arising with the civilization development, as a consequence of anthropogenic impact on nature. A historically unprecedented global relevance of searching for a comprehensive solution to these problems at the turn of the millennium is due, on the one hand, to the awareness by the world community of a natural dependence of the scale of environmental disasters on the intensity of anthropogenic load upon river ecosystems, and, on the other hand, to the urgent need for specific actions aimed at reducing this load and preventing the river degradation [1].

Revealing the main regularities of heavy metals migration in the "catchment – water environment – bottom sediments" system is a rather complex issue that requires field studies, analysis of a large amount of observational materials, and assessment of the role of heavy metals migration by trophic chains. Thus, researches of the heavy metals transportation in the "water environment – bottom sediments" system and quantitative estimations of intensity of these migration processes is a very urgent task. Based on these characteristics one can judge on the presence or absence of a danger of secondary pollution of water objects. On the other hand, the relevance is determined by the fact that the problem of determining the landscape features of the bottom sediment formation has yet to be solved, so the implementation of research in this direction is of particular scientific importance.

It is beyond question that there are no two identical river basins with same characteristics. The peculiarity of each of them is due not only to the natural characteristics, but also, to a sufficient extent, to circumstances related to the development of civilizations [9, 10].

The problem of pollution is now becoming increasingly important for the Uorgolan River basin in connection with the rapid economic development of mining enterprises (the Konder placer mine, as an example).

Bottom sediments of anthropogenic and natural origin worsen the ecological and sanitary conditions of water bodies. If an autopurification of closed water bodies from bottom sediments is impossible, their gradual silting and overgrowing take place to form land from alluvial deposits and of dead biomass from the swamped shores.

A scientific novelty consists in that the monitoring of bottom sediments of water bodies near the placer deposit is carried out for the first time. This monitoring aims to control a possible impact of harmful (polluting) substances on the bottom sediment composition and water amount as a result of household and industrial activities during the production of placer platinum of the deposit.

Bottom sediments in river channels and reservoirs of the Uorgolan and Konder river basins, formed by recent channel processes, were not chemically studied [11, 12, 13, 14].

The formation intensity, thickness, granulometric composition, and chemical composition of bottom sediments depend on the physiographic and anthropogenic conditions of the basin and on the complex of processes that occur in the water reservoirs themselves. As economic development of catchments and reservoirs is in progress, an anthropogenic influence (plowing of catchments, wastes discharge, etc.) acquires an increasing importance in formation of the bottom sediments [15]. Results of studies of river bottom sediments make it possible to identify the most ecologically unfavorable parts of the river and, ultimately, to adjust the composition and scope of the river basin monitoring, to reveal and neutralize the pollution sources [16].

However, the methodology of standardization of pollutants in the bottom sediments of surface watercourses is not sufficiently advanced. The currently existing State standards and guidelines for the study of soils and bottom sediments do not take into account specific features of their composition and peculiarities of pollutants behavior in various natural environments, and often do not meet the current level of knowledge in the field of hydrology, soil science, and colloidal and physical chemistry [17].
3. The objective, tasks, and methods of research

The objective of the research is to study a possible impact of harmful (polluting) substances in bottom sediments, resulted from the production activities in the course of the placer deposit exploitation, on the sediment composition and water quality.

In accordance with the objective, the following tasks were planned to be solved.

1. Analysis of formation conditions of the bottom sediments and revealing the physiographic and climatic characteristics, including characteristics of the landscapes.
2. Identification of geomorphological conditions, dangerous exogenous geological processes and hydrological phenomena, and technogenic conditions of the site.
3. Specification of characteristics of the bottom sediments.

The adopted research methodology included field and laboratory works and a controlling processing of the sample analyses results.

The field works included route surveys with a comprehensive description of the sites located in the Uorgolan and Konder river valleys. The routes were carried out along bottoms of the river valleys with their transverse crossing at some description points. At each of the sites, the features and origin of meso- and microrelief were determined and the loose unconsolidated deposits were characterized. At some points, descriptions of soil sections and field determinations of soil types were performed. At each of the sites, a brief description of the vegetation cover and a photo shooting of the most typical views of the locality were conducted.

Simultaneously, the degree of anthropogenic transformation of natural complexes was visually assessed, and the main types of anthropogenic disturbances were recorded in the photo.

The studies of the relief and exogenous geological processes were carried out using published current guidelines, Set of Rules, and State Standards.

They included:

a) route survey of the territory, including the zone of influence of economic activity on the relief and exogenous geological processes;

b) description of the main morphological and morphometric characteristics of various forms of relief;

c) description of lithological composition and genesis of loose Quaternary deposits;

d) identification of the most dangerous geological processes, based on the visual inspection of the territory.

Erosion processes were studied by visual surveys of parts of river channels, including small watercourses. A description of the watercourses in their natural state was conducted: their width and depth were measured and the channel tortuosity, floodplain afforestation, alluvial deposit composition, and shores characteristics were appreciated. The intensity of channel deformations was also estimated and its determining factors were revealed.

For analytical studies in laboratory conditions, samples of the bottom sediments were delivered to Khabarovsk. The bottom sediments were analyzed at laboratories of the territorial center for environmental monitoring and forecasting of emergency situations of KGKU “Department for Civil Defense, Emergency Situations, and Fire Safety of the Khabarovsk Territory”.

In all the bottom sediment samples, the gross contents of heavy metals (cadmium, copper, arsenic, lead, zinc, nickel, and mercury) were determined. The contents of oil products and of mobile forms of iron and manganese were also determined.

During the desk processing of the materials, the types of the landscapes were specified using the materials of route observations, photographs, comprehensive descriptions, satellite images, and large scale topographic maps. Approximate permissible concentrations (APC) of chemicals in sandy and sandy-loam soils were specified for the bottom sediments.

4. Research results and discussion

Bottom sediments in the river channels and reservoirs of the Uorgolan River basin, formed by recent channel processes and by terrigenous and organic matter deposition in settling basins, are mainly
represented in the upper layer by clayey-silty sediments with sand and gravel admixtures. Their organic matter content is generally insignificant and comprises from 0.1 through 0.15% of the total mass.

Monitoring of bottom sediments of water bodies adjacent to a mineral deposit is carried out in order to control a possible impact of harmful (polluting) substances on their composition and water quality as a result of production activities during the mineral deposit exploitation [18, 19].

A significant portion of the chemicals dissolved in the water is adsorbed by suspended particles and settles to the bottom under an influence of gravitation, where it accumulates in the bottom sediments, especially in the silty fraction of under-oxidized and undecayed humins. Incoming to the bottom sediments for a long period of time, heavy metals accumulate in the upper layer (up to 10 cm thick) and contribute to the territory pollution.

The presented chemical composition of the bottom sediments indicates a generally low contamination by oil products and an insignificant range of their concentrations except for a few samples, which is probably due to a local anthropogenic impact.

Concentrations of heavy metals are more uniformly distributed in the bottom sediments and do not exceed or insignificantly exceed the APC values in all the samples.

To determine the Konder placer deposit exploitation impact on the degree of pollution of the bottom sediments in the water bodies, the samples were taken in July 2017 from the upper layer (up to 10 cm thick) in settling basins within the Konder and Uorgolan river channels. It was considered that the bottom sediments of the Uorgolan River upstream of the wastewater discharge were not subjected to an influence of the mineral deposit operation and could serve as a control relative to the other investigated sites.

Most of the settling ponds is spontaneously overgrown with grass and bushes along the shores. Evaporation from the water surface of the reservoirs is weak. The water color varies from yellowish to yellowish-turquoise.

Abundant precipitation in summer increases the water turbidity and changes its color. The depth of the settling basins is small (2.0 through 5.0 m). Therefore, a circulation of low-alkaline bottom water during the rainy seasons affects the geochemical processes in the bottom sediments, which is confirmed by the studies: the content of chemical elements varies drastically year to year.

The concentration of heavy metals in the bottom sediments within the settling basins depends on the water body age and exhibits certain regularities in the substances distribution (tables 1 and 2).

The bottom sediments in the settling basins are represented by layers up to 20 cm thick composed of fine silt fractions of brownish-bluish tints and are characterized by high concentrations of heavy metals. The following regularity is observed: the earlier the settling basins were formed, the more heavy metals they contain in the bottom sediments. As it was previously observed, the iron content in the bottom sediments of the settling basin created in 2009 was 43.42 mg/kg, while that of the settling basin of 1998 was 49.97 mg/kg. Reservoirs with such a content of Fe in the bottom sediments (while APC is 30 mg/kg) are assigned to polluted (1.5 – 1.7 times higher than the threshold limit value, respectively). The high silt fraction content is favorable for the sorption processes and heavy metals concentration. The contents of other elements in the bottom sediments in the settling basin of 1998 were noted to significantly exceed both the APC and their contents in the settling basin of 2009.

A slight increase in the oil products concentration is noted in the Konder River channel, which is determined by a prolonged existence of a drainage channel of the river and, accordingly, by an extended period of the oil products accumulation.

The study of bottom sediments of the watercourses of the Uorgolan River basin testifies to their low average content of heavy metals, regardless of the material of which they are composed (sandy or clayey particles). Their concentrations are also weakly dependent on the size of the watercourses.

The maximum concentrations of these components are observed in the bottom sediments of the Konder River, which may be associated with a predominantly silty composition of the bottom sediments. The minimum concentrations are in the sediments of the Uorgolan River, which is caused
by a lower content of silt fractions in the inequigranular sands and sandy-gravel sediments and by a faster flow of this river.

The concentration levels of cadmium, nickel, and mercury are more uniformly distributed in the bottom sediments and their values in all the samples do not exceed the APC.

An assessment of a technogenic pressure and identification of mechanisms of the natural watercourses pollution is carried out based on the monitoring results at sites of exhausted and current exploitation workings of the mineral deposits.

The ecological state of the water bodies is not constant in time. The concentration of heavy metals in the bottom sediments of all the artificial reservoirs (settling basins) of the Uorgolan River basin depends on the duration of their existence and on the granulometric composition of the sediments.

Data on chemical composition of the principal pollutants in bottom sediments of the watercourses are presented in table 1.

**Table 1.** Concentrations of the principal chemical components in bottom sediments of the Uorgolan River basin.

| Components   | Measure units | Uorgolan River, downstream of the village | Settling basin, opposite of Konder | Lower settling basin (active now) |
|--------------|---------------|------------------------------------------|-----------------------------------|----------------------------------|
| Iron (total) | mg/kg         | 17 826.05                                | 29 885.4                          | 19 619.7                        |
| Manganese   | mg/kg         | 699.9                                    | 690.9                             | 642.7                           |
| Lead        | mg/kg         | 54.7                                     | 101.4                             | 53.43                           |
| Nickel      | mg/kg         | 62.1                                     | 91.1                              | 57.1                            |
| Cadmium     | mg/kg         | 1.2                                      | 2.06                              | 1.2                             |
| Cobalt      | mg/kg         | 21.5                                     | 41.6                              | 20.74                           |
| Zinc        | mg/kg         | 48.5                                     | 84.8                              | 50.52                           |
| Mercury     | mg/kg         | 1.8                                      | 3.7                               | 2.20                            |
| Copper      | mg/kg         | 17.7                                     | 44.9                              | 21.07                           |
| Oil products| mg/kg         | 29.0                                     | 32.0                              | 63.0                            |

Hereafter, an analysis is present of contents of the principal components in bottom sediments of the Uorgolan and Konder rivers and of the two settling basins (the active and closed ones).

Lead. The maximum concentration is characteristic of bottom sediments of the closed settling basin. The Pb content of its bottom sediments is almost 2 times higher than that of the Uorgolan River (101.4 and 54.7 mg/kg, respectively). However, concentration of this metal in the active settling basins do not exceed the values of 53.43 mg/kg, which is almost the same as in the sediments of the Uorgolan River. All the figures for this metal are in excess of the APC values (32 mg/kg). The maximum concentration level of lead relative to the APC (more than 3) is observed in bottom sediments of the closed settling basin, which may be due to the longer duration of the bottom sediment formation. Levels of excess over APC for lead in the river bottom sediments and in the acting settling basin are significantly lower (about 1.7).

Iron. Natural conditions of the territory cause high iron concentration levels of in all the bottom sediments of the watercourses without exception, regardless of their type and size. The highest iron content is found in bottom sediments of the closed settling basins and comprises approximately 30 mg/kg. The concentrations of iron in the samples of bottom sediments of the Uorgolan River and of the acting settling basin are close to each other and comprise 17.83 and of 19.62 g/kg, respectively, which corresponds to the background values.

Manganese. The manganese content in bottom sediments varies from 643 mg/kg in the active settling basins up to 700 mg/kg in the Uorgolan River sediments. In the closed settling basins, the Mn content increases up to 961 mg/kg, which is related to a high content of settled sludge and to sorption processes. So high concentration levels of this metal may be caused by a significant content of its mobile forms in the surrounding landscapes from where they come into the watercourses.
concentration levels, even in the old settling basin, do not exceed the APC values for manganese equal to 1500 mg/kg.

Zinc. The lowest zinc concentration in bottom sediments of 48.5 mg/kg is inherent in sandy-silty alluvial sediments of the Uorgolan River spits; the value for the acting settling basin is slightly higher and comprise 50.52 mg/kg. The maximum Zn concentration of 84.8 mg/kg is observed in the old (closed) settling basin. Such the concentration levels of this metal testify to the absence of the bottom sediments pollution (the APC in loamy and clayey sediments comprises 220 mg/kg).

Copper. The natural conditions of the territory cause relatively low concentration levels of copper in all the bottom sediments of the Uorgolan River basin watercourses with no exceptions. The copper concentrations here do not exceed the APC values (132.0 mg/kg). The copper content varies within the range of 17.7 through 20.07 mg/kg in the bottom sediments of the Uorgolan River and of the acting settling basin, respectively. The highest Cu concentrations of 44.9 mg/kg are found in the old (closed) settling basin, which is also associated with high concentrations of iron and manganese here. Lower copper concentrations in bottom sediments of the Uorgolan River can be caused by its rapid flow, high river discharge, and intense bottom sediment agitation, as well as by the high copper migration capacity.

Cobalt. The cobalt concentration in bottom sediments of the territory under consideration varies from 21.5 mg/kg in the Uorgolan River channel up to 20.74 mg/kg in the acting settling basin. The metal content in the old (closed) settling basin is 2 times higher and comprises 41.6 mg/kg. It should be noted that all these figures significantly exceed the APC values equal to 10.0 mg/kg. The cobalt content in the bottom sediments also exceeds the regional background of the territory, which is probably due to the high cobalt content of the rocks.

Oil products. Most of the bottom sediments studied contain oil products in amounts that do not exceed the APC (300 mg/kg). Their concentrations are too low and range from 29 through 32 mg/kg. Only in bottom sediments of the active settling basin, the oil products content increases up to 63 mg/kg, which, however, is also significantly lower than the APC. Such an anomaly is associated with a local pollution of the bottom sediments, as well as with an extended duration of their accumulation in the upper section of the sediments.

Nickel. The metal concentrations exhibit an excess over the APC (80 mg/kg) only in the closed settling basin (91.1 mg/kg), which is associated with sorption processes. The nickel concentrations in the alluvial bottom deposits and in the active settling basin comprise 62.1 and 57.1 mg/kg, respectively, which is much less than the APC.

Mercury. This is the most toxic element, it exhibits a tendency to accumulate in the bottom sediments. The gross mercury content in the old settling basin is 3.7 mg/kg, which is 1.5 times higher than the APC value (2.1 mg/kg), and that in the acting settling basin is 2.2 mg/kg, which is insignificantly higher than the APC. The mercury concentrations in bottom sediments of the Uorgolan River comprise 1.8 mg/kg (less than the APC).

5. Conclusions
Thus, the implemented studies of chemical composition of the bottom sediments testify to the absence of pollution of the sediments of the studied watercourses by oil products and to a small amplitude of variations in their concentrations, from 29 through 63 mg/kg.

Heavy metals are even more uniformly distributed in the bottom sediments, and the contents of many of these metals do not exceed the APC values of pollution.

The high concentrations of iron and manganese compounds determine a specific affinity to the hydrate copper ion \([Cu(H_2O)_6]^{2+}\) and contribute to processes of their coagulation and formation of a gel-like copper precipitate (covellite, hydrargillite), which is suggested by the blue tint of the bottom sediments.

The concentrations of cobalt in bottom sediments of all the water bodies engage a special attention. They are significantly higher than the APC. The APC of mercury in bottom sediments of the settling basins is also exceeded, while the mercury content in bottom sediments of the watercourses does not
exceed the APC. According to SanPiN (Sanitary and Epidemiological Rules and Regulations) 2.1.7.1287-03 (sanitary and epidemiological requirements for the soil and ground quality), the bottom sediments belong to the permissible level as to the mercury pollution category.

Technological methods applied during the Konder placer deposit exploitation are accompanied by a flow of various substances of anthropogenic origin into the environment, especially to surface water bodies. They tend to continuous accumulation in the bottom sediments of the watercourses, which should be taken into account when assessing the impact of the production on various components of the natural environment and especially on surface and ground waters and bottom sediments of the watercourses in the immediate vicinity of the stripping site and technological facilities.

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