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REVIEW OF GLOBAL TRENDS IN MEETING THE ECOLOGICAL CHALLENGES OF THE MINING INDUSTRY.

PART I: INTERNATIONAL RESEARCH*

The scope of the present-day open pit mining embraces numerous deposits of diverse solid minerals on all continents. Both surface and underground mining unconditionally entails dramatic environmental impact. The path of this investigative review runs from the continents and countries in the Northern Hemisphere to the Southern Hemisphere and from the Western to the Eastern Hemisphere.

The review of the global research in the area of mining ecology has revealed the main trends of ecological studies on the continents and at various solid mineral deposits, either mined-out or in operation. Challenges facing the mining ecology include land reclamation, soil quality improvement in artificial revegetation, surface and underground mine water treatment and quality analysis, phyto-remediation of disturbed land, recovery of vegetation diversity, investigation of suitability of mined-out open pits and overburden dumps for colonization by insects, birds and wild animals, study of suitability of mined-out pit voids for colonization by aquatic fauna, analysis of soil pollution with heavy metals and cancerogenic substances in the course of mineral mining and processing, after-effect of mining on people health, preservation of the vegetable world and wildlife in the mining-adjacent areas, as well as administration of interaction between mining companies, governmental authorities, civil society and environmental agencies. Each of these trends is promising for the further research and analysis.

To our opinion, these trends are correlated and represent an integral system defined as interaction of the vegetable, aquatic, animal and human worlds. This interaction needs persistent improvement of mining ecology and minimization of the environmental impact of industry. The associate problem solving widely uses eco-mathematical modeling, specialized experimentation at a laboratory scale and accumulation of in-situ information.

Keywords: *global mining industry, mining ecology, international environmental problems, land reclamation, bio-diversity preservation, aquatic and vegetative ecosystem recovery, human ecology*

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Introduction

Solid minerals, without which no economic community can exist, are extracted on all continents of Planet Earth. Open pit mining is vastly carried out all over the world, which unconditionally has a critical environmental impact. Professional theoreticians and practitioners in mining address the mining industry ecology problems in all mineral producing countries. Thus, the present development stage of this research necessitates systematization of the accumulated knowledge in the area of promotion of mining ecologization on a global scale.

Review of applied ecology research in mining sector

Our investigative review follows the country-wise course from the Northern to the Southern Hemisphere and, then, from the Western to the Eastern Hemisphere. The continental-wise path of the research runs from North America to South America, then to Europe and Africa, and, finally, to South East Asia and Australia.

In Alberta, Canada, a large tar deposit has been in operation for more than 50 years. The environmental actions included formation and analysis of mixed soil for reclamation of disturbed land. Addition of coarse waste wood in the mixture of peat and loose overburden improved accessibility of azote for microorganisms to feeв upon. That, after reclamation, increased the number of biocommunities which positively influenced initiation and growth of plant associations on the post-mining recovered landscape [1]. Ecologists inspected dispersal of birds on the recovered land after mining of oil-bearing sands. The population of birds preferring nesting on open pasture land decreases every year. Shrub and plant vegetation development in reclamation areas leads to succession of sites of land birds and to quantity input of bird kinds preferring nesting in the shadow of bushes and forests [2].

Another research into disturbed land reclamation using a humus layer was carried out in Alberta, Canada, in the area of a tar sand deposit under mining. It is found that long storage of a soil stratum removed during mining results in essential worsening of its quality. It is advisable to apply a humus layer on the land being reclaimed immediately after its removal in the planned limits of mining operation, without intermediate warehousing [3]. Furthermore, in the same area, it was for the first time proposed to carry out reforesting with regard to the climate change on the planet. A landscape model of boreal forests afforested on reclamation sites with regard to the climate change trends was studied. It was concluded that domination of coniferous trees such as fir trees could greatly reduce within the horizon period, which should be taken into account in the disturbed land reclamation activities in this region [4].

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In Southern Ontario, Canada, reclamation of land at sand quarries was analyzed. The reclamation soil was added with biocoal, manure and a subculture of arbuscular mycorrhizal fungi. An increase in the manure portion to 4000 kg/h appreciably accelerated plant growth every time [5]. In the west of Alberta, Canada, coal has been produced by the open pit mining method for more than 40 years. Land reclamation includes generation of a self-sustaining ecosystem. Efficiency of reclamation is defined by recovery of vegetation. Spotlight is also on creation of a convenient habitat for big-horns, elks and blacktails. The studies continued for 18 years starting fro 2004. The hoofed species chose habitat areas nearby roads, i.e. where people can be [6].

In Ohio, USA, the open pit coal mine closure activities include reforesting of the areas. In the natural and recovered forests, the amphibian species diversity, namely, salamanders, was examined. The number of salamanders showed no changes but their species diversity slightly reduced. That was associated with the worse water quality in manmade water bodies in mined-out voids of closed open pits [7].

In Pennsylvania, USA, underground coal mining induces subsidence of ground surface under beds of rivers and streams. As a result, deep basins appear and pose a threat to living inhabitants. It was recommended to reshape banks of the manmade water bodies by flattening their slopes on 18 sites, which favored recovery of the live environment of fish communities [8]. On the land reclaimed after coal mining in Ohio, USA, commercial beekeeping conditions were inspected on 12 sites. It was found that growth and reproduction of bee colonies were greatly susceptible to the diversity of flowerage which was the honey flow source. The mining land reclamation activities included bee flow planting [9].

The composition of the White River bottom sediments in Northern Arkansas, USA, was studied to trace the impact exerted by old mines on current water. The concentrations of Pb, Cu, Zn and As in soil in the neighborhood of old mines exceeded the same values in the adjacent areas free from mining operations. The listed elements enter open water bodies with surface water courses. It is required to reduce concentration of metals in soil [10].

In South America, in Cajamarca and Huancavelica in Peru, in the areas of surface and underground gold mining, ecologies revealed essential concentrations of heavy metals (Cd, Cr, Cu, Hg, Ni, Pb and Zn) and one metalloid (As) in the soil layer. It is proposed to use the information on soil pollution with heavy metals to detect the pollution sources and to undertake the required activities to restore the soil cover in the period of land reclamation at the stage of mine closure in the Cordillera and Andes highlands [11].

In Carajas, Brazil, on iron ore mining-disturbed land, endemic pea family plant Mimosa acutistipula and ruderal shrub species Solanum crinitum are cultivated. The plants miss azote, phosphorus and potassium, which should be taken into account in disturbed land reclamation in a similar climate [12].

The influence of concentration of phosphorus applied to the soil layer in forest reclamation on tree growth was studied in the area of bauxite mines in Brazil. It was succeeded in increasing the rate of growth of trees up to the rate of tree growth in natural forests by applying phosphate to the soil layer. That was an important condition of fruitful forest regeneration even in the tropical climate of Brazil [13]. Ecologists disclosed slow reestablishment of vegetation cover in the areas without soil. In such areas, the soil layer removed in the limits of a mineral deposit but never applied in the highlands was placed. After composing and applying a mix of soil and aboriginal vegetation seeds, a positive result was obtained in 4 years in the form of eumorphic herbosa. Ecologists revealed no difference of the new ecosystem from the natural landscape [14].

For more than 30 years in Brazil, sulfide-bearing gold ore underwent metallurgical processing at Nova Lima in Minas Gerais. Waste was placed at Kokoruto. Ecologists studied the mineralogy and geochemistry of flotation and leaching tailings at an operating metallurgical plant. Concentrations of Zn, Cu, Au and As were higher in the operating plant tailings. The studies showed that sulfide waste were protected from acidic effluents. The tests revealed feasibility of outwashing of toxic As and Mn from the closed tailings pond and Sb, As, Fe, Ni and Se from the operating plant tailings. This study emphasizes appropriate and rigorous management and control of both operating and closed tailings facilities in the mining sector [15].

Judged from the open pit kaolin mining chronology in South West England, researchers have found out that 150 years after termination of mining, young soil cover is vegetation-inefficient. It is advised to apply organics and biocommunities to the soil layer in reclamation of kaolin mining-disturbed land, and to amend the reclamation procedure [16].

In the territory of Spain, the rock nesting Sand Martins live. The birds build their nests on cliff slopes of mined-out southwestward pit walls. The birds prefer the pits nearby current water and mortar sand quarries. It is recommended to make spoil banks vertical after open pit mining completion, to make them nesting-suitable for Sand Martins [17]. In Spain as well, the natural habitat of the Black Redstart on rocky hills of a broken relief was inspected. The Black Redstart builds nests in small (area of 0.25 ha) quarries inaccessible for carnivores. Larger quarries, more than 2 ha in area, are selected by the birds if there is a feeding potential and if no harm threatens their nests [18].

Furthermore, ecologists investigated habitats of Eurasian otter (Lutra lutra) in the areas of mined-out gravel quarries. The required habitation conditions include water body bank vegetation and afforestation, and no people presence nearby. The mined-out gravel quarries are assumed to be suitable for living of this mammal [19].

In the old mining region of La Carolina in Spain, the bed bottom sedimentation composition of Rio Grande flowing into a water body meant for the municipal water supply was analyzed. The concentrations of Pb, As and Ba exceeded the regional and European standards. The maximum concentrations of these elements are observed in the valley flat of the river, which naturally induces overrun of environmental indicators (contamination factor, potential ecological risk index, etc.) [20].

In central Spain, ecologists studied concentrations of heavy metals in subsurface of processing waste storages at galena and sphalerite mines. The concentrations of Pb, Zn and Cd are much higher than the maximum allowable values. The lab-test soil samples were applied with seed pieces which died soon. That bio-testing technique was recommended for the ecological evaluation of processing waste in tailings ponds [21].

German RWE Power AG energy company has accomplished reclamation in the area of 30 thousand hectares of open pit mining-disturbed land. Reclamation of mountainous areas provided new knowledge usable to optimizing joint handling of economic and environmental challenges. RWE Power AG promotes and encourages maintenance of biodiversity in reclamation of mining-induced landscape. The Reclamation Office of RWE Power AG carries on cooperation with volunteer environmentalists and reclamation researchers. Within the last two decades, in the coal mining area of the Rhineland, more than 3000 animals and 1300 plant species were identified. Many of them are rare and endangered, and are documented in the Red Book. The reclamation researches show that landscape rehabilitation may follow two ways to the common objective of nature preservation—agriculture and forestry. Restored landscapes enable sustainable increase in regional biodiversity [22].

In Germany issues of mining ecology root in the second half of the 19th century and are connected with the beginning of mining operations in the Rhine lignite field. The ecological problems being solved make ground for the development of new environmental standards. A demonstrative example is the law on forest reclamation of slopes of overburden dumps after open pit coal mining [23]. After unification of East Germany and West Germany, the eastern coal mining industry undertook modification of the coal mining technology with regard to the environmental goals. On the land disturbed by open pit coal mining, with a total area of 105 thousand hectares, reclamation of pitwalls and waste dumps was carried out. The site-individual reclamation projects abided to ecological standards [24].

In 2009 the law on the common public federal management and preservation of nature was enacted in Germany. The law dictated analyzing environmental impact of mining operations. Mining companies initiated softening of the requirements set by the law. However, the mining companies had to reject the initiatives when faced ecological problems [25]. Land reclamation activities in Germany are supervised by regulatory authorities. The reclamation standards are targeted at accelerated recovery of ecological balance, and are amended as per the social, environmental and technical regulations [26]. In early 2014, in central Germany where open pit coal mines operate, a new global ecological problem arose. A funnel-shaped depression formed, with water shortage at the level of 12 Bm^3. The new task of the water balance recovery required a prompt governmental response [27].

In the Check Republic, in 321o pen pits producing solid minerals, ecologists discovered 235 (14%) endangered species of flora. The number of such species was minimal in the pit overgrown with trees. It was found that those species slowly inhabited forested sites on disturbed land after completion of open pit mining [28].

In the mountainous mining areas of the Sudetes in Poland, antimony solubility in dump soil was investigated. Heavy natural beech-tree waste led to swamp formation on the dumps. As a consequence, antimony concentrations grew in surface water. Under such conditions, in rainy seasons, much antimony enters surface water bodies, which impairs natural habitats of all living organisms [29].

In Morocco in Africa, mineral processing waste bearing sulfides continuously emit products of chemical reaction in adjacent areas. Ecologists accomplished phyto-stabilization in a small area, with planting of local wilding species capable to grow on the surface of such waste storages. After two vegetation seasons, it was found that the rooting depth of Atriplex semibaccata, Vicia sativa, Launaea arborescens, Peganum harmala and Asparagus horridus contained essentially higher concentrations of As, Cd, Cu, Ni and Zn. From the evidence of the field studies and lab-scale tests, the listed plants were assumed suitable for phyto-stabilization of the whole surface area of tailings dumps [30].

Zambia's Chingola copper province with a total area more than 30438 hectares accommodates 2807 Mt of mining waste (overburden, tailings, slurry and slag). The concentrations of heavy metals Cu, Co, Ba, Ni, As, Zn, Pb, Cr, V and Cd in these areas are a few tens of times higher than the maximum allowable values. These elements are heavily harmful for health when they enter food chains via products of farming in neighborhood of copper mines, and impair reclamation efficiency on disturbed land [31].

Aimed to reduce high concentrations of heavy metals in soil nearby Kabwe Mine in Zambia for the farming purposes, the soil was applied with a mix of poultry dung, triple super phosphate fertilizer and a compound manure (N, P, K). Introduction of the additives on the cornfields reduced the concentrations of Pb and Zn in dredged corn and in reeds by 18 and 25%, respectively. Alternatively, the concentrations of mobile Cd in dredged corn increased. The conclusion was drawn that introduction of additives in soil reduced the content of heavy metals in dredged corn, and the problem connected with cadmium bioaccumulation should be addressed specifically [32].

In Tochigi Prefecture in Japan, there are closed mines operated in antimony-bearing rock mass. Mining waste contain arsenic. In monsoon seasons, much As and Sb flow with rainfall to surface water bodies. The analysis of the Ayuta River bottom sediments shows that ferrihydrite and antimonite ore clays adsorb As, Sb and Cd. Ecologists think this phenomenon leads to trapping and accumulation of the listed elements, which, finally, can greatly reduce their concentrations in stream water [33].

In the Chinese Yunnan Province, the impact of Lanping lead–zinc mine is investigated by way of the studies into soil pollution with heavy metals in the adjacent areas. The Pb and Zn concentrations in the mining areas exceeded the average global levels by 57 and 47 times, respectively. Farther from the mine, the concentration decreased but were nevertheless higher than the average global level by 6–18 times. The soil pollution evaluation used the geoaccumulation index, the ecological risk index, etc., advisable for the environment management and soil recovery control [34].

In China, in the area of Hua Bay coal deposit, ecologists analyzed water in surface water bodies. The coal mining project involves 16 mines. Mine water is pumped to ground surface during coal seam drainage. Then, water from the surface water bodies is used in coal dressing, in industry and in agriculture. Carbonated and acidic water types dominate in the test water bodies. The implemented research was aimed to develop effective methods of water treatment on a large scale [35].

Copper production in the Tongling Yangtze River valley dates back to the Bronze Age. In the copper ore mining and processing area, ecologists analyzed quality of soil, water and processing tailings. Copper isotopes interpreted as weathering-produced derivatives of copper sulfides are detected in soil and water at short distances from the actual mining and processing operations. Insignificant concentrations of copper are observed in streams at distances to 6.5 km from the ore occurrence [36].

In the southeast of Australia, in Victoria, development and growth rates of local plantlets are studied. The soil layer on overburden dumps is applied with compound fertilizers in different quantities. On sites containing much N and P fertilizers,

Major trends of recovery ecology in mining countries

Mining ecology trend	Country (region)	Source
Land reclamation, improvement of soil quality in artificial revegetation	Canada (Alberta, South Ontario), Brazil, England, Australia	[1], [3], [5], [13, 14], [16], [38]
Surface and underground mine water treatment and quality analysis	Brazil (Nova Lima, Minas Gerais), Spain, Japan (Tochigi), China (Hua Bay)	[15], [20], [33], [35]
Phyto-remediation of disturbed land, recovery of vegetation diversity	Canada (Alberta), Brazil (Carajas), Morocco (Kettara), Australia	[4], [12], [30], [37]
Analysis of suitability of mined-out open pit mines and waste rock dumps for colonization by insects, birds and animals	Canada (Alberta), USA (Ohio), Spain, Australia	[2], [7], [17, 18], [39]
Analysis of suitability of water bodies in mined-out pit voids for colonization by aquatic wildlife	USA (Pennsylvania), Spain	[8], [19]
Analysis of soil pollution with heavy metals and carcinogenic substances in the course of open pit mineral mining, and the impact on health	USA (Northern Arkansas), Peru Cajamarca, Huancavelica), Spain, Poland, Zambia (Chingola, Kabwe), China (Yunnan, Tongling)	[10, 11], [21], [29], [31, 32], [34], [36]
Preservation of vegetable and animal world in mining-adjacent areas	Canada (Alberta), USA (Ohio), Check Republic, Australia	[6], [9], [28], [38]
Administration of interaction between mining companies, governmental authorities, public and environmental agencies	Germany (Cologne, Leipzig, Cottbus)	[22–27]

the overplus and outgrowth of weed plants is recorded, which affects development of tree plantlets [37].

The unprecedented integrated research was performed during transplanting of mature wild orchids, being endangered species, in the coal mining area in the Hunter River valley in New South Wales, Australia. Transplanting of 3030 orchids lasted for 8 years. It was noticed that orchids naturalized better during wet times. Transplanting of root tubers without sod was less effective. The obtained experience should be taken into account in other events of rehabilitation of land disturbed by open pit mining using rare [38].

In Australia in the area of a mined-out open coal pit and overburden dumps, the long-term integrated ecological research was implemented to study recoverability of vegetation cover, wildlife, etc. Researchers arrived to a conclusion that after coal mining, it was expedient to plant overburden dumps with nutrition-nonfustidious trees such as alder, oak, English field maple, silver birch, sallow, common pine, etc. Experts advise to make a mosaic planting pattern with alternate blocks of forests and pastures. This will create a convenient habitat for animals and birds which can prefer either shadow of forests or open air sunny meadows. Furthermore, another conclusion was made on unsuitability of mining landscapes for production and agriculture. Finally, it was decided to use mining landscapes for creation of manmade self-sustaining geoecological systems [39].

On the basis of this review of published studies, we have grouped the problems that have already been handled or are planned to be dealt with in the area of mining ecology into eight major trends (**Table**).

Each trend is promising for the further research, including field studies and laboratory experimentation. To the authors' opinion, these trends are correlated and represent an integral system defined as interaction of vegetable, aquatic, animal and human worlds. This interaction needs persistent improvement of mining ecology and minimization of the environmental impact of industry.

Conclusions

The review of the global research in the area of mining ecology has revealed the main trends of ecological studies on the continents and at various solid mineral deposits, either mined-out or in operation. Challenges facing the mining ecology include investigation of the main constituents of the Earth's biosphere. The associate problem solving widely uses eco-mathematical modeling, specialized experimentation at a laboratory scale and accumulation of in-situ information.

References

1. Kwak J., Scott X., Chang M. et al. Nitrogen transformation rates are affected by cover soil type but not coarse woody debris application in reclaimed oil sands soils. *Restoration Ecology*. 2016. Vol. 24, No. 4, pp. 506–515.
2. Foster K. R., Godwin C. M., Pyle P. et al. Reclamation and habitat-disturbance effects on landbird abundance and productivity indices in the oil sands region of northeastern Alberta, Canada. *Restoration Ecology*. 2017. Vol. 25, No. 4. pp. 532–538.
3. Dhar A., Comeau Ph. G., Vassov R. Effects of cover soil stockpiling on plant community development following reclamation of oil sands sites in Alberta. *Restoration Ecology*. 2019. Vol. 27, No. 2. pp. 352–360.
4. Nenzén H. K., Price D. T., Boulanger Y. et al. Projected climate change effects on Alberta's boreal forests imply future challenges for oil sands reclamation. *Restoration Ecology*. 2020. Vol. 28, No. 1. pp. 39–50.
5. Ohsowski B. M., Dunfield K., Klironomos J. N. et al. Plant response to biochar, compost, and mycorrhizal fungal amendments in post-mine sandpits. *Restoration Ecology*. 2018. Vol. 26, No. 1. pp. 63–72.
6. Beale M. M., Boyce M. S. Mine reclamation enhances habitats for wild ungulates in west-central Alberta. *Restoration Ecology*. 2020. Vol. 28, No. 4. pp. 828–840.
7. Brady J. K. Salamander diversity of reforested abandoned surface coal mines in the Appalachian Region, U.S.A. *Restoration Ecology*. 2016. Vol. 24, No. 3. pp. 398–405.
8. Nuttle T., Logan M. N., Parise D. J. et al. Restoration of macroinvertebrates, fish, and habitats in streams following mining subsidence: replicated analysis across 18 mitigation sites. *Restoration Ecology.* 2017. Vol. 25, No. 5. pp. 820–831.
9. Lanterman J., Goodell K. Bumble bee colony growth and reproduction on reclaimed surface coal mines. *Restoration Ecology*. 2018. Vol. 26, No. 1. pp. 183–194.

10. Potra A., Ruhl L. S., Samuelsen J. R. Legacy Lead from Past Mining Activity and Gasoline Additives: Evidence from Lead Isotopes and Trace Element Geochemical Studies in the White River Basin, Southern Ozark Region, USA. *Geosciences*. 2018. Vol. 8(6). DOI:10.3390/geosciences8060189
11. Santos-Francés F., Martinez-Graña A., Rojo A. P. et al. Geochemical Background and Baseline Values Determination and Spatial Distribution of Heavy Metal Pollution in Soils of the Andes Mountain Range (Cajamarca-Huancavelica, Peru). *International Journal of Environmental Research and Public Health*. 2017. Vol. 14(8). DOI:10.3390/ijerph14080859
12. Carvalho J. M., Ramos S. J., Gastauer M. et al. Influence of nutrient management on growth and nutrient use efficiency of two plant species for mineland revegetation. *Restoration Ecology*. 2018. Vol. 26, No. 2. pp. 303–310.
13. Denise T. G. B., Marina M. D., Casagrande J. C. et al. Recovery of soil phosphorus on former bauxite mines through tropical forest restoration. *Restoration Ecology*. 2020. Vol. 28, No. 5. pp. 1237–1246.
14. Onésimo C. M. G., Dias D. D., Kozovits A. R. et al. Ecological succession in areas degraded by bauxite mining indicates successful use of topsoil. *Restoration Ecology*. 2021. Vol. 29, No. 1. DOI: 10.1111/rec.13303
15. Lemos M., Valente T., Reis P. M. et al. Mineralogical and Geochemical Characterization of Gold Mining Tailings and Their Potential to Generate Acid Mine Drainage (Minas Gerais, Brazil). *Minerals*. 2021. Vol. 11, No. 1. DOI:10.3390/min11010039
16. Lane M., Hanley M. E., Lunt P. et al. Chronosequence of former kaolinite open cast mines suggests active intervention is required for the restoration of Atlantic heathland. *Restoration Ecology*. 2020. Vol. 28, No. 3. pp. 661–667.
17. Rohrer Z., Rebollo S., Andivia E. et al. Restoration and management for cliff-nesting birds in Mediterranean mining sites: The Sand Martin case study. *Restoration Ecology*. 2020. Vol. 28, No. 3. pp. 706–716.
18. Salgueiro P. A., Silva C., Silva A. et al. Can quarries provide novel conditions for a bird of rocky habitats? *Restoration Ecology.* 2020. Vol. 28, No. 4. pp. 988–994.
19. Martin-Collado D., Jiménez M. D., Rouco C. et al. Potential of restored gravel pits to provide suitable habitats for Eurasian otters in anthropogenic landscapes : Restored gravel pit habitats for otters. *Restoration Ecology*. 2020. Vol. 28, No. 4. pp. 995–1005.
20. Mendoza R., Martínez J., Rey J. et al. Metal(loid)s Transport in Hydrographic Networks of Mining Basins: The Case of the La Carolina Mining District (Southeast Spain). *Geosciences*. 2020. Vol. 10, No. 10. 391 p.
21. García-Lorenzo M. L., Crespo-Feo E., Esbrí J. M. et al. Assessment of Potentially Toxic Elements in Technosols by Tailings Derived from Pb–Zn–Ag Mining Activities at San Quintín (Ciudad Real, Spain): Some Insights into the Importance of Integral Studies to Evaluate Metal Contamination Pollution Hazards. *Minerals*. 2019. Vol. 9. 346 p.
22. Esser G., Janz S., Walther H. Promoting biodiversity in recultivating the Rhenish lignite mining area. *World of Mining—Surface and Underground*. 2017. Vol. 69(6). pp. 327–334.
23. Kulik L., Stemann H. Ecology and biodiversity protection in the Rhenish lignite mining area. *World of Mining—Surface and Underground*. 2014. Vol. 66(3). pp. 143–152.
24. Kuyumcu M. Special challenges in lignite remediation. *World of Mining—Surface and Underground*. 2011. Vol. 63(6). pp. 321–333.
25. Freytag K., Pulz K. The New Federal Nature Conservation Act from the perspective of mining projects. *World of Mining—Surface and Underground*. 2010. Vol. 62(4). pp. 214–221.
26. Perti R., Stein W., Dahmen D. et al. Sustainable follow-up use of recultivated surfaces: Evaluation of residual lakes and high dumps in the Rhenish lignite-mining area after the end of mining supervision. *World of Mining—Surface and Underground*. 2013. Vol. 65(2). pp. 92–101.
27. Pulz K. Meeting the challenges and implementingthe management objectives of lignite mining rehabilitation. *World of Mining—Surface and Underground.* 2014. Vol. 66(3). pp. 153–159.
28. Řehounková K., Vítovcová K., Prach K. Threatened vascular plant species in spontaneously revegetated post-mining sites. *Restoration Ecology.* 2019. Vol. 28, No. 3. pp. 679–686.
29. Lewińska K., Karczewska A., Siepak M. et al. The Release of Antimony from Mine Dump Soils in the Presence and Absence of Forest Litter. *International Journal of Environmental Research and Public Health*. 2018. Vol. 15(2631). DOI:10.3390/ijerph15122631
30. Zine H., Elgadi S., Hakkou R. et al. Wild Plants for the Phytostabilization of Phosphate Mine Waste in Semi-Arid Environments: A Field Experiment. *Minerals.* 2021. Vol. 11(10). DOI 10.3390/min11010042
31. Chileshe M. N., Syampungani S., Festin E. S. et al. Physicochemical characteristics and heavy metal concentrations of copper mine wastes in Zambia: implications for pollution risk and restoration. *Journal of Forestry Research*. 2020. Vol. 31(4). pp. 1283–1293.
32. Mwilola P. N., Mukumbuta I., Shitumbanuma V. et al. Lead, Zinc and Cadmium Accumulation, and Associated Health Risks, in Maize Grown near the Kabwe Mine in Zambia in Response to Organic and Inorganic Soil Amendments. *International Journal of Environmental Research and Public Health*. 2020. Vol. 17. 9038.
33. Manaka M. Morphology, Mineralogy, and Chemistry of Ocherous Precipitate Aggregates Downstream of an Abandoned Mine Site. *Minerals.* 2021. Vol. 11, No. 1. DOI:10.3390/min11010032
34. Li Z., Deblon J., Zu Y. et al. Geochemical Baseline Values Determination and Evaluation of Heavy Metal Contamination in Soils of Lanping Mining Valley (Yunnan Province, China). *International Journal of Environmental Research and Public Health*. 2019. Vol. 16(23). DOI:10.3390/ijerph16234686
35. Wang M., Gui H., Hu R. et al. Hydrogeochemical Characteristics and Water Quality Evaluation of Carboniferous Taiyuan Formation Limestone Water in Sulin Mining Area in Northern Anhui, China. *International Journal of Environmental Research and Public Health*. 2019. Vol. 16(14). DOI:10.3390/ijerph16142512
36. Su J., Mathur R., Brumm G. et al. Tracing Copper Migration in the Tongling Area through Copper Isotope Values in Soils and Waters. *International Journal of Environmental Research and Public Health.* 2018. Vol. 15(12). DOI:10.3390/ijerph15122661
37. Nussbaumer Y., Cole M. A., Offler C. E. et al. Identifying and ameliorating nutrient limitations to reconstructing a forest ecosystem on mined land. *Restoration Ecology*. 2016. Vol. 24, No. 2. pp. 202–211.
38. Bell S. A. J. Translocation of threatened terrestrial orchids into non-mined and post-mined lands in the Hunter Valley of New South Wales, Australia. *Restoration Ecology*. 2020. Vol. 28, No. 6. pp. 1396–1407.
39. Haigh M., Woodruffe P., D'Aucourt M. et al. Successful Ecological Regeneration of Opencast Coal Mine Spoils through Forestation: From Cradle to Grove. *Minerals*. 2020. Vol. 10(5). DOI:10.3390/min10050461