Impact of the mining industry on surface waters in the Arctic zone of the Republic of Sakha (Yakutia)

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Abstract. The article presents the results of hydrochemical studies of northern rivers of the Arctic zone of the Republic of Sakha (Yakutia). It was revealed that the background hydrochemical composition of surface waters in the study area is diverse: from hydrocarbonate-sodium waters in the North-West and hydrocarbonate-sulphate waters in the North-East of Yakutia. During the study of the microelement composition of surface waters in the Arctic zone, high concentrations of total iron, manganese, and copper are found everywhere, indicating their natural origin. In places where groundwater influence is observed we found that the characteristic elements are lithium, strontium and barium. Analysing the research results, we can say that each mining enterprise has its own specific effect on surface waters, which makes its own adjustments to the chemical composition of surface waters.

1. Introduction
The natural features of the Arctic region predetermine the increased vulnerability of aquatic ecosystems. Among them are the severity of the climate, the wide distribution of unstable permafrost, low self-purification potential of soils and land waters, low rates of biogeochemical processes of the cycle of substances and self-healing of disturbed ecosystems, low biological diversity, etc. [1]. When the rate and effectiveness of water protection measures are reduced, the likelihood of environmental emergencies and the formation of ecological hotspots of various scales increases.

Sustainable natural resource potential determined the model of economic development of the republic. The modern economy of Yakutia is based on the extractive industries, on the extraction of explored natural resources – diamonds, gold, coal, natural gas, oil, antimony, tin, etc. [2]. The specificity of the impact of a particular mining enterprise on the environment is due to the geological and geochemical features of the deposits, the used equipment and technology for its development. The impact on water bodies is due to a change in the hydrological regime, hydrochemical and hydrobiological composition. Water pollution is manifested in a change of physical and chemical properties, in particular in an increase of the salt and microelement composition.

Diamonds are the main type of minerals that form the mineral resource base of North-West Yakutia. Since the early 2000s, companies ALROSA, OJSC Almazy Anabara and OJSC Nizhne-Lenskoe have started developing diamond deposits in the basin of the Anabar River. In the future, in the basin of the river Udzhya, it is planned to develop one of the world’s largest deposits of rare earth metals in the Tomtor massif. Thus, during the industrial development of North-Western Yakutia, the watercourses of the river Anabar is in varying degrees of anthropogenic pressure.
2. Methods
The materials for this work are the results of hydrochemical studies carried out by employees of the Institute of Applied Ecology of the North, NEFU (IAEN NEFU) in the Arctic zone of the Republic of Sakha (Yakutia). Chemical and analytical studies of surface waters were carried out in the laboratory of physical and chemical methods of analysis of IAEN NEFU by atomic absorption spectrometry, potentiometry, fluorimetry, capillary electrophoresis, photometry.

3. Results and Discussion
The Anabar River is the largest river in north-western Yakutia, the river is formed from the confluence of two rivers – the Bolshaya Kuonapka (Kuonamka) and the Malaya Kuonapka (Kuonamka), originating in the southern part of the Anabar plateau and flowing into the Laptev Sea. The Bolshaya Kuonamka flows along the western part of the plateau, the Malaya Kuonamka – the right tributary of the Anabar River – along the east. The length of the Anabar from the confluence of the Bolshaya Kuonapka and the Malaya Kuonamka is 380 km, the total length is 939 km, and the catchment area is 100,000 km². The source of the Bolshaya Kuonamka is accepted as the source of the Anabar river. The rivers have mixed feed but the main feed is from snow. The Anabar River is characterized by a sharp rise in levels in spring and summer due to rainwater flooding. According to the feeding conditions and water regime, the Anabar river belongs to the East Siberian type of rivers.

According to literature data, the water of the Anabar river is characterized by low mineralization (20-80 mg/l). The lowest values are observed during the flood period, in the rest of the year the mineralization varies from 50 to 80 mg/dm³. In all sections of the Anabar river tributaries, exceedance of maximum allowable concentrations for fishery purposes (hereinafter MACFP) for suspended solids, NH₄⁺, and total Fe is observed. For the middle course of the Anabar river basin high content of total Fe, NH₄⁺ and suspended solids is typical; in the zones of influence and dispersion of development of diamond placer deposits, the content of suspended solids, NH₄⁺, total Fe, NO₂⁻, PO₄³⁻ and Si⁴⁺ in the water increases [3].

According to IAEN NEFU data, the natural sections of watercourses in the basin of the Anabar is slightly mineralized with a slightly acidic, neutral medium. The ionic composition is dominated by hydrocarbonates, calcium and magnesium. However, there are sections of rivers under the influence of anthropogenic impact with a different chemical composition: medium-mineralized with a slightly alkaline medium and complex chemical composition. In addition to hydrocarbonates, the ionic composition is dominated by chlorides and sulphates. These sections have high contents of total iron, manganese, copper and zinc, as well as suspended solids. So, for example, the concentration of suspended solids above the mouth of the Mayat river is rather low and reaches up to 2.0 mg/dm³, after the confluence of the river the content of suspended matter increases up to 10 times. Zn and Cu exceed the MACFP in the water of the Anabar river by up to 3.3 and 2.8 times on average respectively. A high content of oil products was found in the water of the Mayat river.

In general, in the river reaches of the Anabar river basin, not subject to anthropogenic impact, the value of salinity does not reach 100 mg/dm³, water is neutral and very soft. On the sections of rivers under anthropogenic impact, an increase in the value of water mineralization is noted, due to an increase in the concentration of the main ions, including sulphates and magnesium; rather high values of a number of sidero- and chalcophile elements (Mn, Cu and Zn) have also been revealed [4].

In addition to the diamond mining industry, in the basin of the Anabar River, development of the Tomtor rare-earth metal deposit in the Oleneksky District is planned. Geological exploration is currently underway at the Buranny site of the Tomtor field. From 2014 to the present, environmental monitoring of the terrestrial and aquatic ecosystem components has been carried out. The Onkuchakh river and Pomanistochka brook – tributaries of the Udzh River in the Anabar River basin – have been studied.

In the course of ecological and hydrochemical studies, minor fluctuations in the content of the main ions were revealed in Pomanistochka brook, which are mainly associated with the hydrological regime of the watercourse, as well as an increase in the concentration of manganese, copper and total iron in
the areas near the well site and downstream, which is associated with surface runoff from disturbed soil cover during anthropogenic impact. During the last three years in the water of the Onkuchakh river, no significant fluctuations in the values of the main hydrochemical components were noted. The influence of the Pomanistochka waters on the chemical composition of the Onkuchakh river has not been identified either.

In all the studied watercourses of the Buranny site for the period 2014-2016, Ti and rare earth elements (Er, Sm) are characteristic. In the last two years of the study, 100% occurrence in all studied watercourses is characteristic for Sc. The calculated water migration coefficient revealed that lead, manganese, copper and iron in Pomanistochka brook and the Onkuchakh river at Buranny site are very mobile elements [5]. Thus, at the stage of Tomtor field geological exploration, the technogenic impact is mainly of local nature.

The large-scale development of diamond deposits in Western Yakutia required the development of energy, transport and related infrastructure. Currently in the Vilyui river basin there are several large industrial centres. First of all, these are the mining enterprises of ALROSA, as well as the Vilyuiskaya GES. In the lower stream of the Vilyui river is the Sredne-Vilyuiskoye oil and gas complex field, actively exploited by JSC YATEC.

According to literature data, as well as stock materials of IAEN NEFU, the water in the middle stream of the Vilyui river is characterized by low and medium mineralization with a slightly alkaline medium and very low hardness.

Large tributaries of the Vilyui river such as the Malaya Botuobiya, the Daldyn and the Markha rivers are more prone to technogenic impacts. In general, the investigated large tributaries of the Vilyui river are characterized by low and medium mineralization with a neutral and slightly alkaline medium. The ionic composition of waters of major tributaries of the Vilyui river is dominated by hydrocarbonates, calcium and magnesium. However, in some areas of the studied streams, a change in the ionic composition is observed due to the influx of tributaries with different hydrochemical characteristics, which are associated not only with the diamond mining industry, but also with natural conditions. It should be taken into consideration that in the Vilyui river basin, natural outlets of highly mineralized waters are noted, which are sodium chloride and calcium chloride ones with a high content of strontium, barium, lithium and bromides [6].

In the course of long-term observations, it was revealed that the main pollutants of the waters of large tributaries of the Vilyui river are copper, total iron, manganese, which mainly indicate the natural specifics of the studied area. On average, insignificant exceedances of MAC$_{pp}$ values were registered for manganese – up to 2 times, for zinc – up to 1.4 times, for copper – up to 2.8 times and total iron up to 1.2-2.0 times. High contents of strontium, barium, bromides and lithium in the watercourses of the Vilyui river basin are mainly associated with outlets of highly mineralized groundwater.

In addition to the diamond mining industry, the gold mining industry is developed in Yakutia. For many years Yakutia has been one of the leading gold mining regions in the country, where more than 10% of gold is mined annually. The gold mining industry is developed on the territory of South and North-East Yakutia in the Aldan, the Yana and the Kolyma rivers basins.

The North-East of Yakutia is known for gold-bearing provinces. The first data on gold-bearing capacity of alluvium of left tributaries of the Adycha river in the Yana river basin were obtained in 1936-1938 during geological reconnaissance operations. In 1969-1971, the Adichansk GRP VIGRE worked for placer gold in the same area of the 75-90 metre terrace of the Adicha river.

The catchment area of the Yana river basin is composed mainly of difficult to leach Permian, Triassic and Jurassic sandstones, shales, siltstones, etc. The significant tectonic faulting of the area determines the presence of numerous springs in the Yana river basin, where ice forms in winter, which significantly reduces the winter flow (the river freezes over in some years) and increases to some extent the spring-summer flow of the river. Due to the specificity of the region, sulphate ions, formed as a result of the oxidation of minerals of the sulphide group, often play a significant role [7]. They were contained in pyrite nodules of the Jurassic age.
From 2015 to 2016 IAEN NEFU within the framework of the state assignment of the Russian Federation Ministry of Education and Science carried out comprehensive environmental studies in the basin of the Yana river upper reaches. During the study period, the water of the Sartang river at the confluence with the Dulgalakh river is characterized by low mineralization (up to 30.0 mg/dm³) with a neutral medium and very low hardness. The composition of the Sartang river according to the classification by O A Alekin (1953) predominantly SO₄-Mg-Ca. Exceedance of MAC_FP values were revealed for Mn and total Fe (up to 1.9 and 1.3 times, respectively). Water of the Dulgalakh river is also characterized by low mineralization (up to 37.2 mg/dm³), neutral medium and very low hardness. The composition of the water is SO₄-Mg-Ca. Exceedance of MAC_FP values were recorded for manganese – up to 1.3 times and for total iron – up to 6.9 times. Water of the Yana river in the area above and below the city of Verkhoyansk has a low mineralization up to 35.9 mg/dm³, neutral medium and very low hardness. Water composition according to the classification by O A Alekin (1953) predominantly SO₄-Mg-Ca. No exceedance of MAC_FP values for the studied hydrochemical parameters were revealed.

The investigated water of the Yana river in the area above and below the Batagai settlement, as well as its channel, is also characterized by low mineralization, neutral medium and very low hardness. The ionic composition of water is dominated by SO₄-Mg-Ca. Exceedance of MAC_FP in the water of the Yana: the Yana above Batagai – Mn (up to 1.2 times), Fe (up to 10.0 times); the channel of the Yana near Batagai – Fe (4.8 times); the Yana downstream of Batagai – no exceedance of MAC_FP was revealed.

Section of the river Yana above and below the confluence of the Adycha is characterized by low mineralization up to 36.3 mg/dm³. The water has neutral medium and very low hardness, the composition is mainly SO₄-Ca-Mg. The MAC_FP exceedance – for Fe up to 1.6 times in the area above the mouth of the Adycha.

In the Adycha basin several areas were explored, including 4 of its tributaries – the Sentachan, the Sorevnovanie, the Nelgesya, and the Charky. The Adycha is the right tributary of the Yana. The length of the river is 715 km. The basin area is 89.8 thousand km². The source of this river is located on the southern slopes of the Borong ridge at an altitude of 1,815 m. On the first 15 km, the water level drops to 1,150 m. In the upper reaches of the river it flows in a deep canyon with rocky walls 100–120 m high, skirting the Nendelginsky ridge on the left. Below there is an alternation of wide (up to 2 km) and narrow (150-200 m) sections of the valley with steep rocky slopes. On the chemical composition of the Adycha, which before the confluence of the Sentachan is characterized as hydrocarbonate-magnesium influenced by the waters of its tributar ies, in the basins of which mining operations are carried out to develop mineral deposits (the Sentachan, the Sorevnovanie).

Water of the Adycha after the confluence with the Sorevnovanie remains low mineralized with a slightly alkaline medium and very low hardness. The composition of the water is predominantly HCO₃-SO₄-Mg-Ca. Exceedance of MAC_FP in the water of the Adycha below the confluence of the Sorevnovanie was not identified. The water of the Adycha above the mouth of the Nelgesya has a low mineralization with a slightly alkaline medium and very low hardness. SO₄²⁻ and HCO₃⁻ dominate in the anionic composition of water, and Ca²⁺ and Mg²⁺ in the cationic composition. Exceedance of MAC_FP is noted only for total iron up to 5.7 times.

In the section of the Adycha (above and below the mouth of the Charky) the water is characterized by low mineralization with slightly alkaline medium and very low hardness. The composition of the Adycha according to the classification by O A Alekin (1953) predominantly HCO₃-SO₄-Mg-Ca. Exceedance the MAC_FP standards was revealed for manganese up to 1.4 times at the observation point below the mouth of the Charky. The rest of the indicators do not exceed MAC_FP or below the detection limit of the analysis. The Charky is the right tributary of the Adycha. During the study period, it is characterized by low mineralization with slightly alkaline medium and very low hardness. The suspended solids content is 23.0 mg/dm³. The composition of the Charky according to the Alekin’ classification is HCO₃-SO₄-Ca. No exceedance of MAC_FP for the studied hydrochemical parameters were revealed.
In addition to the background areas of the basin of the upper reaches of the Yana, 2 local areas were explored, where the Lazo and Sentochar gold placer deposits are being mined. The characteristics of the chemical composition of waters are presented below.

Site “Lazo”. The Nelgesya is characterized by low mineralization with slightly alkaline medium and very low hardness. The concentration of suspended solids reaches 48.0 mg/dm³. The composition of the Nelgesya’ water is different and has a chloride-calcium-magnesium composition. This tributary is characterized by a different chemical composition due to an increase in the proportion of chlorides and sodium in the ionic composition. Exceedance of MACFP in the Nelgesya was recorded only for copper – up to 2.0 times.

On the site “Sentochar” the Sentochar’ water has a low mineralization with a slightly alkaline medium and very low hardness. There is a very high content of suspended solids, reaching up to 365 mg/dm³, which is on average 2 times higher than the concentration in the water of the Adycha. The composition of the water is predominantly sulphate-calcium-magnesium. Exceedance of MACFP was revealed for manganese up to 1.4 times, for copper up to 2.0 times and total iron up to 7.7 times. Thus, when carrying out mining operations in the basin of the river Adycha, an increase in the proportion of sulphates in the water is observed, as well as an increase in the concentration of suspended solids, total iron and manganese.

In general, the main factors in the formation of the chemical composition of surface waters on the territory of Yakutia are: lithology of the constituent rocks, climatic features, relief, the presence of groundwater and permafrost. The background hydrochemical composition of surface waters in the study area is diverse: from hydrocarbonate-sodium and chloride waters in the West to hydrocarbonate waters in the North-West and hydrocarbonate-sulphate waters in the North-East of Yakutia. In the microelement composition of surface waters, high concentrations of total iron, manganese, and copper are found everywhere, which indicates their natural origin. In places where the influence of groundwater is observed, the characteristic elements are lithium, strontium and barium.

4. Conclusion
Analysing the literature and stock materials, we can say that each mining enterprise has its own specifics of influence on surface waters, which makes its own adjustments to the chemical composition of surface waters. In the places where licensed areas of various natural resources are developed, an increase in the concentration of the main ions is observed, which leads to an increase in the value of mineralization, as well as an increase in the content of suspended solids and a change in pH values. The microelement composition of waters (with regard to the influence of the diamond mining industry) is characterized by the presence in surface waters of strontium, lithium and barium – for Western Yakutia; total iron and zinc – in North-Western Yakutia (due to placer diamond deposits). The gold mining industry is characterized by high contents of total iron, sulphates and manganese in the Adycha river basin (North-Eastern Yakutia). However, their distinctive feature is their local distribution and a constant spectrum of elements that form a natural anomaly.

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