DOI: 10.21440/0536-1028-2020-7-73-82

Minimizing chemical contamination with commercial solutions when producing metal in highland regions

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Abstract

The research aims *to work out in details the measures taken to limit ecological risks when producing ore in highland regions.*

Research methodology *includes applying the methods of X-ray fluorescence spectrometry, neutron activation analysis, and mass spectrometry to study the mechanism and indicators of environmental ecosystems chemical pollution with the products of synergetic interaction among the ingredients in metallic minerals.*

Research results and scope. *The data on the role of water in mining have been introduced. The features of mining industrial wastes impact in the conditions of the Caucasus highland. The leading role played by metallic ore mill tailings in chemical pollution of highlands has been numerically proved by the example of the major fields. The idea has been formulated that highland territories are weakened and public health is deteriorated due to chemical contamination of highland environment by mining waste. Quantitative parameters of mining and smelting impact on public health have been determined, and the prospects of measures taken to protect population from the negative impact of mining have been forecasted. It has been shown that overall protection of environment from chemical pollution is possible only in case of advanced recycling of waste. Advanced methods of trade effluent reclamation have been recommended. Research results may be applied at the underground development of metallic ore deposits.*

Summary. *In the conditions of highlands, ecosystems contamination with the products of synergetic interaction among the ingredients of metallic materials in the process of metal production increases. Environmental protection from chemical contamination with liquid products of mining is possible by extracting chemically dangerous metallic ingredients and reducing their concentration down to the level of hygienic standards with the use of new natural and resource saving technologies.*

Key words: *mining; trade effluent; ecology; mill tailings; ecosystem; public health.*

Introduction. The efficiency of mining is strongly influenced by mine effluent, i. e. groundwater, interstatial water, middle water or fissure water which contains dissolved metals, organic and chemical compounds, and mineral particles. Russian ore mining and processing enterprises surface more than 1.3 billion m^3 of effluents annually.

Many enterprises have been experiencing difficulties within a long time due to deposits inundation. So, 2100–2200 m^3/h of water from the underground mine workings and 700 m^3/h more from opencast mines have been pumped out in the Lebedinsky pit of the Kursk magnetic anomaly. A mean efficiency mine discharges about 1000 m^3/h of sewage to the surface.

Mining facilities deliver mill tailings to the natural environment together with discharges and filtrates from mineral thickening and dewatering, atmospheric and natural effluents drained into the mine workings, and effluent from current flow processes.

In the traditional scheme of field development all the water is delivered to surface, the liquid phase of mill tailings is added, and the whole thing is discharged to the surface, often with no purification. Metal solutions are drained through the underlayer and migrate to the surrounding environment (fig. 1).

In the overwhelming majority of cases, sewage is discharged into the surface watercourses. The main part of water pumped out at field dewatering comes to rivers changing their water regimes. Vast local depressions of groundwater are developed in the mining regions.

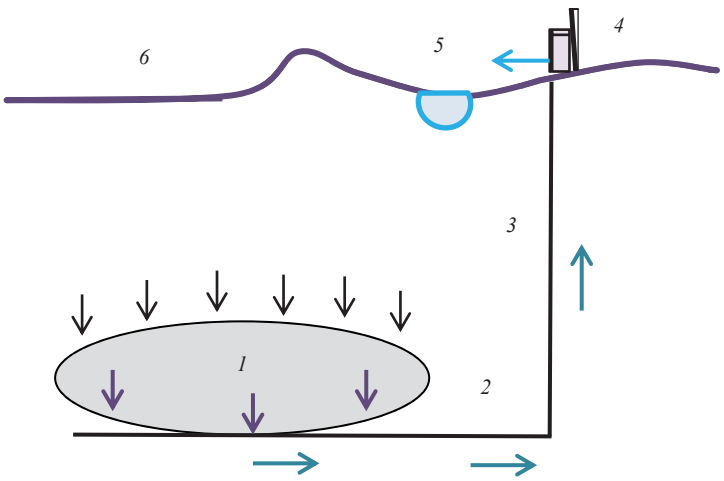

Fig. 1. Movement of water flows at underground mining of a deposit:
1 – deposit; *2* – collecting mine working; *3* – producing miner working; *4* – mine's surface; *5* – river; *6* – relief

Рис. 1. Движение водных потоков при подземной разработке месторождения:
1 – месторождение; *2* – сборная выработка; *3* – выдающая выработка; *4* – шахтная поверхность; *5* – река; *6* – рельеф

When opencasting minerals from placer deposits, water regimes alternation is the consequence of peat and sand preliminary dewatering carried out under hydraulic, bulldozer and excavating methods of development with the help of stream diversion and drainage channels.

During ore fields underground development with conventional technologies, water is used in flow processes of drilling, delivery, dust removal, etc.

Mill waste accumulation in tailings dams is the main reason for the environmental impact of mining. With time, a dome with water mineralization manifold exceeding the threshold limit value (TLV) develops under the storage facility. The dome is the exciter of chemical contaminants discharge into the environment.

Water which leaves the boundaries of the tailings dam contains copper, iron, and sulphur, the concentration of which is often commensurable with their concentration in ore. Dam water drainage in the tailings dam, where the uranium crude processing waste is stored, has radiative forcing on the environment. The main factor of the environmental impact is waste water contamination with sulphates, nitrates, marganese, molybdenum, and other toxic maters.

At small-scale mining, sewage does not significantly contaminate water bodies and watercources, but distributes along the surface differentiating in the soil layer. Water contamination may manifold exceed TLV.

In new methods of development with leaching and dissolution, metal solutions which haven't been isolated from the environment are referred to pollutants.

Polluted water is actively involved in domestic and agricultural cycle affecting flora, fauna and people. The most severe consequence of hydrogeological and thermal regimes alternation is the deterioration of the hydrobiological situation in seas and lakes rivers run into. For the Caucasus it is the Caspian Sea.

Ecological tension in the zone of mining activity has reached its critical level of territory's contamination with heavy metals. For that reason, a prior task of environmental protection is to monitor public health in the mining region.

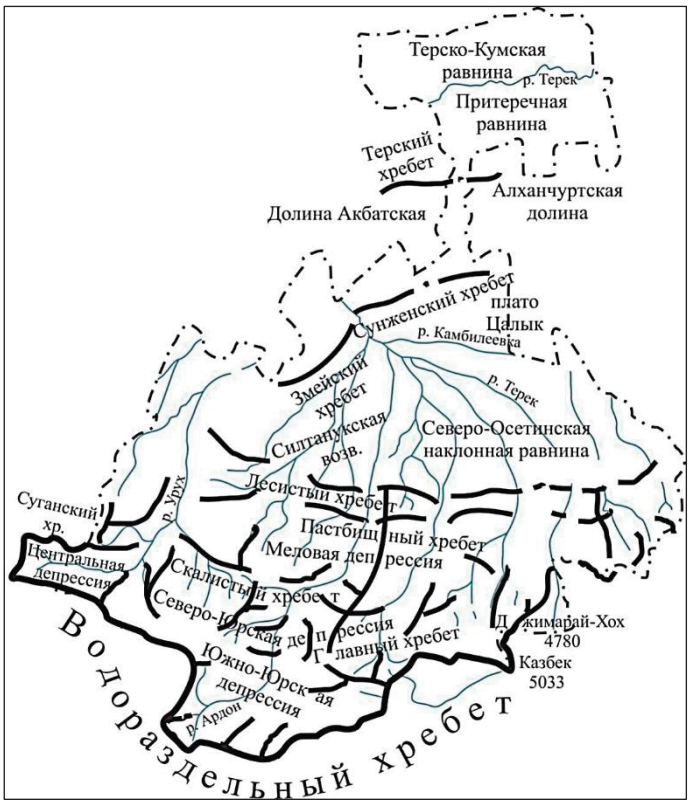

Fig. 2. Orography of the Ossetian part of the Central Caucasus
Рис. 2. Орография осетинского участка Центрального Кавказа

In the organism's reaction to the effect of ecotoxicants, including heavy metals, a crucial role is played by the development of ROI, intensification of lipid peroxidation, membrane damage, DNA damage, which stimulates the development of cancer formation, CVD, neurodegenerative diseases, and mutagenesis.

The issues of minimizing the rate of environmental chemical contamination by mining industry form the problem of global importance. The object of research are the large-scale allotments of industrial production including mineral deposits exploitation in highland regions which are the most insecure areas of the Earth.

The research aims to work out in details the measures taken to limit the ecological risks from mining ore in highland regions of the Russian Caucasus.

Object, tasks, and methodology. The mechanisms and results of environmental ecosystems chemical contamination with the products of synergetic interaction among polymetallic ore mill tailings ingredients in storage facilities have been studied using the integrated method including mill tailings, soil, and water sampling.

The methods of X-ray fluorescence spectrometry, the neutron activation analysis, and mass spectrometry have been used to obtain the information on the content of elements-toxicants.

Research results and discussion. Mining is most hazardous in the conditions of the mountainous terrain which is characterized by diverse conditions, dissected relief and high amplitudes of altitudes. The Caucasus orography controls and intensifies the processes of chemicalization of the natural environment, localizing contamination zones and preventing from concentration reduction across a larger area (fig. 2).

Table 1. Metal concentration in the River Baksan in peak phases
Таблица 1. Концентрация металлов в р. Баксан в пиковые фазы

Interval of the River Baksan	Metal	Concentration, mkg/l					
		minimum		maximum		average	
		winter	summer	winter	summer	winter	summer
40 km	Chrome	0.20	0.95	0.80	5.98	0.45	2.96
	Nickel	0.45	0.72	1.06	3.22	0.82	1.55
	Molybdenum	0.47	0.91	8.35	8.37	2.77	4.03
	Lead	0.27	0.20	0.49	3.62	0.38	1.12
	Zinc	1.50	1.50	2.51	11.76	1.75	4.89
55 km	Chrome	0.20	0.74	0.47	4.20	0.29	1.83
	Nickel	0.90	0.70	0.97	1.91	0.56	1.28
	Molybdenum	2.50	0.92	7.40	16.4	2.89	5.71
	Lead	0.20	0.33	0.53	1.93	0.37	0.96
	Zinc	1.50	1.50	1.50	8.13	1.50	4.01
70 km	Chrome	0.20	0.39	0.38	8.80	0.28	3.65
	Nickel	0.20	0.40	0.68	3.58	0.52	1.88
	Molybdenum	1.34	0.20	6.38	12.03	3.28	4.76
	Lead	0.20	0.20	0.57	2.64	0.31	0.98
	Zinc	1.31	1.30	7.06	5.51	3.72	3.15

Environmental footprint and water streams pollution grows with the expansion of residential mountainous territories; and not in every instance the nature can cope with that. The main collectors of technogenic pollution are the River Baksan and the River Ardon which collect effluent from large mining enterprises, the Tyrnyaus Tungsten-Molybdenum Plant (Kabardino-Balkaria) and the Sadonsk Lead-Zink Plant (Republic of North Ossetia –Alania).

Baksan flows from under the glacial shell of mount Elbrus and accepts more than 15 tributaries, including the River Cheget and the River Cherek. In the valley of the River Baksan, the towns of Tyrnyaus, Baksan, Prokhladny and many other communities are situated. Water is mildly alkaline and neutral, in the winter period pH varies within 7.5–8.0 units, and within 8.0–8.1 in the summer.

Human impact on Baksnan water is most pronounced in the territory of the Tyrnyaus Tungsten-Molybdenum Plant.

Old tailings dam with mill tailings is situated 2 km downhill and represents an embankment 15–20 m high with slopes 30–60 m steep, filled up with 10–15 cm soil layer with vegetation. The main tailings dam is situated at the 55th km marker near Bylym village and includes a retention pond with the area of 70 ha, 2 km long and 220 million m^3 capacity confined by the earth-fill dam 110 m high.

In Baksan water, TLV of copper, for instance, is exceeded by 20–30 times. In the area of the Molybdenum mine and its tailings dam the concentration of copper is exceeded by 50 times.

Baksan water is continuously contaminated by tailings dam effluent. Systematic contamination of water with metal is recorded at the distance from 40 to 70 km (table 1).

It follows from table 1 that almost all components of river water are governed by a general rule: metals concentration decreases with the distance from the contamination source, which proves the tailings dam's role in chemical pollution.

The tailings dam is classified as ecologically hazardous facility, as soon as in case of inundation or earthquake it threatens with destruction to the outlet water tunnel of the River Gizhgit. The River Gizhgit may come back to its natural river-bed, overfill of retention pond, destroy the dam and carry away the mill tailings to the river-bed of Baksan all the way to Terek.

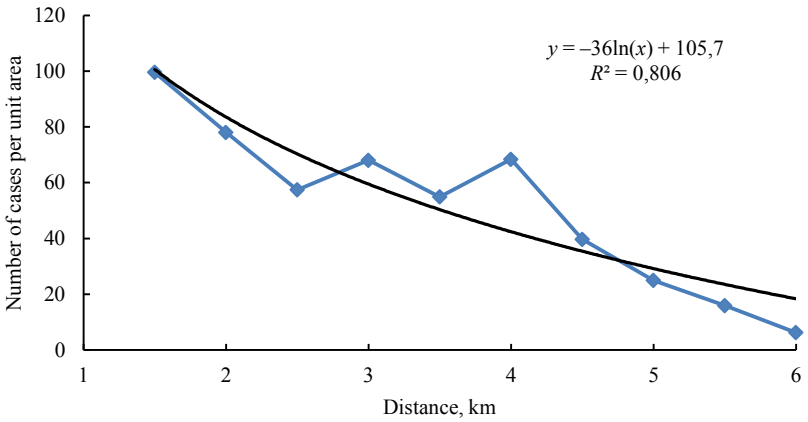

Fig. 3. Dependence between the number of oncological cases and the distance to industrial facilities

Рис. 3. Зависимость числа случаев онкологических заболеваний от расстояния до промышленных объектов

The content of metals in vegetable and grain products is abnormal as soon as people use water for household and practical needs, which may cause irreversible damage to the metabolism of local population.

The impact of the Sadonsk Lead-Zink Plant is the same. Ore extracted from its deposits since 1929 have been dressed at the plant in Mizur town. At its time the plant processed up to 20 thousand ton of ore a day, and the concentrates obtained by selective flotation contained: Pb, Bi, Sb, Ag, Au, Cu, Zn, Co, As and other metals. Up to 1984 tailings have been stored in a narrow side valley of the left tributary of Ardon located over the Mizur town. From 1929 to 1984 some tailings were discharged into the River Ardon polluting it with metals all through. For that reason, in 1984 a new tailings dam was built. The tailings dams of Sadonsky mines are situated in the floodplains of rivers, which promotes to chemically active trade effluent travel.

The River Ardon accepts impure effluent from the mines and the tailings dam 150 × 280 m in size with an earth-fill dam up to 30 m high in the valley of the River Ardon.

Effluent from the lower part of the tailings dam has highly alkaline value (pH 11.2), its total mineralization radically differs from other samples and makes up 10 746 mg/l.

The value of pH of natural water is close to neutral, pH varies from 6.9 to 7.4. Samples higher than the tailings dam are close to each other and refer to hydrocarbonate-sylphate natrium-calcium water. It proves the presence of synergetic processes in the mass of the tailings dam.

In high winds, finely dispersed fraction of mill tailings pollutes the soil of pastures, farming lands and water of Ardon negatively affecting public health. Comparison with the baseline sample in Sadonka water in the vicinity of the tailings dam revealed the excess in the concentration of arsenic by 25 times; uranium – by 14 times; stibium, tellurium, molybdenum – by 6 times; tungsten, lead, and vanadium – by 4 times; and other metals – by 2–3 times.

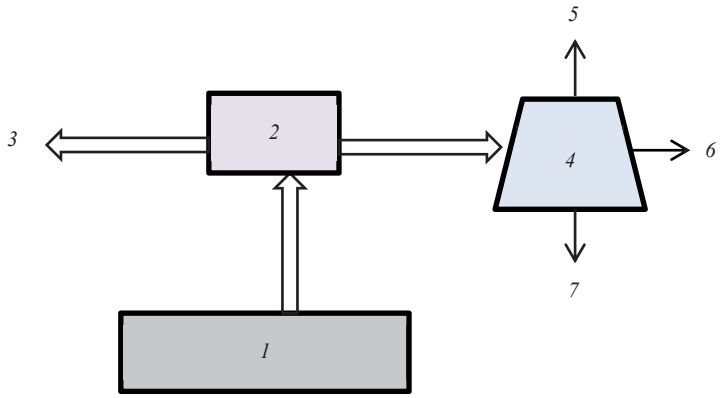

Fig. 4. Movement of water flows when mining with traditional methods:
1 – deposit; *2* – ore processing; *3* – concentrate; *4* – mill tailings dam; *5* – water into the atmosphere; *6* – water into the hydrosphere; *7* – water into the lithosphere

Рис. 4. Движение водных потоков при разработке традиционными способами:
1 – месторождение; *2* – переработка руд; *3* – концентрат; *4* – хранилище хвостов переработки; *5* – вода в атмосферу; *6* – вода в гидросферу; *7* – вода в литосферу

Comparison with the baseline sample in water covering the surface of the tailings dam has revealed abnormal excess of metal concentration: arsenic – by 41 430 times; tellurium – by 17 720; stibium – by 10 430; selenium – by 10 230; tungsten – by 1520; lead – by 930; molybdenum – by 390; vanadium – by 105; germanium – by 70; tin – by 50; and other metals – by 2–26 times.

In a large city of the North Caucasian Federal District, Vladikavkaz, health indicators of adult and child population of the city were studied, including the incidence rate in the following directions: neoplasms, blood diseases, diseases of genitourinary, nervous, and endocrine systems, diseases of ear and respiratory system, caused by the man-induced impact of ore mining and processing products.

Increase in the number of neoplasms among the population was systematized according to the principle of the clinical zoning. The information was plotted on the city map. The dependence between diseases incidence and steelworks vicinity in the north-eastern part of the city was determined experimentally. Heavy metals dispersion halo was discovered in the area of about 40 km^2 where metals concentration exceeded mean concentration by an order.

The number of diseases per unit area decreased with increasing distance from industrial facilities. Quantitative parameters of negative impact from mining and smelting on public health have been determined (fig. 3).

Analysis and discussion. The development of metal ore fields in the mountainous territories of the Caucasus is accompanied by the contamination of highland environment, industrial waste growth, vegetation degradation, and public health deterioration in urban territories especially in the vicinity of mining enterprises.

Analysis of ideas about the minimization of mining impact on the hydrosphere shows that safe methods of storing ore mill tailings do not exist. Overall protection

of environment from chemical pollution is possible only in case of advanced recycling of industrial waste.

Contaminated effluent comes into the environment after flowing out of mine workings to the surface or travels with mill tailings to the tailings dams.

The following options for minimizing the region's chemicalization are available for mining enterprises:

– traditional extraction of metals by means of breaking it in blocks, transporting to the surface and processing at a plant with the uncontrolled mechanism of interaction between natural-technogenic solutions and ecosystems (fig. 4);

– extracting metal from ore in underground mine workings using mining methods with leaching, and managing the flows of solutions by means of localizing them technologically (entrapment and extraction of metals) (fig. 5).

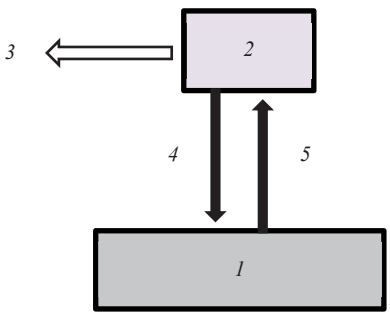

Fig. 5. Movement of water flows when mining with leaching:
1 – deposit; *2* – ore processing;
3 – concentrate; *4* – chemical solution;
5 – production solution

Рис. 5. Движение водных потоков при разработке способом выщелачивания:
1 – месторождение; *2* – переработка руд;
3 – концентрат; *4* – раствор реагента;
5 – продукционный раствор

Hydrometallurgical processing methods with processes activity increase by mechanochemical treatment in desintegrators and other devices may be in demand for waste disposal.

Known technologies of trade effluent purification before discharge into the environment, for instance, liming and chlorination, are harmful for the environment and may cause side effects. Electrochemical, sorption and other technologies make it possible to purify effluent up to the standards of fish industry, but they are expensive and therefore not applied for mine effluents cleaning.

The results of clinical-biochemical examination of residents in the Alagirsky region hosting the mining enterprise, who are influenced by chemically active water streams associated with contamination with heavy metals as a result of the lead-zinc plant activity, have shown serious violation of antioxidant status and development of oxidative stress among the population.

Violation of *prooxidant–antioxidant* system's balance in blood of population can be considered as the manifestation of the metal-induced toxicity, which promotes to poor resistance of the survey organisms to the disturbing factors of the environment and to the development of severe and practically untreatable pathological processes.

By means of managing the flows of solutions in the process of metal production, it is possible not only to reduce the environmental impact on mining regions and receive necessary metal and construction materials, but also reduce the risk of incidence among the population and technogenic catastrophes associated with possible dam failure, or other forms of water streams impact.

Research results may be helpful when upgrading the technologies of underground mining in the ore fields with particular conditions of location.

Conclusion. Liquid ingredients are the instruments for chemical contamination of natural environments being the transporting system for natural and process flow solutions of metals and salt.

Mine effluent plays crucial role in a system of mining impact being the product of synergetic interrelation among ore mill tailings ingredients in tailings dams.

The impact of mineral production and processing wastes on living matter must be assessed with the account of production and processing waste hazardous ingredients migration halo.

Overall environmental protection from chemical contamination with liquid products of mining is only possible by extracting chemically dangerous metallic ingredients from mineral waste up to the hygienic standards using machines-activators.

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Received 10 August 2020

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УДК 504.55.054:622(470.6) DOI: 10.21440/0536-1028-2020-7-73-82

Проблема минимизации химического загрязнения промышленными растворами при добыче металлов в горных регионах

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Реферат

Цель работы *– детализация мер ограничения экологических рисков при добыче руд в горных регионах.*

Методология проведения работы. *Исследование механизма и показателей химического загрязнения экосистем окружающей среды продуктами синергетического взаимодействия ингредиентов металлосодержащих минералов методами рентгенофлюоресцентной спектрометрии, нейтронно-активационного анализа и масс-спектрометрии.*

Результаты работы и область их применения. *Приведены сведения о роли воды в горном производстве. Охарактеризованы особенности влияния промышленных стоков горных предприятий в условиях гористых ландшафтов Кавказа. На примере крупных месторождений дано количественное подтверждение ведущей роли хвостов обогащения металлических руд в химическом загрязнении горных территорий. Сформулирована концепция ослабления экологии горных территорий и ухудшения здоровья населения вследствие химического загрязнения горной среды отходами горного производства. Определены количественные параметры влияния горно-металлургического производства на здоровье населения и дан прогноз перспектив мер по защите населения от негативного влияния горного производства. Показано, что радикальная защита окружающей среды от химического загрязнения возможна только при глубокой утилизации отходов, рекомендованы прогрессивные методы утилизации промышленных стоков. Результаты исследования могут быть использованы при разработке месторождений металлосодержащих полезных ископаемых подземным способом.*

Выводы. *В условиях гористых ландшафтов загрязнение экосистем продуктами синергетического взаимодействия ингредиентов металлосодержащих веществ в процессе производства металлов усиливается. Защита окружающей среды от химического загрязнения жидкими продуктами горного производства реально возможна при извлечении химически опасных металлических ингредиентов и снижении их содержания до уровня санитарных норм с использованием новых природо- и ресурсосберегающих технологий.*

Ключевые слова: *горное производство; промышленные стоки; экология; хвосты обогащения; экосистема; здоровье людей.*

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Поступила в редакцию 10 августа 2020 года

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Для цитирования: Дмитрак Ю. В., Кожиев Х. Х., Дзапаров В. Х., Дзеранов Б. В. Проблема минимизации химического загрязнения промышленными растворами при добыче металлов в горных регионах // Известия вузов. Горный журнал. 2020. № 7. С. 73–82 (In Eng.). DOI: 10.21440/0536-1028-2020-7-73-82

For citation: Dmitrak Iu. V., Kozhiev Kh. Kh., Dzaparov V. Kh., Dzeranov B. V. Minimizing chemical contamination with commercial solutions when producing metal in highland regions. *Izvestiya vysshikh uchebnykh zavedenii. Gornyi zhurnal = News of the Higher Institutions. Mining Journal*. 2020; 7: 73–82. DOI: 10.21440/0536-1028-2020-7-73-82