Assessment of Air Basin Pollution within the Limits of the Technogenic System (Dalpolimetall) Impact Using Mathematical Modeling

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Abstract. The article presents the results of research of air technogenic pollution within the limits of the natural-mining system impact formed by Dalpolimetall mining-metallurgical enterprise activity in the Primorsky Krai. Its development is due to intensive polymetallic ore development and accumulation of significant amount of its processing toxic waste, stored in two tailing dumps, located at the area of 80 hectares, withdrawn from the forest land fund, their volume being 32.2 mln tons. The studies found that in general the waste on the surface of the tailing dump is of the second class of danger (high-hazard), which is currently in the stage of active formation, being a powerful negative impact factor for the environment. The study of the air pollution degree, carried out by gas survey on transversal profiles, shows that the largest number of different heavy metal compounds is contained in the dust selected for analysis near the tailing dump. Its maximum concentration, reaching 86 MAC, was revealed near the concentrating factory. The average concentration throughout the territory of the object under study is 38 times higher than the allowable limits. High concentrations of carcinogenic elements (arsenic, chromium and antimony) are found in the dust samples. The assessment of the air basin impact carried out by the method of computation monitoring using GIS-technology and the Ecologist Software, allows to assert that its pollution by mineral processing waste within the limits of Dalpolimetall impact in Dalnegorsk refers to an extremely high level for toxic dust, heavy metal compounds and sulfate-ion aerosols. The results of the research of air basin technogenic pollution using mathematical modeling allowed to reveal spatial and temporal regularities of the main pollutants distribution.

1. Introduction
At present, the scale of technogenic atmosphere pollution in the process of intensive development of mineral resources in the Far Eastern Federal District (FEFD) and the destabilizing pollutants impact on the eco-sphere are constantly increasing. The accumulation of a large amount of toxic mineral processing wastes stored in the tailings, has caused a crisis ecological situation. However, the existing methods of assessing their impact on environmental objects require deep scientific substantiation for effective mining and environmental monitoring algorithms. Solving these problems, it is important to develop new principles and methods of environment assessment, study the regularities of atmosphere
and biosphere interaction, taking into account the mining enterprise production activity. In this regard, the urgency of the problem is related to the need to conduct research using mathematical modeling of the pollutants transfer and accumulation using information technology, which will predict a level of technogenic pollution of ecosphere from pollution sources. Such systematical researches using mathematical apparatus under the conditions of mining enterprises in the FEFD have not been carried out. In this regard, the purpose of the study was to develop a methodology of geo-ecological assessment of the air basin within the boundaries of the technological system using mathematical modeling and GIS-technologies to create the methods of reducing the negative impact of tailing dumps toxic waste on the environment and human health. The following tasks are defined: 1. To analyze the literature sources on the problem of geoecological assessment of ecosphere under mining enterprises conditions; 2. To study the current state of the technogenic system formed by Dalpolpolmetal mining-metallurgical enterprise operations; 3. To propose methodical approaches to mathematical modeling of technogenic pollution of the air basin in the region under study.

2. Objects and methods of research
The object of research was natural-mining system, represented by toxic waste of polymetallic ore processing, stored in tailing dumps, components of the environment: air basin, snow cover, technogenic soils, vegetation, aquatic objects and human.

The research was carried out in 2014-2018 within the limits of the Dalpolimettal mining enterprise tailing dumps, near the city of Dalnegorsk of Dalnegorsky District, the Primorsky Krai. The following complex of the basic methods and techniques was used in work: system analysis and generalization of theoretical and experimental researches, scientific forecasting, GIS-technologies, cartographic and mathematical modeling, statistical processing of empirical data. Modern instrumental and traditional physico-chemical, chemical and biological methods have been applied in the course of study.

3. Results and discussion
Accumulated great experience of collecting and analyzing information on the problem of the current state of the issues of ecosphere geoecological assessment, impact of mineral processing waste on the environment shows that there is no synthesis of this knowledge [1, 2 et al.]. Therefore, the existing methods of assessing the impact of mining on environmental objects cannot provide full protection of the environment [3, 4 et al.]. Only bioindication methods using higher plants as test-objects will allow to estimate objectively technogenesis, connected with mining production [5-12 et al.]. At the present stage the problem of complex geoecological assessment of technogenic pollution impact on ecosystems and health of population of mining settlements has not been practically studied under conditions of mining enterprises in the Far Eastern Federal District. The basic regularities of pollutant migration in the environment objects have not been well-studied. This circumstance causes importance and urgency of the problem of geoecological assessment of ecosystems technogenic pollution. Our research shows that development of technogenic system is caused by intensive development of polymetallic ores and accumulation of toxic wastes of its processing in large quantity (32.2 mln. tons), stored in two tailing dumps on the area of 80 hectares. In general, the waste on the tailing dump surface is the second class of hazard (high-risk) and is a powerful negative factor of environment impact. It has been found that the largest number of different heavy metal compounds is found in the dust selected for analysis near the tailing dump. Its maximum concentration reaches 86 MAC. The average concentration on the whole territory of the object under research exceeded the norm by 38 times. High concentrations of carcinogenic elements (arsenic, chromium and antimony) are found in the dust samples.

Today, there is no single methods of calculating dust discharge from the emissions of surface sources into the atmosphere using of mathematical modeling [13]. Its fundamental aspects are formulated in the works of M. E. Berlyand, E.V. Genikhovich, R. I. Onikul, N. L. Byzova, A.H. Ostromogilsky, Yu. A. Anokhin and others. [14-17]. Their works reflect different types of models for assessment and forecast of atmospheric pollution and their classification. The main classification
characteristic is the character of the mathematical model – empirical or theoretical. Some models rely on the simplest reasoning when achieving compliance with experimental data, and the others are based on the fundamental equations of diffusion theory with a complex mathematical apparatus [18]. Many of the currently known mathematical models can be divided into three large groups: empirical, semi-empirical and theoretical models.

The models built on mathematical description of physical processes in the atmosphere are the main type of mathematical models describing the distribution of atmospheric air pollution. They are based on the solution of the turbulent diffusion equation.

The linearized model of pollutants distribution has a mathematical solution with uniformity of velocity space-wise vector projections and is given by the equation of parabolic type:

\[
\frac{\partial c}{\partial t} + u(t) \frac{\partial c}{\partial x} + v(t) \frac{\partial c}{\partial y} + w(t) \frac{\partial c}{\partial z} = K_x(t) \frac{\partial^2 c}{\partial x^2} + K_y(t) \frac{\partial^2 c}{\partial y^2} + K_z(t) \frac{\partial^2 c}{\partial z^2} - \lambda(t) \cdot c(t) + Q(t) \cdot \delta(t - t_k) \cdot \delta(x - x_k) \cdot \delta(y - y_k) \cdot \delta(z - z_k)
\]  

(1)

where \(Q\) is the mass of pollutant emitted at \(t = 0\) at the origin \((g)\); \(Q(t)\delta(x)\delta(y)\delta(z - z_k)\) – pollutant source function; \(K_x, K_y, K_z\) – components of diffusion coefficient \(K\) (\(m^2/s\)) for corresponding coordinate axes; \(u, v, w\) – projection of pollutant transfer rate \(U\) (\(m/s\)) for the corresponding coordinate axes; \(c\) – average concentration of pollutants (g/m\(^3\)); \(\lambda\) – rate of pollutants loss (runoff) (\(m/s\)).

The initial conditions are chosen by the content of the fundamental solution \(c(t_k, x, y, z) = 0\), at all points except the origin \(c(t, x, y, z) = 0\), if \((x, y, z) \rightarrow (\infty, \infty)\) [19].

In general the solution of the equation (1) expresses regularities of pollutants distribution in unlimited space, when coefficients of diffusion (turbulence) \(K_x\), \(K_y\), \(K_z\) and flow rate of pollutants \(\lambda\) are considered as known functions of time, and the velocity of moving the gravity center of the pollutants cloud in the direction of the respective axes is determined by the components of the wind vector \(u(t), v(t), w(t)\).

Since the pollutants diffusion is considered in the atmospheric boundary layer, their interaction with the bottom boundary of the layer is defined as follows:

\[
K_x \frac{\partial c}{\partial z} + w \cdot c + \beta \cdot c = 0, \quad \text{at } z = z_0
\]

(2)

\[
\lim_{x, y \rightarrow \pm \infty} c(t, x, y, z) = 0
\]

(3)

The position of the lower boundary \(z_0\) coincides with the height of the surface roughness layer. Upon reaching the lower boundary, the settling or weightless pollutants interact with it and their flow is either reflected, \(\beta = 0\) (\(m/s\)), or absorbed.

The solution of the equation (1) can be automatically transferred to the solution of the stationary equation \((ds/t = 0)\), which is in the form:

\[
u \frac{\partial c}{\partial x} + w \cdot \frac{\partial c}{\partial z} = K_y \frac{\partial^2 c}{\partial y^2} + K_z \frac{\partial^2 c}{\partial z^2}
\]  

(4)

When solving the equation (4), it is assumed that the pollutants diffusion exists only in the transverse and vertical direction to the transfer vector, and there is no scattering in the motion direction. In addition, the "a priori" it means that the processes of horizontal (y-axis) and vertical (z-axis) diffusion are independent. These assumptions simplify the task, but distort the very essence of the process. Therefore, a full analysis of the regularities of the pollutants distribution for stationary mode, can be obtained only from the fundamental solution of the unstationary equation (1).

If there is a limit of function \(Q(t)\) at \(t \rightarrow \infty\) and constantly active source \(Q(t) = Q(const)\), it is possible to get the corresponding equation of stationary pollutants distribution in the form (5):
This fundamental solution of the equation of turbulent diffusion in the form of a formula (5) is general in comparison with other solutions which are special cases, for example, it can be simplified to the known formula of Gaussian diffusion model. If \( K_x = K_y = K_z \), then performing transformations and defining scale coefficients in each of the equations (5), the formula of the Gaussian diffusion model (6) is obtained:

\[
\begin{align*}
\frac{Q}{2\pi \sigma_y \sigma_z} \left( \exp \left( - \frac{y^2}{2\sigma_y} - \frac{(z-h)^2}{2\sigma_z} \right) + \exp \left( - \frac{y^2}{2\sigma_y} - \frac{(z+h-2z_0)^2}{2\sigma_z} \right) \right)
\end{align*}
\]

where \( \sigma_y, \sigma_z \) – dispersions of pollutant distribution in \( y \) and \( z \) directions.

The formula (5) allows to consider interaction of diffusion components in all directions, and gives an opportunity to get the exact solution of the equation of turbulent diffusion without restrictions on transfer velocity and distance from the source.

But the use of the proposed calculation formulas is possible only if the average turbulence coefficients and their dependence on the height \( z \) and thermodynamic state of the atmosphere are known. For various productions, grouped by qualitative characteristics, empirical methods of calculation are applied, based on the reference data of the coefficients of pollutant specific emissions use, in storage of various materials. These models are the basis of the "Methods of calculation the dispersion of harmful (polluting) substances emissions in the atmospheric air" (Order No 273 of 06.07.2017, 2005) [20], widely used for engineering calculations and implemented in some software complexes for the calculation of atmospheric air pollution.

According to the results of computational experiments the graphs of dependence of pollutant concentration as a function of the distance from the pollution source (figure 1) and the wind velocity (figure 2) are plotted.

For the area under study the calculation of atmospheric pollution in accordance with the method [20], using the unified program of calculation of atmosphere pollution by the ECO Center was made. The digital cartographic model of lead and its compounds distribution and majorant for substances and groups of summations in the atmosphere within the locality of Dalnegorsk town, the Primorsky Krai, was constructed. The analysis of the selected samples of dust emissions of the air basin at the territory of the kindergarten No 33 for many years (2007-2017), located near the mining and concentrating plant, allowed to make a forecast of pollutants concentration indicators for the future.
Atmospheric air pollution with Cr compounds is described by the equation:

$$C = 0.0652 x^4 - 1.6985 x^3 + 13.445 x^2 - 23.659 x + 33.835, \quad (7)$$

where $x$ is the year of substances entering the atmosphere.

Strength of relationship is characterized by the determination coefficient $R^2 = 0.9633$.

Thus, the tailing dumps of the Krasnorechenskaya and Centralnaya concentrating factories of the Dalnegorsky District of the Primorsky Krai are a dangerous source of atmospheric air pollution. Spatial and temporal regularities of main pollutants distribution are revealed. The pollutants concentration with distance from the technogenic source is in direct dependence on distance and have the character of exponential loss law.

4. Conclusions

The results of the research showed that pollution of the air basin with mineral processing waste within the limits of tailings dump Dalpolimetall (technogenic system) impact in the town of Dalnegorsk on toxic dust, heavy metal compounds and of sulfate ions aerosols is extremely high. The assessment of the air basin technogenic pollution using mathematical modeling and GIS-technologies has allowed to reveal spatial and temporal regularities of the basic pollutants distribution.

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