Geoecological assessment of the Vilyuy river state under technogenic impact conditions of the diamond mining industry

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Abstract. The article presents the preliminary results of the study of surface waters and bottom sediments of the rivers Irelakh, Malaya Botuobiya and Vilyuy after the technological accident in August 2018. In general, after the accident burst of the dredging site on the Irelakh deterioration of water quality in the Vilyuy by organoleptic characteristics (chromaticity up to 20 MPC, turbidity up to 61 MPC), as well as the most important indicators such as BOD5 (up to 3.9 MPC) and COD (4.5 MPCvr, 2.2 MPC) is detected. High concentrations of suspended solids, turbidity and chromaticity are observed in the channel of the Vilyuy below the mouth of the Markha in the period 02-03 September 2018, where the bulk of the polluted water passed. In the trace element composition of water, the main pollutants are total iron (up to 22 TLV f.w., 7.5 MACw), manganese (up to 12.6 TLV f.w.), aluminum (up to 32.3 TLV f.w., 6.5 MACw) and copper (up to 37 TLV f.w.)

1. Introduction
The River Vilyuy is one of the largest waterways in the Sakha Republic (Yakutia). Industrial facilities of the diamond and gas industry are located in the river basin (Figure 1). In addition, in the basin of the Vilyuy there are 28 settlements of Mirny, Suntarsky, Nyurbinsky, Verkhnevilyuysky, Vilyuysky districts.

The creation of the Vilyuysky Reservoir, the largest man-made reservoir in the North-East of Russia, unparalleled anywhere in the zone of multiyear frozen ground, and its operations for 40 years, as well as the industrial activities of the diamond-mining companies caused a significant transformation in the structure and life of the Vilyuy valley ecosystems and surrounding areas. There was a sharp negative change in the chemical composition of river water caused by flooding of the reservoir bed without preliminary logging and forest cleaning, as well as huge volumes of highly mineralized water discharges from the diamond industry until the early 90s of the twentieth century [1].

On 19 August 2018 on the river Irelakh as a result of a technogenic accident because of significantly higher average precipitation, a dam burst at the Irelakhskaya placer deposit which belongs to the PJSC ALROSA (Figure 2). Water bodies of the rivers Irelakh, Malaya Botuobiya, Vilyuy and Lena were polluted.
Pollution of the rivers Irelayakh, Malaya Botuobiya and Vilyuy seriously affected the provision of clean drinking water to the population and, in general, the ecological situation in the Vilyuysky group of regions. On 27 August 2018, a regime of high alert was announced, it was banned to use the water from the river Vilyuy as a surface source of water supply and it was decided to switch to alternative water supply sources. Thus, at the present the basin of the Vilyuy is one of the most exposed to man-made impact areas of the Sakha Republic (Y).

Surface water. Before the accidental break of the dam of the dredging site on the Irelayakh, the water of the Vilyuy differed by its insignificant mineralization and hydrocarbon composition due to easily soluble salts of soils and sediments of the layer and seasonal thawing in the drainage basin. The major tributaries of the Vilyuy were also characterized by low mineralization throughout the year. Their chemical composition was usually dominated by hydrocarbonates and calcium. The exceptions were some right tributaries (the rivers Kempendyai and Baga), in the basins of which there are powerful outflows of highly mineralized (up to brines) waters with a predominance of sodium ions and chlorides. In the middle reaches, the mineralization of water used to increase and during the spring flood and summer rain floods it was 30-80 mg / l, at the end of the winter low-water period it was 300-500 mg / l. The ionic composition of water in this section of the river during the spring floods and rain floods was determined mainly by the composition of surface waters, and therefore it was characterized by a well-pronounced predominance of hydrocarbonate ions and calcium. A significant role was played by magnesium ions. In the years with the lowest water content for the indicated periods, the ionic composition of the river water could significantly increase the content of chloride ions, respectively the role of hydrocarbonate ions and calcium reduced. As the value of groundwater in the
river feed increased, the relative content of hydrocarbonate and calcium ions decreased and the content of chloride and sodium ions with potassium increased [2].

During the spring floods, the water throughout the river was very soft, during the period of rain floods it remained very soft in the upper reach, in the middle and lower reaches it was often soft. During the winter low water period it was soft and moderately hard. The pH of the water throughout the river varied during the year from 6.0 to 7.2. In the spring-summer-autumn period leaching aggressiveness was typical for the water throughout the river and carbon dioxide aggressiveness was typical throughout the year. The color of water reached the highest values during the spring floods and was 80-210 degrees of chromaticity. During the winter low water period, it decreased to 55-100 degrees of chromaticity. The permanganate oxidation rate during the spring floods period was 22–40 mg O₂ / L in the middle reaches of the river, 15–29 mg O₂ / L in the lower reaches, and decreased to 11–23 and 12–27 mg O₂ / L in the winter period, respectively. Biogenic compounds in water were characterized by the following values: nitrate ions reached 0.75 mg / L in all water regime phases throughout the river, nitrite is 0.03 mg / L, phosphate was 0.026 mg / L, iron was 0.22 mg / L, silicon was 10 mg / L. From the trace element composition of water, the average copper content was 0.0015-0.003 mg / L, total iron was 0.2-0.4 mg / L. The content of phenols, anionic surfactants and petroleum products in recent years has not exceeded the standards of maximum permissible concentrations for fisheries purposes [3].

2. Models and Methods

In the post-technogenic period (after an accident break) in September, the RAEN NEFU staff organized 2 integrated expeditions to study the chemical composition of the waters of the Vilyuy:

- Stage 1: from September 02-03, 2018 in the area of the Viluy from the mouth of the river Botomoyu to the mouth of the river Tyukian. A total of 21 observation points were investigated.
- Stage 2: from 14 to 20 September 2018 the Irelyakh (above and below the dredging site, the mouth part), the river Malaya Botuobia (above and below the mouth of the Irelyakh, the mouth part), the Vilyuy on the site from the mouth of the river Malaya Botuobiya to the settlement of Kysyl Syr. Total 28 points were tested.

All chemical and analytical works were carried out in three laboratories of Yakutsk: Republican State Institution of Biology of the Sakha Republic (Yakutia) "Republican Information and Analytical Center for Environmental Monitoring" (State Enterprise RIACEM) (accreditation certificate No.ROSS RU.0001.516624 of 10.27.2014) FBHI "Center for Hygiene and Epidemiology in the RS (Y)" (FBHI CH and E in the RS (I)) (accreditation certificate RA.RU.510330 from 07.15.2016); Laboratory of Physical and Chemical Methods of Analysis of RAEN NEFU (LPCMA RAEN NEFU) according to generally accepted methods.

3. Results and Discussion

According to the results of research stage 1 in the area of the Vilyuy from the mouth of the river Botomoyu to the mouth of the river Tyukian surface waters have a neutral and slightly alkaline environment. On the studied sites of the Vilyuy ion composition of water according to O A Alekhin classification (1953) [4] is heterogeneous.

Most of the investigated waters are mainly of the hydrocarbonate class of the calcium and magnesium groups. The dominant role of chlorides and sodium in the ionic composition of the waters of the Vilyuy observed in the area above and below the mouth of the river Botomoyu, as well as below the mouth of the river Markha. There is no excess of MAC standards for fisheries purposes and domestic water supply for the main ions. The investigated waters of the Vilyuy in this area have predominantly low mineralization (up to 190 mg / L) with soft water. The BOD₅ value in the studied waters varies from 6.0 to 11.8 mg O₂ / L, which exceeds the standards for maximum permissible concentrations for fishery purposes (hereinafter TLV f.w.) up to 3.9 times and the standard for household and community water use of HS 2.1.5.1315-03 (hereinafter MACw) up to 3.0 times. COD value in the waters of the Vilyuy is in the range of 52-67 mg / L, which also exceeds the TLV f.w.
standards by 4.5 times and the MACw to 2.2 times. The concentration of suspended substances of water of the Vilyuy in the studied area ranges from 14.0 (mouth of the Botomoyu River) to 105.8 mg/L, averaging 37.3 mg/L. The indicator of water color varies from 93.8 (mouth of the river Botomoyu) to 398 degrees. chromaticity (average content - 177.83 degrees of color), which exceeds the standard of drinking water according to HS 2.1.4.1074-01 up to a maximum of 20 times, an average of 8.9 times. The turbidity of the water in the studied waters is within 5.2 (mouth of the Botomoi River) to 157.5 FMU (on average, to 22.9 EFY). Exceeding the standard of drinking water according to HS 2.1.4.1074-01 is a maximum of 61 times, on average, up to 8.8 times. The maximum content of suspended solids and high color, turbidity are observed in the channel of the Vilyuy on the site below the mouth of the river Markha, where the most severe water pollution was recorded. High levels of color and turbidity significantly impair the organoleptic properties of drinking water from the river Vilyuy. The high contents of some elements closely correlate with the maximum concentration of suspended matter in water.

According to the results of the study, it was found that the content of lithium, strontium, barium, thallium, arsenic, silver, cobalt, molybdenum, vanadium is below the detection limit of the analysis. Concentrations of lead, nickel, cadmium, zinc, chromium and silicon are within the limits of TLV f.w. and MACw standards.

TLV f.w. excesses are noted for total iron, manganese, aluminum and copper. On average, TLV f.w. standards for total iron exceed up to 10 times, for aluminum up to 14 times, for copper up to 3.6 times. Excess hygienic standards for drinking water are observed on average for total iron and aluminum up to 3.3 and 2.8 times, respectively. The maximum excess of the standards of maximum permissible concentrations for fisheries and drinking purposes is observed at the site below the mouth of the river Markha, where there is contaminated water with high concentrations of suspended matter.

From the organic compounds the content of petroleum products and phenols are within the standards of maximum permissible concentrations for fishery and household drinking purposes.

Due to the high content of BOD₅ and COD, the most important indicators indicating water pollution with organic substances, additional samples were sent to the Chemical Analytical Center "Arbitrage" of the FGUP “D.I. Mendeleev VNIIM" to estimate a number of organic compounds. As a result of studies of water samples from the Vilyuy the following substances have been found: alcohol esters (glycerol diacetate + glycerol triacetate, butyl citrates), fatty acid amides (palmitylamide, oleylamine, stearylamide), anionic surfactants, nonionic surfactants and cationic surfactants. According to the experts of the above mentioned center, these compounds are likely to be components of collectors and blowing agents used for the flotation of mineral raw materials. For more reliable information, background information on the technological process of the dam landfill "Irelyakhskaya alluvial gold” is needed. In the future, the above indicators can serve as indicators of the impact of the dredging site on the components of the ecosystem of the Vilyuy.

According to the results of stage 2, the surface waters of the studied watercourses have a neutral and slightly alkaline environment. The value of mineralization varies in the range of 56-122 mg/dm³, which corresponds to the waters of low mineralization.

In the ionic composition of the water of the Irelyakh the dominant role of sulfates and chlorides is noted, as well as increasing proportion of sodium below the dam of the dredging site and it can be traced to the mouth of the studied watercourse. In the water of the Malaya Botuobiya after the confluence of the Irelyakh dominance of sulfates and chlorides is observed and an increase in the proportion of sodium in the ionic composition. In the mouth of the Malaya Botuobiya, the composition of water changes mainly to the hydrocarbonate class of the magnesium and calcium group.

In the Vilyuy from the mouth of the Malaya Botuobiya to the settlement Suntar the water composition is homogeneous, also hydrocarbonate class of the magnesium and calcium group, except for the section of the rivers near the villages of Kuokunu and Tenke, where there is an increase in the sodium and chloride proportion. Further down the Vilyuy near the settlements of Elgyai and Arylakh of the Suntarsky District, a change in the composition of water is observed due to an increase in the
proportion of sulfates and sodium. Perhaps due to their introduction with the waters of the right tributary Kempenday.

Near the settlement of Verkhnevilyuysk a different composition of the Vilyuy’s water is recorded, different from the rest of the studied sites, here the dominant role of chlorides and sodium is noted. The trace of chlorides and sodium is revealed up to the settlement of Khomustah of Verkhnevilyuysky district. Around the town of Vilyuysk and Kysyl Syr, the composition of the water is predominantly of the hydrocarbonate class of the magnesium and calcium group.

In general, no exceeding the maximum permissible concentrations for fishery and drinking purposes for the main ions was found.

The concentration of suspended solids on average (according to averaged data from 2 laboratories) in the water of the Vilyuy reaches up to 9 mg / L, chromaticity up to 105 degrees, turbidity up to 6 FTU. Indicators of chromaticity, turbidity and suspension content decrease in the area where the river Markha confluences to the Vilyuy. Further downstream, near the settlement Verhnevilyuysk increase in the values of these indicators is observed. On average, the maximum permissible concentration of MACw in color is up to 5.2 times, in turbidity up to 2.3 times. Maximum exceedances are observed in chromaticity up to 6 times in the Malaya Botuobiya below the mouth of the Irelyakh, turbidity up to 5.8 times in the Irelyakh below the dredging site.

The trace element composition of the water contains lead, cadmium, cobalt, chromium, zinc, arsenic, silver, lithium, barium, strontium, molybdenum and vanadium below the detection limit of the analysis or is within the limits of TLV f.w. and MACw standards. The dynamics of changes in the contents of manganese, aluminum, total iron and copper in the Irelyakh-Malaya Botuobiya-Vilyuy system are presented in figures 3-4.

![Figure 3](image-url)

**Figure 3.** Dynamics of changes in the content of manganese and aluminum in the rivers Irelyakh, Malaya Botuobiya and Vilyuy from September 14 to 20, 2018.
On average, manganese concentrations exceed TLV f.w. standards up to 4 times, aluminum up to 1.1 times, iron up to 5.2 times and copper up to 10 times. Maximum excess is observed in manganese to 8.7 TLV f.w. in the Malaya Botuobiya above the mouth of the Irelyakh, for copper up to 20 TLV f.w. at the mouth of the Irelyakh, on aluminum up to 5 TLV f.w. in the Vilyuy near the settlement Suntar of the Suntarsky District, for total iron up to 13 TLV f.w. in the Malaya Botuobiya.

![Figure 4](image1.png)

**Figure 4.** The dynamics of the concentration changes of total iron and copper in the rivers Irelyakh, Malaya Botuobiya and Vilyuy in the period from 14 to 20 September 2018.

Exceeding the MAC standards for domestic water supply is detected for the total iron on average up to 1.7 times. Thus, high concentrations of the above elements, except for aluminum, are observed in the region of the confluence of the Irelyakh and the Malaya Botuobiya. These elements correlate well with the values of suspended solids indicating the introduction of these indicators with polluted water after the dam burst.

From organic compounds, the content of petroleum products and phenols are within the norm. Concentrations of anionic surfactants are 0.06 mg / L by an average, which does not exceed the MAC_w standards.

Bottom sediments. Most of the bottom sediments of the basin of the Vilyuy have a neutral and slightly alkaline environment; the content of organic carbon varies from 0.19 to 12.6% of the mass (average 1.5% of the mass). A high content of organic carbon is observed at point T-1 (the Irelyakh above the dredging site).

In the salt composition of bottom sediments of the Irelyakh is dominated by sulfates and calcium, the proportion of bicarbonates and chlorides and magnesium is insignificant. In the bottom sediments of the rivers Malaya Botuobiya, Markha and Vilyuy the ion composition is homogeneous: the share of
hydrocarbonates is 16-19%, sulfates - 11-16%, chlorides - 17-23%, calcium - 18-22%, magnesium - 7-19%, sodium + potassium - 12-20%.

The largest variation of accumulation of trace elements was found in the Irelyakh above the dredging sites, which is probably due to a high content of organic carbon (12.6% wt.). An accumulation of copper, cobalt, nickel and manganese is observed below the dam of the dredging site; no excess of the local geophone was recorded in the estuary part of the Malaya Botuobiya above the mouth of the Irelyakh also revealed no excess of the local geophone, the accumulation of a number of elements is noted at a point below the mouth of the Irelyakh (cobalt, nickel, manganese) and in the mouth of the watercourse (copper, arsenic, lead and manganese). In the bottom sediments of the Vilyuy the greatest variation in the accumulation series is noted at six observation points - T-7 (the Vilyuy above the mouth of the Malaya Botuobiya), T-13 (the Vilyuy above the village of Kuokunu, Suntarsky District), T-18 (the Vilyuy above the village of Elgyay, Suntarsky district), T-19 (the Vilyuy above the village of Arlyakh, Suntarsky district), T-21 (the Vilyuy above the town of Nyurba), T-24 (the Vilyuy above the village of Khomustakh). The accumulation of copper, manganese, lead, iron, cobalt, cadmium and zinc is noted here.

4. Conclusion

In general, after the accident burst of the dredging site on the Irelyakh deterioration of water quality in the Vilyuy by organoleptic characteristics (chromaticity up to 20 MPC, turbidity up to 61 MPC), as well as the most important indicators such as BOD₅ (up to 3.9 MPC) and COD (4.5 MPCvr, 2.2 MPC) is detected. High concentrations of suspended solids, turbidity and chromaticity are observed in the channel of the Vilyuy below the mouth of the Markha in the period 02-03 September 2018, where the bulk of the polluted water passed.

In the trace element composition of the water of the Vilyuy significant changes are not observed. The ionic composition of water of the Vilyuy at certain sites is heterogeneous. The dominant role of sulfates and sodium is observed in the area of the rivers Irelyakh and Malaya Botuobiya, as well as on the Vilyuy after the confluence of the Kempendyay, the dominant role of chlorides is observed on the Vilyuy at the mouth of the Botomoyu and below the mouth of the Bychyrdan.

In the trace element composition of water, the main pollutants are total iron (up to 22 TLV f.w., 7.5 MACw), manganese (up to 12.6 TLV f.w.), aluminum (up to 32.3 TLV f.w., 6.5 MACw) and copper (up to 37 TLV f.w.). These elements correlate well with the values of suspended solids, indicating the introduction of these indicators with polluted water after bursting of the dam. Extremely high concentrations of iron, manganese, aluminum and copper adversely affect not only the human body, but also are very toxic to ichthyofauna, the consequences of which will be observed after some time.

In addition, the identified anionic surfactants, cationic surfactants, nonionic surfactants, and mid-volatile organic compounds may also have been introduced by the waters from the dredging site. Detailed information about the dredger test site process would give a more reliable picture of the origin of these indicators. Further study of these indicators is necessary not only in surface waters, but also in floodplain soils and bottom sediments.

References

[1] Savvinov D D 1991 Ecology of the river Vilyuy (Yakutsk: YSC SB RAS) p 119
[2] Surface water resources of the USSR Leno - Indigirska area 1972 (Leningrad: Gidrometeizdat) 17 651
[3] Ageev V I 2007 Rivers and lakes of Yakutia (Yakutsk: Bichik) p 132
[4] Alekin O A 1953 Basics of hydrochemistry (Leningrad: Gidrometeoizdat) p 122