Assessing the environmental risk of mining enterprises by the integral indicator of dust emission

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Abstract. Mineral mining leads to the following negative consequences: disturbance of soil cover and hydrological regime, formation of man-made relief, changes in the quality of land, inhibition of soil formation processes and reduction of soil self-purification capacity and others, and most importantly, pollution of large areas through industrial emissions and, above all, dust emissions. Almost all processing operations, such as blasting, drilling, excavation, transportation of rock mass, storage, performed at mining enterprises are accompanied by dust formation. The aim of this paper was to develop a methodology for the assessment of environmental risks posed by mining enterprises by the integral indicator of dust emission. The objects of research were the largest mining enterprises of the Irkutsk Region engaged in extraction of gold, iron ore, coal and building materials. We analyzed the geoeconomic situation in the area of industrial activity of the enterprises under study. In our work, we calculated the atmospheric dust pollution indices, the areas of distribution of dust emissions, dust load on personnel of the enterprises, and proposed an integral indicator of dust emission which allows assessing the environmental risks of mining enterprises and their degree of environmental impact. It has been established that coal mining enterprises belong to high-risk facilities and it is necessary to introduce innovative dust suppression technologies at different locations.

1. Introduction
In Russia, the Irkutsk Region is known as one of the richest regions with mineral resources being mined, such as brown and black coal, iron ore, placer and ore gold, building materials (granite, marble, gypsum) and many others. Enterprises of the mining sector are successfully operating in the region. Every year the Federal Agency for Subsoil Usage and the Irkutsk Department for Subsoil Usage issue licenses for the use of mineral resources in the region. The increase in the number of subsoil users significantly increases the environmental load on the air, water resources, fertile land, objects of flora and fauna, therefore, creates environmental hazards or risks [1-3].

Currently, an environmental hazard is any change in the functionality of natural, technical, or natural and technical systems, leading to a deterioration in the quality of environmental components beyond the established regulatory standards [4].

The reason for changing the quality parameters of environmental components can be two fundamentally different sources: natural processes and phenomena that determine the evolution of the world, and the second is human activity. A measure of environmental risk is the expectation of damage determined for the whole complex of environmentally hazardous factors that manifest themselves in a given territory [5-8].
In this regard, as a quantitative measure of environmental risk, you can use an indicator that simultaneously takes into account the probability of an adverse event and the possible amount of damage caused by it both directly to the geosphere components and to man. Environmental risk may be acceptable, tolerable and excessive.

The aim of this paper was to develop a methodology for the assessment of environmental risks posed by mining enterprises by the integral indicator of dust emission.

2. Study objects and methods
As the objects of research, we chose the largest mining enterprises of the Irkutsk Region, which are of strategic importance for the region in economic terms, such as Azeysky Open-Pit Mine, a branch of Vostsibugol Company LLC (brown coal), Cheremkhovsky Open-Pit Mine (black coal), Trailing LLC (black coal), Korshunovsky Mining and Processing Plant OJSC (iron ore), Vysochaishy OJSC (aurigerous ore), Angasolsky Crushed Stone Plant (a branch of First Nonmetallic Company OJSC) (granite), Nukutsky Gypsum Quarry CJSC (gypsum).

The most common process that is present at all stages of field development, starting from its preparation and construction, stripping, mining operations and ending with the land reclamation complex, is the process of dust formation. The increase in the intensity of mining is directly proportional to the intensification of dust formation processes [9-10].

Sources of dust emission are wind erosion of destroyed surface areas, such as mine openings themselves, dumps of overburden rocks and substandard raw materials, excavation, drilling and blasting, transportation, as well as loading and unloading [11]. Sources of dust emission are located in large areas, vary in spatial and temporal parameters, are periodic, especially when conducting drilling and blasting operations. As a rule, major blasts form a dust and gas cloud which can reach about 10-25 million m$^3$ in volume, while the height can reach up to 1.5 km, and extend to enormous distances from the blast, significantly exceeding the sanitary protection zone, and possibly settle in nearby settlements or farmland [12-14]. It is known that in 2-3 hours at a distance of 1-3 km, such dust cloud will be dispersed into 1200-2500 kg of fine dust containing up to 90% of particles with a size of about 5 µm [15]. Our research [16] has shown that during coal mining at the Cheremkhovsky Open-Pit Mine, annually up to 36 tons of dust enter the atmosphere in the course of blasting operations. When drilling wells with roller-bit drilling rigs, up to 10 tons of dust per year are emitted into the atmosphere.

In addition to blasting, a substantial amount of dust is emitted during drilling operations, excavation and loading of mineral raw materials or barren rocks by excavators into dump trucks, railway transport or along conveyor belts [17]. It has been established that, during the operation of a single dragline, an average of 77 tons of dust is emitted into the atmosphere [16]. One shovel is accounted for about 2 tons of dust per year, which is significantly less than for a dragline, but in this case, the dust load on the personnel operating the mining equipment increases significantly.

In addition, in-pit roads are another important source of dusting. In-pit roads have a relatively small lifespan due to almost constant changes in the track, and in some cases, intensive traffic of large dump trucks, which significantly increases dust formation and impairs the operation of such roads. It was established that in some cases dust formation from roads reaches up to 80% of all dusting objects [17]. Dusting on in-pit roads occurs due to the drift of fine fractions of dust onto the coating, which adhere to dump trucks that deliver minerals, as well as loose particles of rock in the open truck body which get blown off from the minerals [18].

The personnel of enterprises that extract minerals are exposed to dust both directly as a result of performing technological work on the extraction of fossil raw materials, and in living conditions as a result of environmental pollution [19]. We have found that at the Cheremkhovsky Open-Pit Mine, dust emission on the roads amounts to 4 tons per year [16].

Dust from host and mined rocks can lead to diseases of the upper respiratory tract, lung diseases, various diseases of the skin, negative consequences for the mucous membranes of the eyes, and, in some cases, the digestive system. When dust affects the upper airways, they get irritated and inflamed,
with a clear damage of the nasal mucosa - the first signs of such an effect are throat irritation and coughing [20].

At the studied enterprises, using Golden Software Surfer, we evaluated the areas of distribution of dust pollution from sources under the influence of the movement of air masses, and, using known methods, calculated the atmospheric dust pollution indices, dust load on personnel, environmental and economic damage.

To assess the environmental risk of mining enterprises by the dust factor, we proposed an integral indicator of environmental risk by the dust factor $C_{ER}$, which is the sum of specific dust emissions into the atmosphere, the area of dust pollution and the allowable work period in the working environment with a high level of dust content.

$$C_{ER} = SIAP + SADP + SDL,$$

where $SIAP$ is the specific index of atmospheric pollution by dust in the area of mining, defined as the ratio of the actual index of atmospheric pollution to the degree of pollution characterized as “slightly polluted” (this degree was chosen due to possible self-restoration of the environment after eliminating the source of pollution);

$SADP$ is the specific territorial (social) risk of dust distribution in the areas of mining, defined as the ratio of the area of dust pollution up to MAC to the area of the sanitary protection zone;

$SDL$ is the specific allowable work period of personnel in the area of mining, defined as the ratio of the allowable work period with the allowable (MAC) dust content in the working environment to the allowable work period with the current dust content;

Using this indicator, it is possible to assess the level of risk in a particular administrative territory relative to the region as a whole.

3. Results and discussion

The results of the calculation of specific risk indicators for the mining enterprises of the Irkutsk Region are shown in Table 1.

| Enterprise | $SIAP$ | $SADP$ | $SDL$ |
|------------|--------|--------|-------|
| branch Azeysky Open-Pit Mine | 11.52 | 1.96 | 2.63 |
| Angasolsky Crushed Stone Plant | 2.96 | 3.98 | 3.3 |
| Trailing LLC | 4.8 | 1.51 | 3.85 |
| branch Cheremkhovsky Open-Pit Mine | 2.84 | 2.41 | 4.81 |
| Korshunovsky Mining and Processing Plant OJSC | 1.59 | 3.21 | 2.1 |
| Nukutsky Gypsum Quarry CJSC | 1.19 | 2.08 | 2.84 |
| Vysochaishy OJSC | 1.78 | 1.11 | 3.21 |

Table 2 presents the results of the calculation of the environmental risk integral indicator by the dust factor and the assessment of the environmental hazard level of the studied enterprises.

The use of this indicator, despite its conventionality, makes it possible to compare the ecological situation in the operation areas of mining enterprises and to determine the appropriate set of measures to reduce environmental risks. As can be seen from Table 2, a high level of environmental risk was identified mainly in the operation areas of mining enterprises specializing in extraction of coal and granite. First of all, this is due to the specifics of mining (mined raw materials, extension of mine openings, wind characteristics in the areas of the fields), as well as mining technology and equipment used.
Table 2. Assessment of the environmental hazard of mining enterprises based on the comprehensive indicator of environmental risk.

| Enterprise                                    | Integral indicator of environmental risk by the dust factor, $C_{ER}$ | Environmental hazard level |
|-----------------------------------------------|---------------------------------------------------------------------|---------------------------|
| branch Azeysky Open-Pit Mine                  | 16.11                                                               | Extreme                   |
| Angasolsky Crushed Stone Plant                | 10.24                                                               | High                      |
| Trailing LLC                                  | 10.16                                                               | High                      |
| branch Cheremkhovsky Open-Pit Mine            | 10.06                                                               | High                      |
| Korshunovsky Mining and Processing Plant OJSC | 6.9                                                                 | Medium                    |
| Nukutsky Gypsum Quarry CJSC                   | 6.11                                                                | Medium                    |
| Vysochaishy OJSC                              | 6.1                                                                 | Medium                    |

4. Conclusion
As a result of the assessment, we confirmed an indisputable fact - dust pollution is catastrophic and has a negative impact not only through pollution of the atmospheric air by dust particles, but also of nearby territories, polluting water and land resources, disrupting the natural processes of flora and fauna, causing irreversible effects on human health.

The application and development of the proposed methodology will allow for comparing environmental risks of various mining enterprises, which was previously impossible due to fundamental differences between them. In its turn, the use of the methodology gives a clear picture of the areas most vulnerable to the adverse effects of the mining sector. Such zoning will allow for identifying environmental hazard areas that will be targeted for the implementation of measures to reduce environmental risks.

References
[1] Chemezov E N, Delets E G 2017 Dust control in open pit mining Bulletin of the Scientific Center for the Safety of Work in the Coal Industry 1 pp 42–46
[2] Gasaynieva A G, Gasaynieva M G 2017 On atmosphere pollution by fine dust and on its impact on human health Don Engineering Bulletin 4 (47) p 173
[3] Rogalis V S, Pavlenko M V, Shilov A A 2016 Combination of the coal dust and radiation effects on the health of miners Mining Research and Information Bulletin (scientific and technical journal) 3 pp 109–120
[4] Ishtiaq M, Jehan N, Khan S A 2018 Potential harmful elements in coal dust and human health risk assessment near the mining areas in Cherat, Pakistan Environmental Science and Pollution Research 25(15) pp 14666–14673
[5] Gorlenko N V, Timofeeva S S 2019 Assessment of environmental damage from oil sludge to land resources in the Irkutsk region IOP Conference Series: Earth and Environmental Science 229 012019
[6] Sairanen M, Selonen O 2018 Dust formed during drilling in natural stone quarries Bulletin of Engineering Geology and the Environment 77 3 pp 1249–1262
[7] Burmistrova T B, Artemova L V, Yanshina E N 2017 Radiological and clinical features of modern forms of silicosis from exposure to high-fibrogenic quartziferous dust Occupational Medicine and Industrial Ecology 9 pp 30–31
[8] Tworek P, Tchorzewski S, Valouch P 2018 Risk Management in Coal-Mines – Methodical Proposal for Polish and Czech Hard Coal Mining Industry Acta Montanistica Slovaca 23 pp 72–80
[9] Kashuba N A 2018 On new approaches to assessing the impact of dust on the respiratory organs Hygiene and Sanitation 97 3 pp 264–268
[10] Cheberyachko S I, Radchuk D I 2016 Unsolved problems of protecting miners from dust Safety and Labor Protection 4 (69) pp 75–77
[11] Chakraborty M K, Ahmad M, Singh R S, Pal D, Bandopadhyay C, Chaulya S K 2012 Determination of the emission rate from various opencast mining operations Environmental Modelling and Software 17 pp 467–480
[12] Kremenev O G 2016 Particle size distribution of dust in the atmosphere of the air supply and ventilation openings of the coal mine Bulletin of the Scientific Center for the Safety of Work in the Coal Industry 3 pp 110–118
[13] Chakradhar B 2014 Fugitive Dust Emissions from Mining Areas Journal of Environmental Systems 31(3) pp 279–288
[14] Zhang L 2013 Ecological Risk Assessment of Yulin Coal Mining Area: Based on the PETAR Method Advanced Materials Research 726-731 pp 1115–1120
[15] Papichev V I, Proshlyakov A N 2017 Assessing the hazard of dust from quarry sources affecting soil Mining Research and Information Bulletin (scientific and technical journal) 2 pp 315–327
[16] Luzhkov Yu A, Timofeeva S S 2008 Impact of technological processes and coal mining-and-transport equipment on the environmental load of the Cheremkhovo Municipality Mining equipment and electrical engineering 3 pp 38–41
[17] Korshunov G I, Kovshov S V, Safina A M 2017 Methods of controlling dust in open pit mining. Current state of physical and chemical research European Research 1 (24) pp 9–11
[18] Yastrebova K N, Moldovan D V 2016 A comprehensive solution to improve the atmosphere of the quarry area after major blasts Labor Safety in Industry 1 pp 30–32
[19] Petrova K I 2017 Assessment of dust hazard in mining enterprises Mining Research and Information Bulletin (scientific and technical journal) 5 pp 413–417
[20] Patra A K, Gautam S, Kumar P 2016 Emissions and human health impact of particulate matter from surface mining operation-A review Environmental Technology and Innovation 5 pp 233–249
[21] Perera I E, Sapko M J, Harris M L, Zlochower I A, Weiss E S 2016 Design and development of a dust dispersion chamber to quantify the dispersibility of rock dust Journal of loss prevention in the process industries 39 pp 7–16
[22] Timofeeva S S, Medvedeva S A 2014 Ecology of the technosphere (Moscow: Forum: INFRA-M) p 160
[23] Timofeeva S S 2017 Methods and technologies for assessing environmental risks (Irkutsk: Publishing house of Irkutsk National Research Technical University) p 240