JAES | JOURNAL OF APPLIED ENGINEERING SCIENCE | www.engineeringscience.rs
ISTRAŽIVANJA I PROJEKTOVANJA ZA PRIVREDU

Indexed by

# SUSTAINABLE MINING TOWARDS ACCOMPLISHING CIRCULAR ECONOMY PRINCIPLES

**Nela Petronijević**
*Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade, Serbia*

**Vesna Alivojvodić**
*Belgrade Polytechnic, Belgrade, Serbia*

**Miroslav Sokić**
*Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade, Serbia*

**Branislav Marković**
*Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade, Serbia*

**Srđan Stanković**
*Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Deutschland*

**Dragana Radovanović**
*Innovation Centre of the Faculty of Technology and Metallurgy Ltd., Belgrade, Serbia*

***Key words:*** *mine waste, raw materials, circular economy*

**doi:**10.5937/jaes0-27460

***Cite article***:
Petronijevic, N., Alivojvodic, V., Sokic, M., Markovic, B., Stankovic, S., & Radovanovic, D. [2020]. Sustainable mining towards accomplishing circular economy principles. *Journal of Applied Engineering Science*, 18(4), 493 - 499.

***Online aceess*** *of full paper is available at: www.engineeringscience.rs/browse-issues*

Istraživanja i projektovanja za privredu
Journal of Applied Engineering Science

Original Scientific Paper

doi:10.5937/jaes0-27460

Paper number: 18(2020)4, 718, 493 - 499

# SUSTAINABLE MINING TOWARDS ACCOMPLISHING CIRCULAR ECONOMY PRINCIPLES

*Nela Petronijević[1]*, Vesna Alivojvodić[2], Miroslav Sokić[1], Branislav Marković[1], Srđan Stanković[3], Dragana Radovanović[4]*

*[1]Institute for Technology of Nuclear and other Mineral Raw Materials, Belgrade, Serbia*
*[2]Belgrade Polytechnic, Belgrade, Serbia*
*[3]Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, Deutschland*
*[4]Innovation Centre of the Faculty of Technology and Metallurgy Ltd., Belgrade, Serbia*

*Today human society is already witnessing rapid depletion of non-renewable ore resources. As the distribution of raw material resources globally is very off-balance, and preassure on environment as the consequence of ore exploatation is not negligible, re-utilization and recycling of industrial side-streams gaining on importance. Finding new potentially anthropogenic resources of material (at first place critical raw materials) are inline with sustainable waste management goals, and in correlation with boundaries given by the circular economy principles. Side-streams from mines can become source for recovery of these materials. The aim of this paper was to analyze position of mining waste in correlation with circular economy principles, as well potential for implementation of them within extraction industry in the Republic of Serbia.*

*Key words: mine waste, raw materials, circular economy*

## INTRODUCTION

It is estimated that global consumption of materials such as biomass, fossil fuels, metals and minerals is expected to double in the next forty years [1], while on the other side annual waste generation is projected to increase by 70% by 2050 [2]. Around 50% of the world's current greenhouse gas emissions result from the extraction and processing of natural resources, and the prediction is to double emissions by 2050, under a 'business-as-usual' scenario. [3] Mining is a major economy driver of many countries in the world. Significant amounts of mining waste generated during the mining and processing of ore represent a major environmental hazard. The problem of mining waste is of a global character and dates back to the beginning of the industrialization process. However, in recent decades we have encountered the consequences of intensive mining and environmental pollution. The mining industry faces increasing challenges to find practices that are sustainable for waste streams that are already obtained (tailing pond, acid drainage, and fly ash) [4, 5].

In the Republic of Serbia the total amount of mining waste is around 24 million cubic meters [6]. According to the *Report on Critical Raw Materials and the Circular Economy* (2018) the imbalance exists between the upstream steps (extraction / harvesting) and the downstream steps (manufacturing and use) [7]. Considering that the secondary supply sources of CRMs are very limited, the need for access to primary sources (including ores, concentrates, processed or refined materials) is huge and crucial for twenty-first-century industries [7]. Nowadays, a few researches investigated the chance to recover raw materials (RM), critical raw materials (CRM) and secondary raw materials (SRM) from mining waste [8, 9].

Accordingly, legislation is changing in most countries and investing significant money in remedying the negative effects of an industry that has brought economic prosperity. The imperative of today is to increase the awareness of both individuals and corporations about realizing economic benefits while taking care of the environment. One of the imperatives of modern society is the implementation of sustainable development principles which ought to include the minimization of industrial waste streams, different recycling technologies, as well as the waste treatment before disposal [10].

The approach to production and consumption, which involves the exploitation of primary mineral raw materials, their processing, often short-term use, and ultimately disposal, is no longer sustainable. Generated waste should be converted into usable raw materials, with the intention of minimizing the generation of new waste, which is also in line with the approach promoted by the circular economy. This concept is now a widespread in many fields and areas of anthropogenic activities.

## CIRCULAR ECONOMY CONCEPT

In last fewdecades it became obvious that a linear economic model of production and consumption of goods, based on the assumption that natural resources are unlimited, and readily available, had to be seriously revised [11]. According to the 7th Environmental Action Program of the European Commission: "Our prosperity and healthy environment stem from an innovative, circular economy where nothing is wasted and where natural resources are managed sustainably, and biodiversity is

**n.petronijevic@itnms.ac.rs*

protected valued and restored in ways that enhance our society's resilience" [12].

Instead of the linear pattern of "take-make-use-dispose", new CE concept was developed with the tendency of eliminating the very concept of "waste" (Figure 1.), as through the lance of circular economy principles everything has a value [11, 14, 15]. European Commission adopted Circular Economy Action plan (March 2020.) as a tool to accomplishing the Sustainable Development Goals (SDGs) [14]. Having in mind that one of the fundamental drivers of this CE concept is constraints of resources, because of wastefulness of the current economy [15], it implies that efficient management of natural resources, as well as, sustainable approach, throughout its lifespan got a new importance. Mobilizing new potentials and opportunities is a challenge for CE model. At present, only 9% of the global economy is circular [3], but to make "business-as-usual" is no longer a preferable choice. Obtain secondary materials from earlier waste streams, will soon become a new paradigm. This approach is exceptionally important within mining sector, as the compelling volume of metals are hold in industrial process residues (for example in metallurgical sludges, tailings, slags, ashes anddusts) [7, 16]. Some of the elements that can be put in focus as extracting part of mining waste are for example critical raw materials (CRM). Demand for CRM growing daily, as they are particularly important for high tech products and uprising innovations [7, 8], mining waste can became potential future resource for some of these materials.

## *CIRCULAR ECONOMY WITHIN MINING SECTOR*

The starting point of most product value chains is the mining sector, so it is responsible for the dissipation of non-renewable mineral resources in various ways. An optimization of the mineral excavation and processing can be by build

An optimization of the mineral extraction, and processing can be carried out by rising importance of the mining life-cycle (exploration and design phase), and focusing on the prevention of waste formation (to the extent possible) [8]. The traditional mining process is based on mineral resources to form a "mineral exploration - exploitation - primary product processing - fine product manufacturing - product consumption - waste dumping", linear operating mode [17]. Implementation of circular economy principles in the standard mining protocols needs suitable economic standard, at the same time following caracteristic and ecological order of mineral resources with improvement in employment sector and broad application of mineral resources and by-products [18]. The mining waste can be observed as waste present in closed/abandoned or currently operating mines in the in-use material stock from, and each of them can be implemented within the CE framework loops. CE principles can help minimize and create value from mining waste, as an industrial reject. [19] In mining where is easy-to-access, mineral deposits are usually in lower concentrations or with more complex structures [5]. Economic benefit of exploration of metals from such ores is commonly poor with nowadays industrial technologies [5]. Beside it, developing of new strategies and approaches by sharing of best practice for the recovery of disparate materials from mining waste (e.g. CRM from tailing pond) he best option for particular site could appear. [20] In order to simplify an economic estimate of potentials for future recovery of CRMs from mining residue, it is important to have information of waste characterization in active mines, of the presence of CRMs [20].

The 3R model of circular mining economy is based on three basic principles: reduce, reuse and recycling [18].

### Reduce

During exploration process, refinement and usage of mineral resource, diminishing of mining waste reflected in [18]:

- the more adequate exploitation of the raw materials, applying of modern industrialization, better automation of the process, with the optimization of exploitation during the whole process [18],
- Decreasing mining dilution ratio and ratio of ore losing and increasing recovery rate of mineral-processing and smelting to upgrade total recovery results by constant studding mining technologies and melting process promoting of overall benefit of resource development by decreasing in pollutants emissions such as tailing, gangue and mine wastewater [18].

Essential part of any mining activities is management of large volume of mining water. Mining water is problem in both, closed or active mining sites, and challenges to find sustainable practice for mineral processing sites and to deal with acid mine water problem [5].

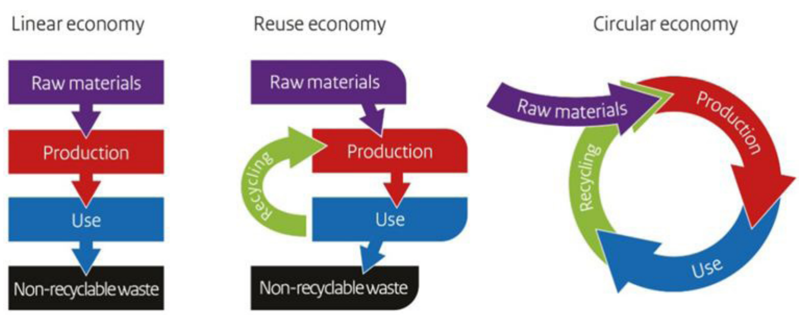


*Figure 1: Concept of circular economy [13]*

## Reuse

This principle covers the reuse of acid mine drainage (AMD). Overburdens and flotation tailings are the main sources of acid mine drainage [21]. According to the general consensus, acid mine waters are the most critical environmental problem caused by mining [21], but also one of the most compelling environmental risks on the global level. Hundreds of thousands of hectares of land and thousands of kilometers of watercourses worldwide are threatened by acid mine drainage [22].

Wastewater treatment processes can be chemical, physical and biological, as well as passive or active [23]. What they all have in common is high cash investments in their implementation. The principle of wastewater treatment is based on the separation of impurities. After treatment, water is returned to the system and reused or safely discharged into wastewater streams.

As the main sources of wastewater generation, overburden and flotation tailing, can be reused and converted into useful material.

There are two potential ways to utilize waste and tailing [18]:

- Firstly, by progress in mineral processing machinery which implies on increasing in recovery rate of difficulty recovered part of the ore [18]. The crushing and grinding cost 49% to 56% of the total cost of the mineral processing to achieve concentrates (further action and calculation have to be applied to find effectiveness of processing and application of materials with adjustment within approaches) [18].
- The second is to produce new outputs (e.g. building materials, using waste tailing produce building materials such as cements, glass, building ceramics, cast stone products, but it also can be used for farming fertilizer, reclamation for mined area, road making, coal waste fired power, etc [18].

Circular economy of mining sector attributes to an economic system, which are some kind of biomimicry (following of natural ecological rules which essence is highly efficient exploitation and extensive application of mineral resources [18]. It constitutes a closed-loop material flow as “mineral resources - mineral products - renewable mineral resources” according to mineral exploration, exploiting, processing, melting, deep processing, consumption and other processes [18].

## Recycling

Reducing the amount of waste by processing the raw materials used in order to obtain commercial products. In the world, 45% of the steel output, 62% of copper, 22% of aluminum, 40% of lead, 30% of zinc and 30% of paper products are from renewable resources recovery [18]. Increasing the production and consumption of metals leads to the development and continuous improvement of technologies for their processing. The application of new technologies allows for an increase in the amount of metals obtained by recycling; Aluminum factories are increasingly common where 100% of aluminum is recycled, rare earth elements are generated from electronic waste, etc.

Waste recycling leads to a more rational use of primary mineral resources, energy savings and reduced waste materials, thus directly protecting the environment from pollution. It is estimated that recycling one kilogram of aluminium also saves up to 8 kilograms of bauxite, 4 kilograms of chemical products and 14 kilowatt hours of electricity [24].

Newer methods of treating acid mine waters include backfilling which involves refilling an open cast/underground mine with its waste-rock post-closure or waste-heap dry covers: Single to multi-layered systems that consist of low permeable, non-reactive solid material on waste-rock heaps and tailings. Tailings themselves can act as dry covers, hardpans, which increase the performance of a dry cover system [23].

Having in mind the characteristics, and the purpose, of particular mine, the decision has to implement the circular economy model on its own, or to form an “Eco-parks” scheme. Eco-park means industrial symbiosis with another factory or branch of industry. An eco-park is formed by making waste from one plant an input raw material to another, which turns waste into a useful resource (which is in the core of CE concept) [25, 26].

Raising awareness among general public and policy makers of the benefits of CRM / SRM recovery from landfill and extractive mining sites, can be one of specific objectives for establishing strong foundation for quality implementation of circular economy principles [20].

Serbia's legalization is on the right track towards incorporating a circular economy. The Ministry of the Environmental Protection formed the Circular Economy Working Group, and then the Chamber of Commerce also formed the CE Sector. At the same time, the importance of mining waste was recognized by the Ministry of Environment Protection, and the European Union funded the development of The Cadaster of Mining Waste as a significant inventory (aiming to further develop and improve the mining waste management system in the Republic of Serbia). What is also significant is that The Mine Water Cadaster with their characteristics has been developed [27]. An important prerequisite for the development of Eco-parks, as a kind of symbiosis of waste producers in order to transform waste raw materials into useful ones, is the formation of a by-product rulebook, so that waste from one factory can be input raw material into another [28].

## *SERBIA CASE STUDY*

In attempt to connect industrial waste with the concept of CE in the Republic of Serbia, several examples were taken into consideration: a) acidic mine drainage from Bor's mine, b) flotation tailings from a copper mine in Majdanpek and c) fly ash from the thermal power plant Nikola Tesla (Obrenovac). The Bor and Majdanpek copper mines are part of the ZijinBor Copper mining and smelter complex.[29] After long period of exploitation (in the case of Bor's mine it is more than a century, as the mine had been opened in 1903.), the local disturbance of geological structure occurred, surface and underground water became contaminated, and the life cycle of animals and of vegetation have also been exposed to adverse negative effects.

**Acid mine drainage** and **tailing pond** were taken as an example having in mind that the large areas of land were degraded by mining activities, with resulting production of large quantities of solid waste materials (open pit mines, flotation tailings, etc.) and acid mine drainage was formed [30]. Due to their geographical location and proximity to the Danube river, the acid mine drainage have potential to cause international tension. In addition, more than 780x$10^6$ tons of mining waste (mines and flotation tailings) containing over 1,140,000 tons of copper (Cu) have been deposited in Bor [21] and its surroundings over the past 100 years. It has also been estimated that by leaching of mining waste, 290-350 tons of copper are irreversibly lost annually, with the consequent contaminating of surface flows [31]. Tailings resulting from former mining activities can become alternative sources for CRM, and to lower supply risks [20].

*Table 1: Characteristics of input raw material*

| | Consequences of waste disposal | Benefits of integral treatment |
|---|---|---|
| **Tailing pond** | • A source of fine dust which can contain harmful chemical elements<br>• Healthy risks<br>• constant danger of possible breakage or overflow of dams and leakage of flotation pits<br>• Source of Acid Mine Water | • metal revalorization<br>• economically viable<br>• there is no formation of new acidic mine water<br>• reduced pollution and<br>• reduces costs for remediation |
| **Acid Mine Drainage** | • Food chains and ecosystems are rapidly collapsing<br>• toxic nature<br>• mobility<br>• aesthetic pollution of watercourses<br>• pollution of agricultural land | • Food chains and ecosystems are rapidly collapsing<br>• toxic nature<br>• mobility<br>• aesthetic pollution of watercourses<br>• pollution of agricultural land |
| **Fly ash** | • may pollute the air, soil, water<br>• expensive escrow fee<br>• expensive landfill maintenance | • Free agent for neutralizing acid mine waters |

In order to utilize disposed waste and to form appropriate integral treatment of the waste, it is necessary to analyze and synthesize the all available data. Before reaching the results that the raw materials described above can be an input data of the integral treatment, many parameters were processed and extensive modeling and experiments were done. Some of these results have been presented [34, 35].

After defining the mineral and chemical composition of the tailings, as well as the chemical composition of acid mine waters [34], the stability test of the waste in atmospheric conditions such as in the field conditions, as well as in the more invasive conditions in case of excesses, were performed. Numerous computer simulations have been done [36], in order to isolate potential integral treatments which will obtain best results. In addition to the positive results obtained by software simulations, the proposed concept was proven in laboratory conditions and purified water was obtained, which can be discharged into natural recipes safely, but even better to return to the technical process of ore processing. The precipitated metals particles remain in solid residue and they can be recovered revalidated from tailings. Also there are a lot of selective precipitation suggestions [37], which can and should be further considered. Potential environmentally safe integral treatments for Serbia case study are given in Table 2, as well as the benefits that would be obtained if these raw materials were included in the integral treatment.

In the example above, we interpreted both types of treatment, passive and active. Extensive synthesis and analysis of data, narrows our search for inputs, as e necessary co-participants in the process also, reduces the time frame of research as well as the cost of experiments in the laboratory. The quality choice of raw materials gives us the best result: reduced amount of waste in nature, reduced its ability to generate further waste, free waste treatment, metal revalorization, the possibility of applying additional neutralization methods (to accelerate the process), and reduces of cost of neutralization. Financial frameworks for the rehabilitation of abandoned mining areas, in order to prevent AMD from becoming very expensive, even for the most developed countries [36], therefore, it is necessary to maximize the application of waste as a free raw material for AMD neutralization treatment.

Table 2: Potential environmentally safe integral treatments for Serbia case study

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Acid Mine Water from Robule Lake | + | Tailing pond from Majdan-pek mining site | = | **Neutralized Acid Mine Water** | + | **Solid residue** | **Active treatment** |
| Advantages: | | | | • Can be used as technical water<br>• Can be safe for discharge | | • To be used for briquette production<br>• In the construction industry, e.g. for the production of cement<br>• Back-filling<br>• Waste-heap dry covers for extraction of Critical Raw Materials | |
| Acid Mine Water from Robule Lake | + | Fly ash | = | **Neutralized Acid Mine Water** | + | **Solid residue** | **Passive treatment** |
| Advantages: | | | | • can be used as technical water<br>• can be safe for discharge | | • To be used for briquette production<br>• In the construction industry, e.g. the production of cement<br>• Back-filling<br>• Waste-heap dry covers | |

***CONCLUSION***

To establish a circular economy system approach within the mining industry sector is a new challenge, to save natural recourses, and obtain higher recovery rates of materials.

Sharing the best practice for the recovery of materials (particularly, critical raw materials) from mining waste can be of great help in order to develop approach suitable for local conditions, as the type of ore, residual materials and included production technologies are usually site specific.

By raising awareness among policy makers, and joining efforts of science and engineering in order of developing new lines of action in this particular field can be the way to obtain new, more sustainable solutions.

It is also important to improve understanding of circular economy approaches, of all potential stakeholders within mining sector, to get best possible solutions, based on good understanding of both sides – mining processes, and potentials that can offer circular economy concept.

***ACKNOWLEDGEMENTS***

This research was supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia Contract No. 451-03-68/2020-14/200023 (subproject TR 34023 " Developing technological process for nonstandard copper concentrates processing with the aim to decrease pollutants emission").

***REFERENCES***

1. OECD (2018). Global Material Resources Outlook to 2060.
2. World Bank (2018). What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050 https://www.wastedive.com/news/world-bank-global-waste-generation-2050/533031/
3. https://www.weforum.org/agenda/2020/01/the-world-needs-a-circular-economy-lets-make-it-happen/ Accesed: April 25th 2020.
4. Stankovic, S. (2016). Microbial diversity of an extremely acidic lake Robule and effect of the lake water on oxidation of sulfide minerals, Doctoral Dissertation, University of Belgrade, Faculty of Mining and Geology, Belgrade
5. Kivikyto-Reponen, P., Ulla-Maija, M., Makinen, J. (2016). Added value from responsible use of raw materials, VTT Research Highlights 13, ISBN 978-951-38-8498-7, https://www.vttresearch.com/sites/default/files/pdf/researchhighlights/2016/R13.pdf
6. https://katastarrudarskogotpada.rs/ Accessed:19 May 2019.

7. European Commission (2018). Report on Critical Raw Materials in the Circular Economy, doi: 10.2873/167813 https://ec.europa.eu/docsroom/documents/27348/attachments/1/translations/en/renditions/native
8. European Commission (2019). Development of a guidance document on best practices in the Extractive Waste Management Plans Circular Economy Action, doi: 10.2779/061825, https://ec.europa.eu/environment/waste/mining/pdf/guidance_extractive_waste.pdf
9. Dino, G. A., Mehta, N., Rossetti, P., Ajmone-Marsan, F., De Luca, D. A. (2018). Sustainable approach towards extractive waste management: two case studies from Italy. Resources Policy, 59, 33-43. https://doi.org/10.1016/j.resourpol.2018.07.009.
10. Radovanovic, D. (2017). Stabilization and solidification process of hazardous sludge generated during wastewater treatment process, Doctoral Dissertation, University of Belgrade Faculty of Technology and Metallurgy, Belgrade.
11. Alivojvodic,V., Kokalj,F., (2018).Upravljanje otpadom I cirkularna ekonomija, text book, Belgrade Polytechnic, Belgrade, ISBN 978-86-7498-077-4.
12. http://ec.europa.eu/environment/action-programme/ Accessed May 19th 2019.
13. https://www.government.nl/topics/circular-economy/from-a-linear-to-a-circular-economy/ Accessed April 17th 2020.
14. European Commission (2020). A new Circular Economy Action Plan For a cleaner and more competitive Europe, COM 98 final.
15. Lacy, P., Rutqvist, J. (2015). Waste to wealth: The circular economy advantage, Accenture, Palgrave Macmillan, ISBN 978-1-137-53070-7
16. Petronijevic, N., Stankovic, S., Radovanovic Ivsic, D., Kamberovic, Z., Sokic, M., Markovic B., Zildzovic, S. (2019) Software simulation of the proposed integral treatment of acidic wastewaters and overburden of the Cerovo copper mine. 4th Metallurgical & Materials Engineering Congress of South-East Europe 2019, p. 37-37.
17. Lottermoser, B. (2010) Mine Wastes: Characterization, Treatment and Environmental Impacts, Third Edition, Springer, p.5, DOI 10.1007/978-3-642-12419-8
18. Drljaca, M. (2015). Koncept kruzne ekonomije. Kvalitet&izvrsnost, 4, 18-22, ISSN: 2217-852X; UDC 330.341.
19. Yiqing, Z., Li, Z., Li, Z., Qin, J. (2012). Discussion on the Model of Mining Circular Economy. Energy Procedia, 16, 438-443, DOI: 10.1016/j.egypro.2012.01.071.
20. Lebre, E., Corder,G., Golev,A. (2017). The Role of the Mining Industry in a Circular Economy: A Framework for Resource Management at the Mine Site Level.Journal of Industrial Ecology, 21, 3, 662-672, DOI: 10.1111/jiec.12596.
21. Blengini, G. A., Mathieux, F., Mancini, L., Nyberg, M., Viegas, H.M. (2019) Recovery of critical and other raw materials from mining waste and landfills: State of play on existing practices, EUR 29744 EN, Publications Office of the European Union, Luxembourg, ISBN 978-92-76-03391-2, doi:10.2760/494020, JRC116131. https://publications.jrc.ec.europa.eu/repository/bitstream/JRC116131/aaa_20190506-d3-jrc-science-for-policy-ecovery_of_rm_from_mining_waste_and_landfills_4_07_19_online_final.pdf
22. Dimitrijevic, M. (2013). Oksidacija pirita kisele rudnicke vode, Tehnicki fakultet u Boru, Univerzitet u Beogradu, ISBN 978-86-80987-99-6.
23. Stevanovic, Z. (2012). The leaching of heavy metals from flotation tailings, Doctoral Dissertation, University of Belgrade, Technical Faculty in Bor, Bor.
24. Pavlovic, J., Stopic, S., Friedrich, B., Kamberovic, Z. (2007). Selective Removal of Heavy Metals from Metal-Bearing Wastewater in a Cascade Line Reactor. Environmental Science and Pollution Research, 14, 7, 518-522, DOI: 10.1065/espr2006.09.345.
25. Moodley, I., Sheridana,C. M., Kappelmeyer, U., Akcild, A. (2017). Environmentally sustainable acid mine drainage remediation: Research developments with a focus on waste/by-products. Minerals Engineering, 126, 207-220, DOI: 10.1016/j.mineng.2017.08.008
26. Myer, K. (2007) Environmentally Conscious Materials and Chemicals Processing, p. 264, ISBN 987-0-471-73904-3
27. Geng, Y., Zhang, P., Cote,R.P., Fujita, T. (2009). Assessment of the National Eco-Industrial Park Standard for Promoting Industrial Symbiosis in China. Journal of industrial ecology, 13, 1, 15-26, DOI: 10.1111/j.1530-9290.2008.00071.x.
28. Van Berkel, R., Fujita,T., Hashimoto,S., Geng,Y. (2009). Industrial and urban symbiosis in Japan: Analysis of the Eco-Town program 1997–2006. Journal of Environmental Management, 90, 3, 1544–1556, DOI:10.1016/j.jenvman.2008.11.010.
29. Atanackovic, N. (2018). Risk assessment of water pollution caused by abandoned mining operations in Serbia, Doctoral Dissertation, University of Belgrade, Faculty of Mining and Geology, Belgrade.
30. “Official Gazette of the RS” No 76/09 of 25.10.2019, Rulebook on the criteria for determining of by-products and the form of the by-products report, the method and deadlines for its delivery.

31. Spasic, N., Stojanovic, B., Nikolic, M., (2005). Uticaj rudarstva na okruzenje I revitalizacija degradiranog prostora. Arhitektura i urbanizam, 16-17, 75-85, UDK 622.271:502.171.
32. Dimitrijevic, M., Milic, S. (2017). Sulfidni rudarski otpad karakteristike, uticaj na zivotnu sredinu I tretman, Tehnicki fakultet u Boru, Univerzitet u Beogradu, Bor, ISBN 978-86-6305-063-1.
33. Milicevic, S., Milosevic, V., Povrenovic, D., Stojanovic, J., Martinovic, S., Babic, B. (2013).Removal of heavy metals from aqueous solution using natural and Fe(III) oxyhydroxide clinoptilolite. Clays and Clay Minerals, 61, 6, 508-516, doi.org/10.1346/CCMN.2013.0610603.
34. Karanac, M. (2018).The utilization of fly ash modified by calcium hydroxide and ferric oxide for the removal of heavy-metal ions from water, Doctoral Dissertation, University of Belgrade Faculty of Technology and Metallurgy, Belgrade.
35. Connors, E. (2015). Coal-ash management by U.S. electric utilities: Overview and recent developments. Utilities Policy, 34, 30-33, DOI: 10.1016/j.jup.2015.03.004.
36. Petronijevic, N., Stankovic, S., Radovanovic, D., Sokic, M., Marković, B., Stopic, S., Kamberovic, Z. (2020) Application of the Flotation Tailings as an Alternative Material for an Acid Mine Drainage Remediation: A Case Study of the Extremely Acidic Lake Robule (Serbia). Metals, 10, 1, 16, doi.org/10.3390/met10010016.
37. Sokic, M., Radovanovic, D., Markovic, B., Stojanovic, J., Kamberovic, Z., Petronijevic, N., Stankovic, S. (2019) Treatment of the acidic effluent from a copper smelter by flotation tailings, Hemijska industija, 73, 2, 115-124, doi.org/10.2298/HEMIND181009010S.

*Paper submitted: 10.07.2020.*
*Paper accepted: 03.09.2020.*