Ecological-geochemical investigations of dust emissions over the aldan mining node area (Sakha Republic, Yakutia) by studying the snow cover

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Abstract. Since the first time of its exploration (1924), the Aldan District, being an administrative and territorial unit of the Sakha Republic (Yakutia) of the Russian Federation, has become one of the largest and most developed mining areas in Yakutia. Here deposits of molybdenum, uranium, iron, chemical raw materials, fluorite, phlogopite, construction materials, gems and semi-precious stones, as well as ground waters, are concentrated. Due to its unique richness in terms of its natural resources, the territory has been the subject of intense economic development, which could not but have negatively impacted the ecological situation in the natural environment including, in the first place, in the residential areas. A snow cover geochemical survey was carried out over the Aldan District in order to assess the changes in the geological environment (as an ecosystem component) under the influence of natural and technogenic factors. The studies covered an area of 8600 km². The analysis of the total chemical composition of snow water as well as solid and soluble snow cover components not only allowed the background parameters to be characterised, but also made it possible to establish the distribution areas for the anomalous concentrations of pollutants as well as reveal the sources of their formation. Two large nodes of technogenic pollution having areas of 320 km² and 220 km² respectively were identified in the studied area along with a number of smaller sites. The mapped nodes and sites are formed as a result of the activities of mining complexes, transport enterprises and residential areas. On the basis of the results of the snow geochemical survey, it can be concluded that regional (long-range) pollution in the district is absent.

1. Introduction
The Aldan District is located in the Southern part of the Sakha Republic (Yakutia) and occupies a significant part of its territory. Its area comprises 156.8 thousand km², comprising a population of 39858 persons as of January 1, 2017. The district has 19 residential areas. The main residential locations in the area under study are: the city of Aldan (population of 20,700 as of January 1, 2017) and the townships of Nizhni Kuranakh, Verkhny Kuranakh, Leninsky, Lebediny, Yakokut, Orochon, Bolshoy Nimnyr, Yakokit, Khatystyr and Ugoyan (Fig. 1). The basis for the mineralogical wealth of the Aldan District consists in gold, phlogopite, graphite, apatite, vermiculite, molybdenum, uranium, rock crystal, rough semi-precious stones and groundwater. Recently, some other kinds of mineral raw materials such as platinum, marble and construction materials have been the object of active
exploration. Despite the wide range of mineral resources, the economy of the district is primarily associated with the exploitation of gold deposits. In the valleys of rivers and streams, the alluvial gold is mined both by dredging and selective mining methods. Ore gold is extracted using different versions of cyanidation technology.

Figure 1. The survey map of the area under study.

The almost century-long exploration of natural resources in this territory, especially gold ore deposits, has determined the need for extensive geochemical research and cartographic mapping with the purpose of obtaining the information on the current state of the geological environment, the sources and extent of pollution, and the degree of technogenic impact on the environment.

The primary objects of the geochemical study include depositing (soil, snow and vegetation cover, bottom sediments of watercourses and water reservoirs) and transporting (surface water) environments. However, the most informative object in the detection of atmospheric technogenic pollution is the snow cover [1-2, 4, 6, 15-18, 20]. In the territory under study, the permanent snow cover is established at the end of September and remains for 220-230 days, reaching 1.5 m in thickness in some places. Possessing high sorption capability, the snow captures an essential part of technogenic products and accumulates them over the course of the winter period. The chemical composition of the snow cover is made up both by the input of various chemical elements associated with solid sediments as well as the absorption of gases, vapours and aerosols.

2. Methods and the Content of Works

According to the snow cover testing data, the following main pollution indicators were determined [10]: 1) Dust load \((P_d)\) – the mass of dust falling per area unit over a certain time interval (kg/km\(^2\) – days or kg/km\(^2\) for the winter period); 2) the concentration coefficient of the chemical element \((K_c)\), which is calculated as the ratio of the element content in the investigated object relative to its background content and characterises the intensity of the technogenic impact; 3) the distribution of chemical element associations, whose quantitative measure is the total pollution index \((Z_t)\). The \(Z_t\) index characterises the impact of the chemical element group on the environment (Table 1). Since technogenic anomalies, as a rule, have a polyelemental composition, then:
\[ Z_c = \sum_{i=1}^{n} K_k - (n - 1) \]

where \( n \) is the number of anomalous chemical elements.

**Table 1.** Scale of environmental pollution assessment [11].

| The level of environmental pollution | The degree of pollutant concentration |
|-------------------------------------|--------------------------------------|
| Minimal                            | Tolerated |
| Weak                               | Moderately dangerous |
| Medium                             | Dangerous |
| High                               | Extremely dangerous |

| Pollutant | Concentration | Tolerated | Moderately dangerous | Dangerous | Extremely dangerous |
|-----------|---------------|-----------|----------------------|-----------|--------------------|
| \( P_d \), t / km² | < 2 | 2-10 | 10-20 | 20-100 | >100 |
| \( Z_c \) (solid phase) | < 32 | 32-64 | 64-128 | 128-256 | >256 |
| \( Z_c \) (soluble phase) | < 32 | 32-64 | 64-128 | 128-256 | >256 |

The main task of geochemical studies of environmental pollution nature is to identify geochemical anomalies. One of the main characteristics of a geochemical anomaly is its intensity, which is determined by the degree of accumulation of the pollutant element in comparison with the natural background [5, 11-14, 19]. In this regard, the correctness of the background determination acquires great significance since it is with respect to this that the \( K_k \) and \( Z_c \) geochemical indicators are calculated.

The study of the background snow cover parameters of the area under study was carried out at definitively “clean” areas in 1991, 1994, 1996 and 1998 across the specific profiles and areas. The obtained data were further compared with the results of sampling carried out on the territories of mining and processing enterprises, mines, farmlands, places of compact settlement of people, etc. The list of sites selected as a reference for the detailed studies is indicated in Table 2 (Figure 2). The testing was carried out at the end of the stable snow cover season before the beginning of thawing, intensive granulation and compaction of snow (in the second half of March). The macro- and micro-component composition as well as the slag particles of solid and soluble snow constituents were determined in analytical laboratories.

**Table 2.** List of key sites.

| No | Site name | Area, km² | Location |
|----|-----------|-----------|----------|
| 1  | Tobuk     | 32        | Middle flow of the Khatystyr-Yuryakh stream (right tributary of the Aldan River) |
| 2  | Nimnyrsky | 24        | Middle flow of the Bolshaya Nimnyr River |
| 3  | Yukon     | 22        | Interfluve of the Talaya and Yuhukhta rivers |
| 4  | Zarya     | 5         | Watershed of the Left Yllymakh - Yakokit rivers |
| 5  | Seligdarsky | 8     | Floodplain and terraces of the Aldan River right bank (below the estuary of the Seligdar River) |
| 6  | Aldansky  | 127       | Around the city of Aldan |
| 7  | Nizhny Kuranakh | 244 | Territory of the Kuranakhsky ore mining and processing enterprise activity (gold recovery factory, quarry, tailing dump, heap leaching sites, technological transport base, township) |
8. Lebedinsky  50 Territory of the “Lebedinya” mine (gold recovery factory, quarries, mines, tailing dump, township)
9. Koltykonsky  24 Territory of extraction of ore and placer gold (adits, trial pits, quarries, prospecting sites, heap leaching sites)
10. Samolazovskiy  9 Territory of geological exploration, preparation for the ore gold deposit exploitation
11. Yakokitsky  10 Farmland

3. Results
As a result of the snow geochemical survey, two major technogenic pollution sites were identified in the studied area: Aldansky (320 km²) and Kuranakhsky (220 km²), along with a number of smaller sites [16].

The scale of natural environment technogenic contamination is most clearly expressed in the contamination scheme of the snow cover represented in Figure 2.

Figure 2. Snow contamination map.

Figure 3. Pollution of the environment (Zc) left – solid phase, on the right – soluble phase
The macro-component (total chemical) composition of snow water from the territories of technogenic objects is characterised by a low content of \( \text{Ca}^{2+}, \text{HCO}_3^2 \), Si \((K_k = 1.5-2, 2)\) and a more noticeable accumulation of \( \text{Mg}^{2+}, \text{F}, \text{NO}_2^- \) and \( \text{SO}_4^{2-} \) \((K_k = 2.8-5)\). A small degree of response to contamination is indicated by the value \( Z_c = 10-25 \). However, the obtained values of the dust load indexes \((P_d)\) indicate widespread and intense air pollution. The dustiness of atmospheric air increases up to 200 times (from 0.23 to 49.9 t/km\(^2\) or 1,4-280 kg/km\(^2\) days) as compared to the background environment in the territories of the main pollution foci - the city of Aldan and the town of Nizhny Kuranykh. It is characteristic that the fraction of solid dust particles in the total volume of pollutants reaches 90-95\% (Figure 4).

The study of the microcomponents of the snow cover solid phase (slags, Figure 3) allows the recorded pollution level to be considered not only as extremely high, but also environmentally hazardous \((Z = 500-10000)\). A group of widely distributed pollutants that can accumulate in the snow cover up to critical thresholds is formed by Zr, Al, Si, P, Ti, Mo, Fe, less often by W, Ga. An intensive accumulation of heavy metals in snow water (soluble phase) is also observed. The degree of contamination is noticeably weaker than in the solid phase but nevertheless reaches high and very high levels. The range of anomalously soluble chemical elements is also wide. The most noticeable contribution to pollution is made by Ga, V, Mo, Mn, Pb, Fe, Ag, Ce, Co.

When comparing the snow contamination indicators for the solid and soluble phases, the following facts are noted. Within the allocated large pollution nodes, anomalous concentrations of chemical elements are inherent in both the solid and soluble phases.

Nevertheless, in some cases, the pollution of snow water is either not fixed (the village of Bolshoy Nimnyr) or is poorly developed (the village of Lebediny). Most likely, the observed differences in the snow cover contamination depend on the nature of the pollution source (the predominance of dust or salt atmospheric constituents).

In general, it can be concluded on the basis of the results of the snow cover geochemical survey that regional (long-range) pollution in the district is absent. However, in the mapped nodes and areas, especially contrasting by the dust load, high concentrations of a significant number of chemical elements are formed as a result of the activities of mining complexes, transport enterprises and residential areas.

4. Conclusions

In most cases, the recorded contamination of the investigated area is due to the presence of “disturbing” objects, both natural or technogenic, as well as, more typically, of combined origin. The territory under study is highly saturated with various deposits of a number of mineral resources, which ores contain high (ecologically dangerous) concentrations of many chemical elements, including radioactive. While there are significant areas of concentrated natural pollutant distribution, in some cases, exceeding environmental standards, the technogenic pollution is generally much more intensive and covers relatively small areas. The dust pollution of the air basin (ground surface layer) is considered as the main specific feature of anthropogenic activity in the studied area. In connection with the long and continuous technogenic impact on the natural environment, as well as the prospects for industrial development of the region for the near future, further deterioration of the ecological situation in the Aldan District can be expected.

The work was prepared on the basis of the geo-ecological survey report of the Aldan mining complex at 1:200000 scale (Responsible Executive A.V. Luparev).

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