Assessment of the Ecological State of Soils Near the Platinum Deposit

S S Golovkin¹, M N Shevtsov¹, A F Makhinova², A I Makhinov²

¹Pacific State University, Khabarovsk, Russia
²Institute of Water and Environmental Problems of the Far Eastern Branch of the Russian Academy of Sciences, Khabarovsk, Russia

E-mail: 000458@pnu.edu.ru, amakhinov@mail.ru

Abstract. The research is devoted to the ecological state of soil resources in the area of the Konder platinum placer deposit in the Khabarovsk Territory. The environmental impact of the Konder mine activities was established based on chemical analyses performed. In general, the study has demonstrated that the Konder field development and operation cause a complex multicomponent pollution of the landscapes. The pollution is more than local in nature, since the environmental problem related to violation of soil resources and to chemical contamination of soils and natural watercourses in areas of mineral development is becoming increasingly acute. As a result of the studies, geochemical features of the soil space and the main sources and factors of the soil contamination have been determined.

1. Introduction
Development of mineral deposits causes not only income of various anthropogenic pollutants that tend to be accumulated in the environment, but it also transforms the landscape, which must be taken into account when assessing the impact of mining on various components of the natural environment [1]. The construction of mining complexes and exploitation of mineral deposits disturb the terrain topography, change the regime and composition of the surface and underground waters, cause pollution of the soils and air basin, and violate the spatial and species structures of the phyto- and zoocenoses [2, 3].

Acuteness of the environmental situation in mining areas is determined by the mineral deposit types, geological features, work volumes, technological processes, and local natural conditions.

In the northern Khabarovsk Territory, hundreds of placer deposits were exploited beginning from the 1930s, which has significantly transformed the natural landscapes in certain sections of the river valleys. As a result, a significant change of the natural landscapes occurred over a large area with their transformation into especial natural–anthropogenic objects. These objects are characterized by various specific processes directed to the environmental restoration after ending the mining operations. The restorating landscapes in the disturbed areas commonly possess a more complex structure and high diversity as compared to natural–environmental complexes.

The Konder placer deposit is situated in the southern Ayano-Maysky District of the Khabarovsk Territory, 90 km west of the village of Nelkan. According to the physiogeographical zoning, this area is assigned to the North Dzhugdzhur Province of the Dzhugdzhur Mountain Region. This area is characterized by very specific natural conditions that manifest themselves in peculiarities of the
surface water regime, topography, exogenous processes, soil cover, and other components of the landscapes, so it is of special scientific and practical interest in the environmental and economic aspects.

2. Relevance and scientific significance of the issue
One of the most pressing environmental problems of our time is an increasing anthropogenic impact on the lithosphere. The main lithosphere components, soils of rock and the subsurface, are subjected to the technogenic transformations as a result of works at mining enterprises. All the civilized community is particularly concerned about the degradation of soils that are one of the most important components of the environment.

The openpit-type operation of the Konder placer deposit promotes transformation of large areas of forest lands, which has an impact on the environmental situation in the surrounding area. There occur mechanical destruction of the soils and their degradation.

Noting the fact of changes of the forests and suggesting various hypotheses to identify the main causes of their vitality decrease, we comprehend a complex of diverse factors, among which anthropogenic ones play an important role. The impact of the complex of adverse anthropogenic factors, such as deforestation, chemical, physical, and biogenic pollution of soils by industrial and domestic wastes, affects the ecological state of the forests and the surface water quality. The present work is aimed at assessing the ecological state of the main components of natural landscapes and, first of all, the quality of soils in the zone of influence of the enterprise.

Geochemical features of a soil space are determined by the physicochemical state of the solid, liquid, and biogenic phases of the soils [3, 4, 5]. Processes of molecular interaction between the soil phases and the gravitational moisture ensure the dissolution and removal of the dissolved substances by the intrasoil runoff. The geochemical activity of elements at the phase interfaces of the heterogeneous soil system is determined by the iron and manganese contents. The media acidity and the humus quality maintain an equilibrium of the chemicals and control the state of the migration flows and geochemical background.

The state of the geochemical background of a territory is estimated using concentration coefficients of chemical elements in soils (Kj) relative to their contents in the soil-forming rocks. Three types of the element concentration levels are commonly distinguished: a, levels of accumulation (Kj>1.1); f, levels of background (0.7<Kj<1.1); and d, levels of deficit (Kj<0.7). The accumulation coefficients are implicated as additional information to identify factors that disrupt the biological cycle of soil formation and facilitate the element concentration and the soil contamination [6, 7].

Snow melting and heavy rain precipitation cause washoff of the finely dispersed material from slopes and its income into upper organogenic horizons of soils, as well as into river channels.

As it was demonstrated by our previous investigation, in the course of the Konder placer deposit openpit-type operation, due to the loose character of the overburden rocks that provides their good water permeability and aeration, the wastes stored on the surface have turned into a powerful source of soil pollution for decades [8].

3. Statement of the problem and research methodology
The research tasks include: assessment of the pollution level and study of a possible influence of harmful (polluting) substances on the soil characteristics, resulted from production activities during the placer deposit development; determination of geomorphological conditions, dangerous exogenous geological processes, and technogenic conditions of the mine site.

The accepted research methodology envisaged the field and laboratory works and a control processing of the sample analyses results.

The field works included route surveys with comprehensive description of sites located in the Uorgolan and Konder river valleys. The routes were set along bottoms of the river valleys with their transverse crossing at some description points. At each site, the meso- and microrelief features and origin were detected and the loose sediments were lithologically characterized. At selected points, the
soil sections were described with field determination of the soil types. At each of the sites, a brief description of the vegetation cover and photographs of the most typical landscape views were performed.

Simultaneously, the degree of anthropogenic transformation of the natural complexes was visually assessed and the main types of anthropogenic violations were photorecorded.

The relief and exogenous geological processes were studied using published methodological guides, codes of rules, and state standards.

The investigation included:
- route survey of the territory including zone of influence of the economic activity on the relief and exogenous geological processes;
- description of the main morphological and morphometric characteristics of various landforms;
- description of the lithological composition and genesis of loose Quaternary sediments;
- identification of the most dangerous geological processes, based on a visual survey of the territory.

The route survey was accompanied by taking necessary samples for their further laboratory investigations.

The analytical investigations of the samples are performed in Khabarovsk, in the laboratory of the Federal State Budgetary Institution Center for Agrochemical Service "Khabarovsk", that has a state accreditation for such an activity.

4. Theoretical section
The soil cover forming under severe natural conditions of the Fore-Okhotsk region is weakly contrast in composition. It is characterized by a low variety of the soils. The predominant elements of the background soils are rubble-containing brown taiga soils with signs of illuvial-humus removal, that are located under larch forests, on slopes of various steepness.

Their position in the relief determines the content and quality of organic matter, as well as the illuvial-humus process intensity. The soil profile in the mountains is thin (30-40 cm thick), increasing up to 70 cm on gentle slopes in the Uorgolan River valley. Weak bacterial decomposition of the forest litter and mosses leads to organic matter accumulation and to formation of humus or peaty horizons on the soil surface. Mineral horizons of the profile exhibit a rather low content of clayey fine-dispersed material (4-6%), while the lower section of the profile is characterized by the presence of long-term seasonal permafrost.

The upper humus-organogenic horizons with a thickness of 7-12 cm produce humus with high concentrations of water-soluble aggressive fractions. Structural groups of the brown ulminic and fulvic acids (comprising 58-88% of the total content) are reactive even at low temperatures.

The soils of the territory under consideration have an acidic reaction of the medium (pH 3.9-5.8) and their profile is enriched in sesquioxides of iron and manganese, whose soluble forms comprise 40-45% of the total content. Distribution of oxalate-soluble forms of amorphous iron is consistent with the content of the structural groups of fulvic acids.

During snow melting and atmospheric precipitation periods, the water passed through the rock dumps is drained into the underlying soils, sharply reducing their acidity and forming organo-mineral complexes. Large volumes of saturated solutions enter the soils, causing their pollution.

Iron sulfides play an important role in the composition of overburden rocks of the Konder placer deposit. The sulfides in the near-surface zone of the loose rocks come in contact with atmospheric air to be oxidized according to the scheme: $2\text{FeS}_2 + 2\text{H}_2\text{O} + 7\text{O}_2 = 2\text{FeSO}_4 + 2\text{H}_2\text{SO}_4$ with formation of unstable iron sulfates.

1. In aeration zone of acid soils with free drainage, adsorption of fine undissolved fractions by organic matter and chemical interaction of humic acids with metals take place. Under the hydrogeochemical conditions of the taiga soils, the following biochemical processes occur: sulfur reduction with organic carbon as a reducing agent, according to the reaction: $\text{SO}_4^{2-} + 2\text{Corg.} = \text{S + 2CO (1);}$ sulfur reduction with molecular hydrogen, another possible widely distributed natural
reducing agent, according to the reaction: \( \text{SO}_2^{2-} + 8\text{H}^+ = \text{S} + 4\text{H}_2\text{O} \) (2). These processes are active in the course of filtration of aqueous solutions into the lower horizons.

2. In zone of undrained peaty and peaty-gley soils (swampy areas with oxidizing-reducing soil formation regime), polyorganic complexes of heavy metals are synthesized under an influence of reducing agents (\( \text{Fe}^{2+}, \text{Mn}^{2+}, \text{H}_2\text{S} \), organic matter). Biogenic-chemogenic mechanisms are possible at the redox boundaries between acid soil solutions and mineral horizons of the soils under conditions of electrochemical reactions with participation of organic substances, molecular oxygen, and microorganisms.

However, low temperature gradients diminish activation of the in-situ geochemical processes in soils and do not prevent the downslope migration of the pollutants with the intrasoil runoff [9]. The distance of migration of the soil solutions is determined by the surface slope, permafrost thawing depth, organogenic horizon decomposition degree, and fine-dispersed humus content of the soil, the humus substance serving as a screen on the path of the pollutants.

Heavy metals with the atomic weight >40 are of most importance in assessing the ecological state of the surface waters, soil cover, and bottom sediments. Almost all of them are assigned to xenobiotics. Toxicant metals incorporate copper (Cu), chromium (Cr), nickel (Ni), cobalt (Co), lead (Pb), zinc (Zn), manganese (Mn), and, to a certain extent, iron (Fe) [10]. Among them, lead and cobalt are the most toxic for the animal and human health.

5. Practical significance, implementation suggestions and results, and experimental data
The experimental studies of the total content of heavy metals in the soils revealed their noticeable accumulation in the upper horizons in the immediate vicinity of the mine site. There are several causes of such a situation: a) localization of most of the sedimentation lakes here; b) large thickness of the peaty horizon with a stagnant regime, where soluble organic acids interact with metals to promote their accumulation; c) an increased content of mud fractions on which sorption of the metals occurs.

**Table 1.** Average indicators of accumulation-dispersion levels for some chemical elements in the natural-technogenic soils.

| Soil sampling sites | pH | OM, % | Levels of microelement abnormality (Kj/Kj1) |
|---------------------|----|-------|-------------------------------------------|
|                     |    | Fe total | Mn | Zn | Pb | Cu | Co | Ni | Cd |
| Inside the ring (exhausted sites 2 and 3) |     |         |     |    |    |    |    |    |    |
| Konder River tributary | 5.9 | 5.2 | 0.9/1.2 | 0.9/1.1 | 0.8/1.1 | 1.2/1.1 | 0.6/0.9 | 0.3/0.6 | 0.2/ | 0.1/0.8 |
| Konder River floodplain | 6.2 | 2.1 | 1.0/1.2 | 0.9/1.1 | 0.6/1.0 | 1.1/0.8 | Tr. | 0.2/0.6 | Tr. | Tr./0.3 |
| Sites 6 and 7 (near settling basins) | 6.6 | 3.1 | 1.0/1.5 | 0.9/2.0 | 1.0/1.1 | 1.2/1.1 | 1.0/0.9 | 0.3/-- | 0.2/ | 0.1/0.8 |
| 20m from a settling basin | 6.1 | 2.6 | 1.1/1.2 | 1.0/2.1 | 0.5/0.8 | 1.1/0.9 | 0.7/1.4 | 0.3/-- | 0.2/ | Tr./0.8 |
| 50m from a settling basin |     |       |         |    |    |    |    |    |    |
| In the Uorgolan River valley | 6.5 | 3.5 | 1.1/1.2 | 0.8/1.2 | 1.0/1.0 | 0.9/1.1 | 0.9/1.1 | Tr. | 0.3/0.7 | Tr./0.9 |
| Above the overburden | 6.0 | 2.9 | 1.0/1.1 | 0.7/1.1 | 0.8/1.1 | 1.1/1.2 | 0.1/1.0 | 0.1/0.6 | 0.2/0.9 | Tr./0.6 |
| Below the overburden |     |       |         |    |    |    |    |    |    |

Notes: Kj, accumulation of trace elements relative to the clarkre values; Kj1, relative to the regional background (regional background is the content of elements in the background soils in the dispersion state).

OM, organic matter. Tr., traces.
In soils outside the influence zone, concentrations of heavy metals exhibit a uniform accumulative distribution in the soil profile, which is mainly related to their content of the soil-forming rock. The contents are close to the clark values, while their biogenic accumulation takes place in the upper peaty horizons only. The average accumulation (dispersion) levels of some chemical elements in the natural–technogenic soils are shown in Table 1.

Previous experimental studies performed at monitoring sites over the past 7 years have revealed the following. Concentrating of the chemical elements are most often observed in the immediate vicinity of the mining sites, where natural–technogenic soils form. The anomalous concentration levels of distribution of the chemical elements at all the sites of the natural–technogenic soils are rather low. However, their indicators suggest some chemical contamination of the soil cover.

In the soils, the anomalously elevated concentration levels are demonstrated by iron, manganese, lead, and more rare zinc (Kj>1.1). Such elements as copper and cobalt, that exhibit an affinity for iron, may be assigned to the most inert ones with the concentration levels corresponding to the background (0.7<Kj<1.1). The behavior of elements with high migration activity, such as nickel and cadmium, is ambiguous. Their anomalous concentration levels depend on the content of soluble forms of organic matter. The biogenic accumulation of these elements is noted in the peaty horizons, and the deficit, in the mineral ones (Kj<0.7).

The manganese content increases 2 times in organogenic horizons of the soils as compared to the control, which is caused by processes of its sorption and precipitation on the geochemical barrier due to the reduct conditions characteristic of peaty-gley soils.

A contamination of the upper mineral horizon of the soils with the toxic elements Cr, Pb, Zn, and Mn above the background concentrations has been detected down to a depth of 35 cm.

However, the maximum content of all the elements is observed in the upper organogenic horizons, where the soil formation is accompanied by an in situ accumulation of aggressive fine-dispersed fractions of mobile fulvate humus, that are capable of sorption of the soluble compounds.

The most active migration of the soluble forms of chemical elements in composition of intrasoil solutions and by means of mechanical transport due to a planar hillslope washout is observed during snow melting and atmospheric precipitations. During periods of prolonged heavy rainfalls, erosion processes on the slopes and along the roads become more intensive. The water flows displace a large amount of terrigenous material, which significantly increases contents of the chemical elements in the soil cover.

However, the concentration levels of the elements are not constant, and their indicators are significantly dependent on anthropogenic factors, such as the duration and volumes of the mining operations.

An important factor that leads to the soil contamination and affects the water quality is forest fires. The fires and deforestation intensify thawing the soils, which leads to the development of erosion processes, to the washout and transfer of the pollutants into the watercourses. The disturbed soil cover at the overburden sites also contributes to the contamination mechanisms.

The Research Project No. 24/19 ASA – 00162 "Assessment of the Konder mine impact on the natural environment and development of recommendations for improving the industrial environmental control" was fulfilled by specialists of the Pacific State University and the Institute of Water and Environmental Problems of the Far Eastern Branch of the Russian Academy of Sciences under contract with AO "AS" Amur. The recommendations are implemented at the enterprise when carrying out environmental protection measures.

6. Conclusions
The principal results of the research performed are formulated as follows:

1. Intricate combinations of natural landscapes, formed In the Uorgolan River basin, have different resistance to anthropogenic activities and, accordingly, they allow for different limiting levels of the impact on them. The main production objects and other facilities were located with considering the resistance of the natural landscapes in the sphere of influence of the operations. These objects are
almost always set within the most stable natural landscapes and include the village territory and its recreation zone, drinking water intakes, and roads serving the village.

2. The recent studies based on assessment of the natural evolution of the environment allow us to predict a restoration of the soil cover and a decrease in the level of pollution of the water bodies outside the operation area.

3. The maximum hazard as to the soil contamination with heavy metals (especially Pb, Cu, Ni, Cr, Cd) threatens the territories adjacent to the settling basins and the diversion drainage channel. However, the soils of these areas are light in mechanical composition and therefore the contamination of these soils is temporary. No significant excess of the mobile heavy metal content over the background values and maximum permissible concentrations (MPC) was found in soils along the roads, with an exception of some data on cadmium.

In general, the contents of manganese, copper, cadmium, and zinc in the background soils of the Uorgolan River basin is slightly lower than the world clarkes. The lead accumulation in all the studied environmental groups is approaching the MPC. The nickel content often exceeds the MPC, which may be explained not only by the significant anthropogenic pollution of the territory, but also by geochemical features of the underlying rocks.

A minor negative impact on the soils of the surrounding areas is exerted by roads. But this influence is often hidden and does not manifest itself in increasing the mobile forms of heavy metals in the soils because of the specific features of the soil cover along the roads. However, plants of the wayside response to the soil contamination along the highways.

7. References

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