Ecological situation in the area of non-ferrous metals mining on the slopes of the Eastern Caucasus

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Abstract. The article provides information on the history of the development of Sadon ore field, Tyrnyauz tungsten-molybdenum and Urupsk deposits. A description of landscape changes occurred in the process of mining and processing of non-ferrous metal ores in places of mining enterprises dislocation is given. It has been shown that soil pollution in the area of mining facilities activity with heavy and toxic trace elements has mineralization of mining origin. It has been established that in the areas of dislocation of existing mountain objects, landscapes and soils, which are an integral part of ecosystems, have a pronounced zonation, each of which has certain components that influence the formation of ecological situation. Low levels of lead and zinc have been found in seasonal vegetables (potato tubers) and high, exceeding MAC – in perennial fruit crops (apples, pears). It is noted that only the use of scientifically based measures based on real positive results, taking into account geo-environmental factors, can affect efficient environmental management under the considered conditions.

1. Characteristics of the zone of non-ferrous metals mining in the North Caucasus Sadon ore-bearing region

The deposits of polymetallic ores of North Ossetia are localized both in foundation rocks and in Jurassic volcanic-sedimentary deposits. The most significant in terms of reserves of polymetallic ore are Sadono-Unal ore field, represented by Sadon, Zgid, Arkhon, Oktiabrskeoe, Kholst deposits, etc. Venous deposits, the main ore minerals are sphalerite, galena, pyrite, pyrrhotine, chalcopyrite, secondary – arsenopyrite and marcasite. The main useful components of ores are lead and zinc; the associated ones are silver, copper, cadmium, and indium. The distribution of the main ore elements is extremely uneven, the lead content in the ores varies from 0.42 to 12.8 %, zinc from 1.87 to 26.2 %.

Fiagdon ore field is represented by deposits of Levoberezhnoe, Kadatskoe, Khanikamskoe, Kakadurskeoe and etc., located in thick sandy shale strata of Jurassic in the form of brecciation and carbonatization zones. Brecciation zones carry galena, sphalerite, pyrite, arsenopyrite, chalcopyrite; the satellite elements are tin, silver, gold, cadmium, bismuth.

The area of activity of the Sadon mines is located in the mountainous part of North Ossetia and is characterized by medium-high-altitude relief with absolute elevations of 1.800–2.800 m and relative elevations up to 800–1.600 m. Mountains are sharply divided by numerous rivers and their tributaries into a number of narrow and long gorges of various directions. The longest gorges have submeridional
directions and are formed by Ardon, Urukh, Fiagdon rivers – the main tributaries of Terek river. The climatic regime and nature of vegetation in gorges is variable and closely related to the relief. The relief also determines local distribution of thermal regime, humidification regime, and air flow direction.

The valleys of Ardon and Fiagdon rivers belong to th “Solar valleys” with a characteristic microclimate. By the number of days with solar activity, this zone does not concede to Swiss Alps. The average temperature of the warmest month of July in the area of Unal and Fiagdon villages is + 16 °C and the coldest in January is −2 °C. Annual precipitation is 300–400 mm with the highest loss in summer and autumn. Winters are with little snow with periodic snow cover about 10 cm. The area is characterized by strong valley winds up the gorge during the day and back at night.

There are two main types of soil within the valleys: wormwood-grass and slope mountain-forest-meadow; brown podzolized and humus-carbonate soils. Agriculture has a major fruit-vegetable and livestock trend in the area. Apple-pear orchards are widely developed here; they have not only of local, but also wide industrial significance. Potato and corn are the most common among vegetable and grain crops.

In the transverse profile of the Ardon river valley is asymmetrical. The left bank is steep, bounded by rock outcrops of sedimentary rocks of the Middle Jurassic and landslide sediments of Kion-Khokh Mountain. Transcam road connecting Transcaucasia with the North Caucasus passes through it. The right bank is represented by a series of multi-level accumulative basement river terraces. All terraces are composed of boulder-pebble sediments with a gravel-sandy aggregate and covered with a layer of loam, often loess-like. The upper soil layer is represented by black soil with a thickness of 0.2–0.3 to 0.4 m in the area of N. Unal village, Unal tailing dump, commissioned in 1984 is on the lower terrace near the bridge across Ardon river. It is located in the floodplain of the left bank of Ardon river, 0.5 km north of N. Unal and 10–12 km north-east of Mizur concentrating mill. The tailings dump beds are pebbles of Ardon river, the right board is separated by a concrete dam from the riverbed. The absolute mark of of the floodplain river bottom is 873.3 m; N. Unal village is 900 m above sea level. Refinement tailings of Mizur concentrating mill are fed to the tailing dumps. The entire infrastructure of Sadon Lead-Zinc Combine, including residential zone, is located in the narrow valley of Ardon. The bedrock and geological exploration waste by motor transport are simultaneously removed and stored in the floodplain of Ardon. Fiagdon tailing dump has been functioning since 1970. It is located in a narrow, canyon-shaped gorge of Khanikomdon river, a right tributary of Fiagdon river at an altitude of 1250 m above sea level. It has a sharply elongated shape, bounded by rocky sandy-rocky and limestone outcrops of the Jurassic and Cretaceous on both sides. Fiagdon tailing dump is separated by a high bulk dam from the river valley; and it is located about 600 m downstream of Khanikomdon river from Old Dzuarikau village. The village is located in the floodplain of a narrow valley of the brook; a dirt road between Khanikom gallery and Fiagdon concentrating mill passes along the left slope of 400–500 m. Tails were fed by pipeline hydrottransport to the tailing dumps by two lines.

2. Tyryauz tungsten-molybdenum deposit

The field is worn out by the underground mine “Molibden” and single-breasted quarries of “Mukulanskii” and “Vysotnyi”.

Mine production facilities are located at various levels: concentrating mill − 1350 m, amenity complex and main haulage adit − 2004 m, main scarn − 2 600 m, “Mukulanskii” quarry − 2700 m, “Vysotnyi” 3300 m. The town of Tyryauz occupies floodplain terraces of Baksan river and its tributaries Sakashili-Su and Kamyk-Su at elevations of 1250–1300 m from sea level. The area is characterized by a strong dissection, narrow deep gorges, rocky slopes, large amplitudes of relative heights. The relief features are also clearly defined traces of glacier activity, which gave the river valleys a trough-shaped form, known as troughs. The activity of glaciers is rocky ridges on the banks of rivers. There are powerful terraces composed of loose-detrital material resulting from the erosion-accumulative activity of glaciers in areas of river valleys, especially in the mouths of rivers flowing into Baksan river, as well as in Baksan gorge. The formation of loose-detrital material on the bottom and on the slopes of river valleys is explained by the weathering of rocks. The reasons for the formation of terraces and loose
cones of loose-detrital material are mudslides in most watercourses of the region.

The vegetation cover of the region is of zonal in nature. Floodplains of Baksan river valley are covered with grass and bushes. Woody vegetation appears higher on the slopes of Baksan gorge. First deciduous trees are dominated, with a height giving way to pine forest. Areas of alpine meadows with xerophytic vegetation – mosses, lichens, and alpine grasses are above the forest zone.

Baksan river and its tributaries in the upper part of the basin are mountain-type watercourses. The main base of the water regime is the spring-summer flood, during which, even during rain floods, rivers carry suspended and sediment. Loose-detrital material is piled up on the slopes of gorges in many places: taluses, debris cones, etc. Formation of air pollution sources is associated with the wind regime of the area and heat and moisture factor.

The wind regime of the area is determined by orographic conditions and temperature conditions defined by the location proximity of eternal snows-glaciers, in accordance with which local mountain-valley winds dominate, characterized by diurnal variability. During the day, the wind blows from the bottom up – the valley wind; at night – in the opposite direction – the mountain wind.

In the area of the mine, strong side winds are observed from the Greater Caucasus Mountain Range side, descending into the valley of Baksan gorge. Winds have the character of mountain dryers. The environment is polluted by dust particles from their places of dislocation – debris on terraces, dumps of overburden rocks of “Mukulanskii” and “Vysotnyi” quarries; the accumulation of geological work dumps, etc. [3].

The wind regime is characterized by average annual repetition in the directions of Table 1 and average annual wind speeds in the directions of Table 2.

| Table 1. Average annual repetition of winds in directions, % |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                 | N   | NE  | E    | SE  | S   | SW  | W   | NW  |
| N               | 22.8| 43.8| 2.2  | 1.7 | 12.2| 15.5| 1.0 | 0.8 |

| Table 2. Average annual wind speed in directions, m/s |
|-----------------|----------------|----------------|----------------|----------------|----------------|----------------|
|                 | N   | NE  | E    | SE  | S   | SW  | W   | N-W |
| N               | 4.7 | 4.8 | 2.0  | 2.1 | 6.7 | 4.7 | 1.1 | 0.9 |

3. Characteristics of mining enterprise activities

Mountainous provinces are ecosystems specific for mountainous areas, characterized by their significant isolation in terms of water and air flows distribution, the concentration of slope demolition in thalwegs, and mosaic microclimatic conditions. Anthropogenic load of mountain valleys determines the degree and nature of pollution not only of the valley, but also of flat landscapes in their mouth parts.

The current level of anthropogenic pressure on mountain valleys is very high: the distribution of load across different valleys of the North Caucasus is extremely uneven. The most tense environmental situation has developed in the valleys of Fiagdon, Ardon, Baksan and Urup rivers, where mining complexes with a developed surface infrastructure operate.

4. Soil horizon contamination with heavy metals

Studies conducted at Geological Faculty of Moscow State University have found that the content and toxic metals in the soil are in the area of activity in which regularities are located, and the content of metals in thickness depends on the depth of soil horizon, which is evidenced by negative impact of mine activity on the extraction and processing of non-ferrous metal ores.

The ingress of metals into the soil occurs in the process of applying environmentally harmful and hazardous technological processes of production: transportation of ore from mines in dump trucks to the processing complex; concentrate on metallurgical processing; removal of dust fractions from the surface of the tailing dumps and landfills of sub-standard ores; incomplete cleaning of mine runoff and wastewater from the processing plants; pollution of the atmospheric basin by polluted air removed from
the mines; leaching of ore minerals in warehouses, dumps, sludges, etc.

The most dangerous environmental pollutants are mercury, cadmium, lead, arsenic, chromium, copper, nickel, zinc, iron, sulfur, etc. Fluently trace elements are considered to be of particular ecological, biological and health significance.

The behavior of trace elements in the soil is very different, the residence time of pollutants in the soil is incomparably longer than in other parts of the biosphere, and its contamination with especially heavy metals is almost eternal.

According to CMGE laboratory, lead, zinc, copper, cobalt, strontium, molybdenum, cadmium, silver, bismuth, arsenic, selenium, manganese, chromium, nickel, and thallium are present in the soils of the Sadon industrial region.

Metals that accumulate in soils are slowly assimilated by plants, and also as a result of erosion and soil deflation, form dust pollution of the atmosphere.

In respect that the ecosystem under consideration includes continuous industrial development of non-ferrous metals, the applied technology allows using only a small part (first percent) of the extracted rock mass. The rest is accumulated on the surface in the form of dumps and sludge, which are potential sources of environmental pollution by a wide range of chemical elements.

The presence of residential areas located in the zone of influence of the mining complex, as well as agricultural development sites with the cultivation of fruit and vegetable crops, while simultaneously occupying the population living there with livestock raising creates a real danger of environmentally safe living in this area [4].

Research has established that the content of the main ore elements in soils in the territory of Nizhny Unal village is: lead – 0.15 %, zinc – 0.4 %, copper – 0.1 %, silver – 30·10^{-5} % and they are confined to soil humus horizon. Low levels of lead and zinc have been found in seasonal vegetables (potato tubers) and high, exceeding MAC – in perennial fruit crops (apples, pears) [2].

The areas and intensity of soil contamination by ore elements exceeding MAC in the area of Nizhny Unal village are given in Table 3.

The background contents of ore elements correspond to average values of alluvium-deluvial formations for North Ossetia in general [3].

Landscapes and soils being an integral part of the ecological systems under consideration are distinguished by a great variety. High-altitude zonality of landscapes, forming the corresponding climatic zones, each of which has certain components (Table 4) is pronounced in the areas of dislocation of existing mountain objects (Sadon mines, “Molibden” and “Urupsk” mines).

| Chemical elements | MACs | Contamination area % | Contamination area | Drift, MACs | Cmax, MACs | qeμ2m |
|-------------------|------|----------------------|--------------------|-------------|------------|-------|
| Pb                | 47.5 | 200                  | 45                 | 460         | 2.3        | 1500  |
| Zn                | 100  | 400                  | 50                 | 1200        | 3.0        | 2000  |
| Cu                | 27   | 100                  | Dotted             | 100         | 1.0        | 100   |
| Ag                | 0.05 | 5                    | Dotted             | 2           | 1.0        | 2     |

Table 3. Contamination area and the content of ore elements (mg/kg) in the soils of Nizhny Unal village

Glacial-nival zone is located above the snow line and is an area of snow accumulation, which turns into firm and glacier ice. Intensive physical weathering is developed in this zone, as a result, detrital material is formed.

The soils are thin, chirping, representing the formation stage of mountain-meadow soils in the subnival belt.

Table 4. Zonality of landscapes

| Zones       | Belt | height of floodplain from sea level, m | Note (mine) |
|-------------|------|---------------------------------------|-------------|

4
Glacial-nival

| Elevation | Description |
|-----------|-------------|
| More 3500 | “Molibden” |
| Mountain-meadow | subnival - alpine |
| 3000–3500 | |
| alpine | 2400–3000 |
| subalpine | 1000–2500 |
| Mountain-steppe | 800–2000 |
| Mountain-forest | Pine and birch forests |
| 1600–2400 | “Sadon” |
| Deciduous forests | 750–1600 |
| “Urupsk” |

Erosion processes and especially chemical weathering play a large role in the alpine and subalpine belts [4–6]. Here, the slopes of the ridges are dissected by deep valleys, the bottom of which lies at an altitude of 1800–2000 m. The bottom of basins and the lower parts of slopes are accumulation place of detrital material, and with mountain-long winds its dust-like fractions serve as a steady source of atmospheric dusting.

5. **Conclusions**

1. It is established that ecological state of the environment depends on the interaction and location of pollution sources and destruction objects.
2. It is shown that soil pollution in the activity area of mining facilities with heavy and toxic trace elements has mineralization of mine origin.
3. It is shown that a pronounced zonality, each of which has certain components that influence the formation of ecological situation takes place in dislocation areas of existing mountain objects of landscapes and soils, which are an integral part of ecosystems.
4. It is established that on the territory of N. Unal village the content of the main ore elements in soils amounts to: lead – 0.15 %, zinc – 0.4 %, copper – 0.1 %, silver – 30·10⁻⁵ % and they are confined to the humus horizon of the soil.
5. Low levels of lead and zinc are found in seasonal vegetables (potato tubers) and high, exceeding MAC – in perennial fruit crops (apples, pears).

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