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Use of Remote Sensing to Assess the Vegetation Setting of The Territories – Zones of Mining Complex Enterprises - Depending on the Complexity of Their Production Infrastructure

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Abstract. The paper presents and analyzes the quantitative assessment of environmental impacts of technogenic load in the time slot for the response of the biota in the territory of the placement of several mining enterprises in Russia, depending on the complexity of the production infrastructure production and life of the field, the degree of toxicity of raw materials, climatic condition. It is confirmed that in time NDVI dynamics objectively reflects the integrated assessment of the state of the environment and can serve as a criterion the degree of environmental hazard applied geotechnology and enterprise as a whole.

Keywords: Mining enterprises, industrial infrastructure, technogenic load, environmental assessment, land cover, remote sensing, vegetation index.

1 Introduction

The problem of formation of natural industrial spheres and, as a result, malfunction of natural ecosystems is one of urgent problems in modern geoecology. Specifically, this is characteristic of the territories of Russia, where anthropogenic activities are associated with intense processes of georesource development. It should be noted that mining enterprises themselves having simple production infrastructure (e.g., single underground mine or small open pit) are not major sources of enviromental. But they acquire degree of increased ecological risk in combination with the complex of concentration manufacturing facilities and moreover of iron-and-steel and heat-and-power enterprises.

Despite numerous studies of consequences of environment pollution, science still cannot establish predicted patterns of compatible change in biological and technological parameters. This requires theoretical knowledge on mechanisms of interaction of natural and technogenic factors having controlled over long-term changes of natural environment.

Assessment of landscape change and degradation of natural environment associated with intense human economic activities is known to be a traditional form of ecological monitoring. Special attention shall be paid to control of ecological state of developed territories, since improvement of ecological situation and recovery of disrupted territories requires huge efforts and financial expenses. It is a consequence - disturbed state of natural ecosystems, determining quality of environment favorable for human habitation and population health - that cumulatively determines ecological status of enterprises developing georesources.

Aggravation of ecological problems mining in Russia associated with their immensity and geography of field distribution throughout the vast territory of our country demand the need for the use of space monitoring methods. Since the second half of the 80s of the last century, cardinal directions remote sensing (RS) of the Earth began measuring cosmic shooting (Rouse 1937, Shovengerdt 2010). Remote sensing offers an inexpensive and fast approach to gather information on land degradation (Dzhi 2008).

The advantage of RS is that it allows detecting 3-D models of landscape peculiarities, obtaining information with various time resolutions and at any scale, analyzing territories being explored many times and comparing today's events with past ones. Besides, and perhaps the most important is that RS allows obtaining latest information in real-time mode.

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2 Methods of Research

It is known that the balanced state of biosphere is determined by the cycle of matter and energy in all its structural constituents. The rate of metabolic processes varies in different environments. The time required for reproduction of environmental quality within the structure and function of biosphere (environment) represents system inertness, and return state – its response time. Based on available data, inertness of natural components ranges forming the following inter-related hierarchical order in regard to recovery (Fig.1).

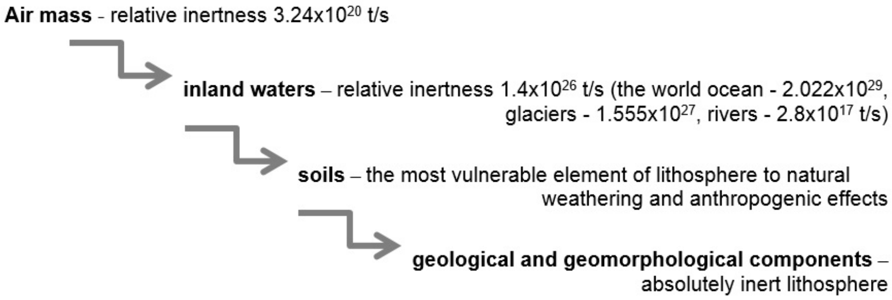

Figure 1. Hierarchical order of inertness of nature components.

The comparison of the given data shows that soils and surface waters are most vulnerable and less inertial spheres. Therefore, possibility of minimization appears as regards measurement of biospheric parameters during implementation of monitoring of natural environmental condition. Since nutrition regimen and soil fertility define presence and volume of biomass on a specific territory, it is required and it is enough to control dynamics of vegetation. The growth of phytotoxicity of soils and, as a consequence, their erosion is one of the most typical negative parameters of anthropogenic effect. Such amount of metal in soil decreasing productivity of plants by 10% as compared to pure control is regarded as phytotoxic (Kata, Pendis A., Pendis H. 1989). It is possible to obtain comparative characteristics of territorial units and also to define level of anthropogenic load using soil phytotoxicity rate factor. "Physical and chemical criterion" (PCT) as a ratio of sum of concentrations of exchange bases (calcium and magnesium (mg/kg)) to concentration of heavy metals in soil (mg/kg) justified earlier, was used for assessment of soil phytotoxicity rate (Evdokimova 1982). The higher this ratio is, the less is toxicity of soils. The scale for assessment of the soil toxicity rate is determined experimentally for every type of soil for the purpose of detection of exchangeable chemical bases and top-priority heavy metals– main pollutants of specific deposits of commercial minerals.

Remote methods are as a rule indirect, since they are used to measure not parameters of the object which are interesting to us but coefficient of spectral brightness (CSB) (Kondratyev, Fedchenko1987) for these objects in several areas of optical region. Preliminary studies including various tests to study state of plants using biological methods, their coefficients of reflection in various areas of spectrum and at various locations of Sun – source of light, vegetation and measuring device are required to decipher such data. Modern means of RS allow identifying various type of vegetation by spectral characteristics (CSB) (Rouse 1937, Kondratyev, Fedchenko1987). Usually, reflection spectra are combined in red and infrared regions, since vegetation is intensively absorbing incident radiation in red region of spectrum (up to 90%, induced by leaf pigment). Meanwhile, green leaves are strong reflectors in infrared region during vegetation. Contrast of coefficient of reflection is observed only in green vegetation, whereas bare ground represents the same coefficient of reflection both in red and in infrared region.

Vegetation is an important biophysical indicator of degradation of land and desertification. Analysis of vegetation is carried out during growth. Duration of growth period will vary in different climatic conditions. If a plant is under stress, its spectral properties will change. Therefore, biomass serves as an integrated measure of biological productivity. Its deviation from local norm can be regarded as a measure of degradation. Dependence of trends of changes in Normalized Differential Vegetation Index (NDVI) on value of technogenic load from the source shall be determined for this purpose. NDVI is a non-dimensional value characterizing volume of biomass per unit of area. NDVI varies from 0 to 1.0 or

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from 0 to 100% and it is the most important parameter of existence and condition of vegetation. A higher index is associated with a higher level of intact vegetable cover, whereas clouds and snow account for index about zero creating the impression that vegetation on this area is less green. Table 1 shows NDVI values for some land objects.

Table 1. NDVI values for some surface objects

Type of the object	Reflection coefficient in red spectral range	Reflection coefficient in near-infrared spectral range	NDVI values
Dense vegetation	0,1	0,5	0,7
Rarefied vegetation	0,1	0,3	0,5
Uncovered soil	0,25	0,3	0,025
Clouds	0,25	0,25	0
Snow and ice	0,375	0,35	-0,05
Water	0,02	0,01	-0,25
Artificial material (concrete, asphalt)	0,3	0,1	-0,5

The implication is that condition of soil mantle becomes an objective informative index of territory disruption, and dynamics – trends of changes in biomass volume - serves as a criterion. In this case, zero trend of biomass volume with time evidences balance of natural and technogenic spheres in general for this technogenic load, in climatic and geobiochemical conditions of region (a). The negative trend demonstrates process of environmental degradation (b). Positive trend – ongoing process of recovery of vegetation cover through demonstration of preserved natural potential of the territory (c). (Fig.2).

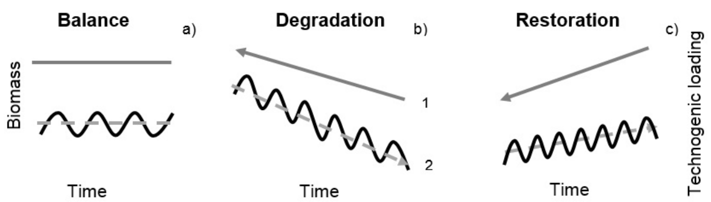

Figure 2. The ratio of technogenic loading and biomass trends (1 - the trend of technogenic loading; 2 - the trend of biomass).

The results of satellite measurements are used for the first time for the purposes of quantitative assessment of environmental conditions under the influence of technogenic load. The approach proposed by us and provided in detail in the article (Kalabin 2011, 2012) may be also used for assessment of ecological efficiency of technological modernization of enterprises. In this case, there appears a possibility to have assessment of sufficiency of technological renewal for preservation of natural potential.

3 Research Results and their Discussion

We will give test assessments of environmental condition on the specific territories of location of enterprises of mining complexes, with various production infrastructures in hierarchical sequence from a simple production infrastructure to a more complicated one. More complicated production infrastructure allow to increase depth of processing of mineral raw materials. It, in turn, leads to overgrinding of ores and wastes product and their potential danger of during the entire cycle from mining, processing it to obtain the final product. As material move on this cycle the natural chemical bonds are destroyed due to the fine grinding (till 40 microns), applied of chemical reagents (many of which are toxic). As result,

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the most dangerous dust-gas waste (soluble oxides and sulfate compounds in the ionic form) come in natural ecosystems. In this case, the probability of the potential toxicity hazards of feedstock is maximum.

3.1 *Underground mine "Vostok-2" of "Primorsky" (*Kalabin 2012) with a capacity of 350,000 tons of crude ore per year is being explored as an integrated field of tungsten ore of a small scale. *When such deposits are being developed using underground method,* mining activities are carried out in mine openings with closed path and they are performed with partial change of lithosphere condition in the mining zone. Hence, being *a local perturbation source for the natural environment, the underground mining does not induce any serious adverse consequences in regard to condition of the natural environment.* Meanwhile, the degree of environmental risk is mainly determined by infrastructure and technologies of surface operations determining local variability of natural components (biocommunity) and also toxicity of waste (Kalabin 2011).

The technogenic load on the territories of location of the enterprise Mining Processing Plant (GOK) "Vostok-2" is practically constant in time and is defined by the technology of dressing plant waste storage and by dusting of drift roads during delivery of or to the plant using dumping trucks. Waste has low toxicity. Natural conditions are favorable. Besides, there is no anthropogenic load, since settlement of mineworkers is located 7 km from the mine site of the industrial complex. All objects are spatially bounded by means of mountainous land configuration, therefore, local technogenic load of production and concentration complexes and anthropogenic load are not summarized. Fig.3 shows obtained mean values of NDVI on the territory of location of GOK "Vostok-2".

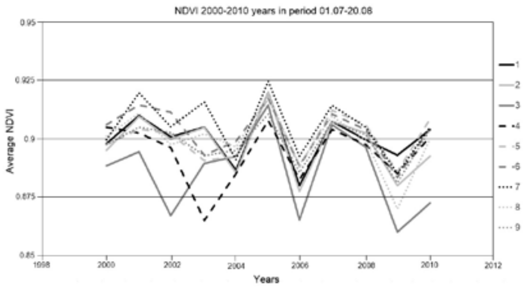

Figure 3. Mean NDVI values for the summer season on the territory of location of "Vostok-2" GOK (1-8 number of valleys, isolated area around the mine and settlement, 9 - is the average for the rest of the area)

Analysis of results shows that maximum values of index are observed in "summer" period of the year. Furthermore, NDVI takes on values from 0.87 to 0.92 during the period under investigation, which gives evidence of absence of negative ecological consequences associated with the activities of the enterprise.

3.2 *Gold ore field "Vorontsovskoe" ("Zoloto Severnogo Urala" of Sverdlovsk region")* is a small-scale field, it is being explored by open-cut mining since 1999 and it is one of few fields in Russia, where two ecologically acceptable technologies are used simultaneously for refining of two types of ores: oxide-bearing - using method of heap leaching with stack filling and primary – using carbon-in-pulp technology. Production infrastructure of plant master plan is very simple and includes open pit and sites for heap leaching. Produced or is transported for processing to the gold recovery plant (ZIF-2) located at the distance of 7 km, outside the territory of interaction with technogenic load defined by work of open pit. Technogenic load is mainly defined based on mechanical action in case of increase in size of open pit.

Natural conditions and technogenic factors are favorable for preservation of natural potential. The field has been exploited only for 13 years. Toxicity of feed stock is associated with low risk (Au, Ag, S, As). Condition of understory of young regeneration of pine-trees and epigenous fungi bears evidence that level of air pollution on the examined territory is rather high (Baytalskaya 2002).However ecosystems of the territory are in the area of exposure to Bogoslovsk aluminium smelter, which injects acid gases and fluorine compounds into the atmosphere. Fig.4 represents average values of NDVI on the territory of location of open pit, calculated using the results of satellite measurements during 2000-2011 years.

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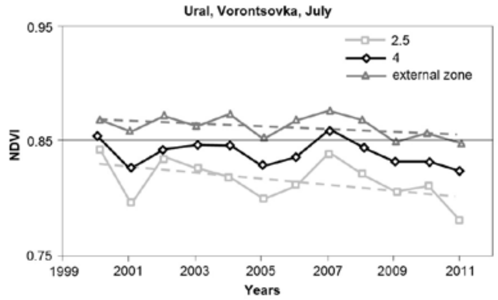

Figure 4. Spatial and temporal NDVI variations within the zone of the facility for mineral resources development affecting the natural ecosystems. The dashed lines designate long-term trends. The numbers indicate radii (km) of the zone around the facility.

Analysis of results shows that minimum values of index are observed in the area of location of open pit and heap leach pads. It should be noted that NDVI has a negligible tendency to decrease during the period under examination taking values from 0.82 to 0.8, which gives evidence of slight negative ecological consequences associated with activities of the enterprise and influence of neighbour metallurgical plant.

3.3. *Sorsk mine of copper-molybdenum ores (Khakassia)*, which has been developed since 1950 by means of open-pit mining with *ex situ* ore handling and which belongs to high deposits with typical large mass flows: mine rock wastes, concentration tailings and slag. Production infrastructure of "Sorsky GOK" includes complex of concentration manufacture, Central Heating and Power Plant (CHPP), "Sorsky ferromolybdenum plant" located within limited territory with a diameter of 6.5 km. Besides, city of Sorsk with 13,000 of inhabitants is situated in the immediate vicinity of the mine site. The listed technogenic factors demonstrate the presence of a certain ecological risk. However, toxicity of molybdenum compounds is relatively low. Therefore, dust released into the atmosphere contains no toxic substances in active form and does not induce any serious consequences for health if it penetrates into the human body.

Unlike underground mining method, production processes in open pit are progressing in open-path mines open to the atmosphere. They are carried out with complete demolition of biota, withdrawal of soil mantle and mine rocks. Area of disturbed territories is increasing during while in service due to mechanical impact, when size of open pit is being increased, and also due to diffuse and inertial processes. In the operation area of disturbed areas is increasing due to mechanical impact by increasing the size of the open pit as well as diffusion and inertial process.

Satellite measurements for the period of 1999-2011 have shown that internal zone (with a diameter of 6.5 km), where Sorsky GMK (mining-and-metallurgical integrated works) (Fig.5) is located, is characterized by low values of NDVI (Kalabin, Gorny, Kritsuk 2014).

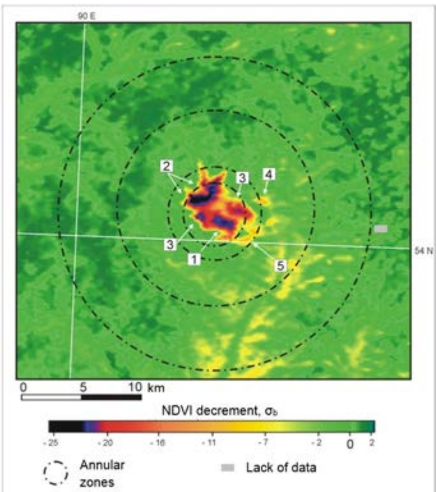

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Figure 5. The central fragment of the NDVI decrement map, the area where the Sorsky mining and smelting complex is located. Legend: NDVI decrement is given in standard deviation units of NDVI spatial changes in the external (background) area bounded by the circles with diameters of 62 and 96 km. The arrows indicate: 1 - Mine, 2 - Tailing dump, 3 - Mine dump, 4 - Lake Teploje, 5 - Town Sorsk.

On Fig.6, curve 1 characterizes multiannual dynamics of NDVI on the territory of location of open pit, tailing pit and larger part of rock dumps.

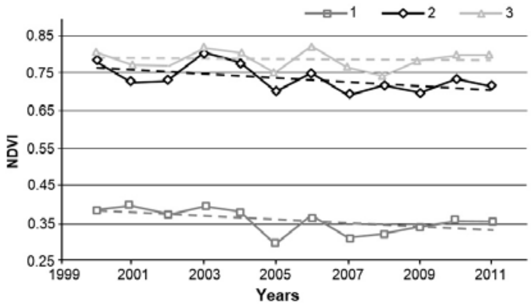

Figure 6. Annual variations of average NDVI values in July (193-rd day of the year) for the period from 1999 to 2011 for the annular zones bounded by circles with diameters (see legend): 1-0 km - 5 km; 2-5 km - 8 km; 3-62 km - 96 km (background). The dashed lines indicate long-term trends.

Curve 2 – new dumps and city. Curve 3 – background region, which is not affected by Sorsky GMK. Therefore, we analyze dynamics of NDVI combining two annular zones limited by circumferences with diameters 0 to 5 km – impact zone and 5 to 8 km – impact buffer zone. NDVI has insignificant negative tendency - 0.028 - in impact zone as regards multiannual aspect with absolute value of NDVI =0.351 (2011). NDVI has also insignificantly decreased in the course of 12 years inside impact buffer zone (curve 2 on fig. 6) from 0.79 in 2000 to 0.71 in 2011.

Therefore, there was no significant degradation of vegetation cover during the period under examination. All events associated with abrupt decrease in volume of phytomass occurred earlier, when open pit, tailing pit, rock dumps were formed and developed and the city was built. If we sum up what we have specified, mean value of NDVI shall be taken for the territory of two zones and it is 0.56-0.58.

3.4 *GMK "Karabashmed" (Chelyabinsk region) [13].* Most representative are the results of investigations of those objects, where a considerable decrease in technogenic load occurred for various reasons. One of them is "Karabashmed" located within the city of Karabash with 45,000 of inhabitants (as of 1990). It is characterized by a complex multi-industry production infrastructure, multi-annual (more than 100 years) and extremely high ecotoxicological technogenic load on the environment. Here, the 1st phase of a large ecological project "Complex for disposal of sulphur of tail gases of copper-converting manufacture" was completed after shutdown of enterprise and out migration of population (as of today -15,000 people) in 2005. As a result, sulphur dioxide emissions decreased 35-fold to 4,900 tons per year, dust emission – to 50 tons per year, more than 200-fold (Fig.6) (Brusnitsyn 2005).

The analysis of graphs (Fig.7) has shown that NDVI has started growing since 2005 with decrease of technogenic load, and this growth lasted for two years until the event of accidental emission into the atmosphere, which occurred in 2007, which is demonstrated on the given graphs.

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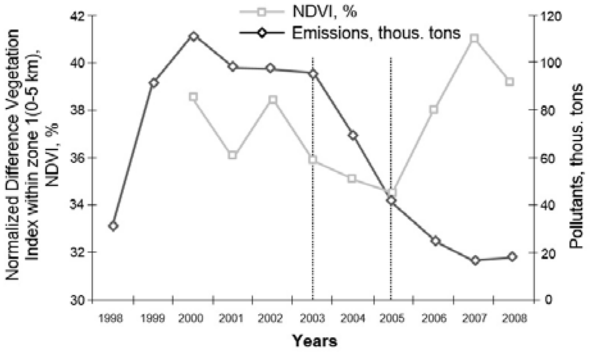

Figure 7. Long-term variations of the average normalized NDVI values within the impact zone (0-5 km) for the period 2000-2007 within the background zone (52 km). Averaging time for each year: from 81-st to 273-rd day at the background of technogenic loading decline.

However, water and soil pollution remains highly toxicological despite the fact that generally there are conditions for the self-recovery of vegetation of the territory in the region. Suffice to say that examined soils (Kalabin, Titova, Sharov 2011) have ash content that is very high for the top soil (up to 84-97%), i.e. they contain many mineral compounds. Organic substances in them account for a negligibly small percent. Humidity of samples is also very low due to such small amount of organic matter. The content of exchange cations of calcium and magnesium in soil samples is small, which is indicative of a weak buffer power of soils. The amount of copper in analyzed samples of rocky soil in the layer of 0-10 cm is very high – 10-fold and even 100-fold exceeding Maximum Permissible Concentration of this element.

NDVI has taken different values from 0.27 to 0.38 during the period under examination, which evidences hazardous negative ecological consequences associated with enterprise activities. Loss of vegetable cover is 59%. Self-recovery of vegetation cover is not possible without elimination of negative impact of technogenic wastes accumulated in natural landscape, and the situation will still remain the same for a great while.

Further, tabulate their 2 technical characteristics, natural and technological conditions and technogenic factors and also NDVI values for assessment of condition of the vegetation cover on the territories depending on the complexity of production infrastructure of enterprises.

Besides, we give values of index for nominally background zones and their correlation with its values in impact zone for quantitative assessment of vegetation loss.

Analysis of data given in tab.2 shows that growth index of vegetation is decreasing so far as production infrastructure is becoming more complicated and toxicity rate of feed stock is increasing and also volume of production and duration of exploitation deposit, which is indicative of increasing process of environmental degradation on this territory. Climatic zone defines tendency of NDVI to a lesser extent, but it depends to a large extent on amount of falling precipitates and duration of vegetation period.

Technical and technological parameters of first two enterprises ("*Vostok -2*" and "*Zoloto Severnogo Urala*") are compatible with functioning of biological systems and are practically balanced. Their influence on the environment can be assessed as acceptable ecological risk. Natural potential is preserved here and the process of self-recovery of vegetation cover is ensured after shutdown of the enterprise and elimination of technogenic load.

The natural potential preserved on the territory of location of "Sorsk GOK" may be assessed as "relatively favorable" for self-recovery of vegetation cover after elimination of technogenic load considering that toxicity of molybdenum compounds in waste is relatively small. Besides, it shall be taken into consideration that loss of vegetation (37%) is mainly associated with mechanical disruption of soil and vegetation cover during construction of enterprise infrastructure, development of open-pit mining and keeping of huge volume of overburden rocks and concentration tails on the surface.

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Table 2. Condition of a vegetable cover of the studied territories depending on complexity of production infrastructure

The territory where GMK“Karabashmed” is located is “the territory of ecological disaster”. The natural potential has been completely disturbed for the period of more than 100 years as a result of impact of toxic emissions of heavy metals and sulphur oxides into the atmosphere. Besides, local wood material, which was obtained by means of clear-felling of conifer forests growing on neighboring hill-sides, was used to provide plants with charcoal, to build industrial objects and dwelling. Total area of disrupted vegetation in the vicinity of the city of Karabash is about 7000 ha. Self-recovery of vegetation cover is impossible without elimination of negative impact of technogenic highly toxic wastes accumulated in natural landscape, and the situation will still remain the same for a great while.

Object and lifecycle	Infrastructure		Potential danger toxicity of waste	Climatic zone	Duration of vegetation period, days	NDVI		Ration NDVI back./ NDVI imp.	Loss of vegetation, %
	initial	current				Back-ground zone	impact zone/ period of satellite measurements		
1. GOK “Vostok-2” (Primor-sky Krai) 46 years	Open pit, dressing plant	Underground mine, dressing plant	Low-risk (W, Bi, Ag, Au)	Far East	112	0.9-0.92	0.87-0.92 (2000-2010)	0.8	2.0
2. “Zoloto Severnogo Urala” (Sverdlovsk region) 13 years	Open pit (heap leaching)	Open pit, gold recovery plants (7 km from open pit)	Low-risk (Au, Ag, S, As)	Middle Ural	85	0.84-0.87	0.80-0.82 (2000-2011)	0.94	6.0
3. "Sorsk" GOK (Khakassia)-62 years	Open pit, dressing plant	Underground mine, dressing plant, metallurgical complex (2006)	Low-risk (Mo, Cu, S, Fe)	Moderate South	115	0.85-0.86	0.56-0.58 (2000-2011)	0.63	37.0
4.GMK “Karabashmed” (Chelyabinsk region)-101 years	Underground mine, dressing plant, metallurgical complex	Metallurgical complex	High-risk (Cu, Pb, As, Cd, A)	Moderate South	117	0.79-0.80	0.27-0.38 (2008-2010)	0.41	59.0

4 Conclusion

From the research results, it follows that growth index of vegetation is decreasing so far as production infrastructure is becoming more complicated and toxicity rate of feed stock is increasing and also volume of production and duration of exploitation deposit, which is indicative of increasing process of environmental degradation on this territory. Climatic zone defines tendency of NDVI to a lesser extent,

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but it depends to a large extent on amount of falling precipitates and duration of vegetation period. The proposed approach makes it possible to assess the environmental risk of enterprises at the stage of its design, without special studies, the degree of toxicity of the original ore and the planned set of technological methods, i.e. the complexity of the enterprise production infrastructure.

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