PROBLEMS OF THE EARTH'S SURFACE DISTURBANCES BY MINING OPERATIONS IN THE CONDITIONS OF THE KRYVYI RIH IRON-ORE BASIN

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DOI: https://doi.org/10.30525/978-9934-26-309-5-11

Kryvyi Rih iron-ore basin is a powerful industrial region, where 75% of all iron ores in Ukraine are mined by underground and open-pit mining method [1, p. 170]. Mines and quarries in the Kryvyi Rih iron-ore basin annually produce 150-160 million tons of iron ore. As a result of the technological process of complex open-pit and underground mining of iron ore deposits, the earth's surface around the city of Kryvyi Rih is experiencing a powerful anthropogenic influence: there is a subsidence of the daylight surface in the form of failure and sink-hole formation, as well as the accumulation on the earth's surface of mining and processing wastes from the enterprises of the mining-metallurgical complex (MMC) [2, p. 3]. The mentioned problems create a complex of ecological and social-economic problems in the region and require attention from the state supervision bodies and business structures involved in the industrial development of iron ore deposits.

If to consider the complex mining of reserves of iron ore deposits in the Kryvyi Rih basin, the following types of the earth's surface disturbance forms can be generally presented (Figure 1). Further, the peculiarities of existing earth's surface disturbance forms, their causes, the scale of formation are analyzed, focusing an attention on the urgent development of mechanisms to significantly reduce these negative technogenic phenomena.

Formation of quarry cavities. To date, there are 9 largest quarries mining iron ore in the region. These are quarries in the area of Kryvyi Rih city – quarry No. 1, No. 3, No. 4 (METINVEST group of companies, PJSC Central Iron Ore Enrichment Works), Pershotravnevyi Quarry, Hannivskyi Quarry (METINVEST group of companies, PJSC Northern Iron Ore Enrichment Works), quarry (METINVEST group of companies, JSC Inhuletskyi Hirnycho-Zbahachuvalnyi Kombinat), quarry («Pivdennyi GZK» Mining and Processing Plant), quarry No. 3, quarry No. 2-bis (PJSC ArcelorMittal Kryvyi Rih).

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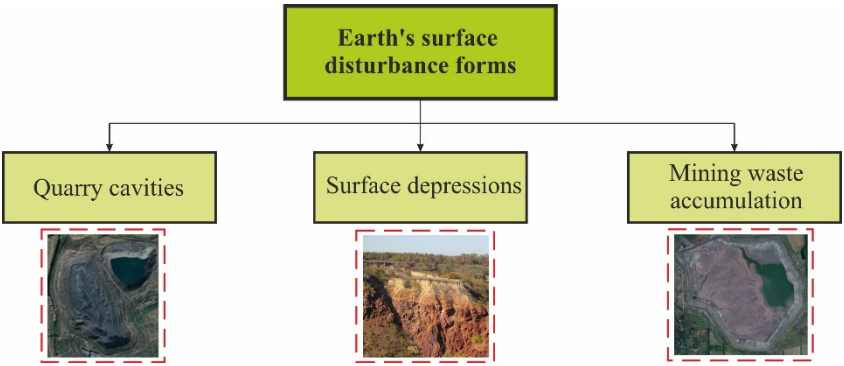

Figure 1. Types of the earth's surface disturbance forms during complex mining of iron ore deposits in the Kryvyi Rih region

The land area disturbed directly by quarrying, based on monitoring data by geoinformation systems, is estimated at more than 3 thousand hectares. It should be noted that there is an inactive quarry No. 2 on the western outskirts of the city, where filling (reclamation) of cavities with overburden rocks of the active quarry No. 1 is performed. On the western outskirts of the city, there is also an old unreclaimed K. Liebknecht quarry, and in the south of the city, there is a closed flooded quarry No. 3 (NKGZK).

The problem of restoring the lands disturbed by quarries is that in open-pit mining, the volumes of overburden rocks stockpiled near quarries are insufficient to fully reproduce landscapes after mining is completed. When exploiting a mineral deposit from the subsoil, as a rule, millions of tons of mineral reserves and associated rocks are withdrawn. Therefore, overburden rocks (soft and hard) can be used at the technical stage of reclamation only as a partial filling of the mined-out space. If the task is to fully restore the former landscape and eliminate technogenic cavities, there is a need to use additional reclamation material.

Subsidence and failure of the daylight surface. Underground mining of iron ores is conducted by 6 mines using the level open stoping mining system (55%) and with sublevel caving (45%) [3, p. 84]. Mining of ore reserves using the existing mining technology does not provide for filling the formed cavities with backfill material. The only iron ore enterprise that conducts environmentally friendly mining of iron ores using an uncemented rockfill is PJSC Zaporizhzhia Iron Ore Plant (the village of Mala Bilozirka, Zaporizhzhia region) [4, p. 77; 5, p. 162].

As a result of the lack of backfilling of underground cavities in the Kryvbas mines, the rock mass is shifted, and subsidence sink-holes are formed on the surface, covering large areas. Such zones are observed within the boundaries of

the land allotments of the Yuvileina, Frunze and other mines, including old closed ones. Thus, the significant earth's surface destruction in the form of sink-holes and failures on an area of 16 hectares as a result of its undermining by the Ordzhonikidze mine is a striking example of the negative effects of underground mining. The consequences are high losses, fatal accidents, stopping the work of mine for 3 months and revision of the mining technology. Separate destruction of the village civilian objects as a result of the earth's surface subsidence was also noted earlier around all 6 underground mines. To date, the area of the undermined territories, according to the estimate of the SE State Institute for Design of mining enterprises «Kryvbasproekt», is 3.6 thousand hectares, and the area of failure sink-holes within the rock displacement trough in the fields of operating and abandoned mines is about 1 thousand hectares. The depth of depressions and subsidence reaches 100 m. Today, the sink-holes formed near the industrial sites of the mines have approached the districts of the Kryvyi Rih city. In nearby villages, there are destructions of civil and infrastructural facilities, resulting in the resettlement of people. Known negative phenomena of the formation of large-scale surface failure zones occurred in 2010 and 2013 and there is a danger of their recurrence.

Formed surface cavities are partially filled with mine rocks, but there is no scientific substantiation and no approaches to the formation of a stable loose mass, which, over time, will probably cause the daylight surface subsidence. If quarry cavities after the completion of the stages of mining operations are subject to mandatory reclamation, then the issue of restoring territories with suddenly formed surface failures remains insufficiently disclosed and scientifically substantiated.

Accumulation of waste from the activities of mining-metallurgical complex enterprises. The state of the natural environment of the Kryvyi Rih region is significantly complicated by the annual generation of large-tonnage industrial waste in the form of quarry overburden and waste rocks, mine waste rocks, beneficiation tailings, and metallurgical slags. The main operating mining enterprises of the city that generate large-scale waste are PJSC Suha Balka, JSC Inhuletskyш Hirnycho-Zbahachuvalnyш Kombinat, PJSC Central Iron Ore Enrichment Works, «Pivdennyi GZK» Mining and Processing Plant, PJSC Northern Iron Ore Enrichment Works and PJSC Kryvyi Rih Iron Ore Plant.

There are at least 13 rock dumps, 8 large tailings dumps, 4 metallurgical slag dumps in the region, and the disturbed land area is more than 10 thousand hectares. According to the authors' preliminary estimate, more than 10 billion tons of overburden and waste rocks, as well as more than 4.5 billion tons of beneficiation tailings and metallurgical slags have been accumulated. Enterprises pay millions of hryvnias of ecological tax for storing the specified

waste within the boundaries of the settlement. Infiltration of substances from technogenic waste accumulations significantly pollutes soils and groundwater. Numerous areas, which are valuable for agricultural use, are allocated for the technogenic waste storage. At present, the completion of the design dimensions of the tailings storage facilities for beneficiation products, which are 95% full, is an acute problem, and free promising land areas in the Kryvyi Rih region for new tailings storage facilities are not provided.

According to the authors, the main ways to solve environmental problems today are the following measures:

1. To prevent the occurrence of subsidence and failures of the daylight surface, it is expedient to use full or partial backfilling with waste rocks, as well as rockfill mixtures and backfill materials, for which technogenic waste can potentially be used. The world practice of backfilling technologies shows a successful experience of using technogenic waste as backfill components, despite significant capital and operating costs.

2. In order to eliminate the already formed cavities, subsidence and failures of the earth's surface, it is proposed to form a combined backfill mass from technogenic waste in them. However, these measures currently need to be carefully studied, which is insufficient. The formation of backfill masses will lead to minimization of daylight surface deformations. Given the fact that industrial wastes are owned by single enterprises, it is expedient to combine the «cavity-waste» system in the form of a backfill mass.

Acknowledgements. The research was performed within the framework of scientific research under the grant project of the National Research Foundation of Ukraine (NRFU) 2021.01/0306.

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