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Reclamation methods and their outcomes in Serbian mining basins

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ABSTRACT
The reclamation plan is introduced in the early planning phase of exploitation of mineral deposits by the national Law on mining and geological research. This way the reclamation practice is joint and adapted to the excavation and ore processing technology in order to achieve more efficient, low cost and sustainable solutions. However, reclamation activities in Serbian mining basins are still considered poorly applied in practice. Non-selective deposition of overburden material, sporadically coupled with improper technical reclamation, aggravates and slows down the process of biological reclamation and the improvement of physical, chemical and biological characteristic of underlying Technosols. Besides, management of reclaimed land and further maintaining of reclaimed surfaces often remains questionable. During previous decades, although interrupted with periods of economic crisis, certain efforts have been made towards improving the reclamation practice. Short and long-termed outcomes of reclamation activities are achieved so that some examples of good practice may be displayed. This is particularly reflected in the development of ecosystem processes in artificially created ecosystems, including the development of the soil cover and the increase of biodiversity. The objective of this paper is to give a review of the reclamation methods used in practice and the outcomes of biological reclamation activities in some of the most important mining basins in Serbia, on base of which the basic guidelines and directions for the adequate management measures can be given in order to enhance the successful outcomes in future reclamation activities.
Identification of relevant publications, technical reports and unpublished sources was undertaken prior to their systematic review. The results and the conclusions of relevant studies are summarized and interpreted in order to answer the research questions.
Methods of reclamation in large mining basins in Serbia are described within context of ground preparation, use of artificial covers or topsoil cover, prevailing type of biological reclamation, and additional scientific researches. Agricultural and silvicultural approach to biological reclamation of mining sites largely dominates in Serbia, often being coupled with ameliorative approach. As a consequence of reclamation measures, content of nitrogen and organic matter in Technosols overly increased in reclaimed areas, and their biogenity has generally been improved. Systematic monitoring of reclaimed areas may provide information on soil and vegetation development that could significantly contribute to the quality of future reclamation activities.
KEY WORDS: reclamation, outcomes, management, good practice

INTRODUCTION
Mining operations are temporary land use activities. In order to minimize the impact to the local environment after the end of mining operations a mine reclamation plan is required. Reclamation techniques include technical and biological processes. Technical reclamation covers landscape shaping and levelling, drainage control measures, stabilization measures and topsoiling. The main objective of biological reclamation process is the establishment of diverse artificial ecosystems most suitable for designed post-mining land use. Successful biological reclamation restores the natural capital of biota and productivity of land, which have been previously destroyed by mining operations (Sheoran et al, 2010).

According to the The Law of Mining and the Geological Explorations (Official Gazette 101/2015) after the exploitation of mineral resources company is obliged to carry out reclamation of the land according to the project study. The reclamation plan is introduced in the very early planning phase of of mineral deposits exploitation, which enables that the reclamation technology can be adapted to the excavation and ore processing technology in order to achieve more efficient and lower cost solutions. The project documentation for the performance of the reclamation work is regularly made, but the projects are still poorly applied in practice. Due to the periods of economic crisis, lack of financial resources often caused discontinuities in reclamation processes, or the absence of proper management measures. In addition, the information on the results of reclamation efforts is often missing, or it is partial and incomplete (Ranđelović, 2015, Stanković et al,2015).

One of the basic preconditions for the biological reclamation is the adequate ground preparation. Landfilling is still subordinate to the technological process of exploitation and not the biological reclamation process. To ensure the optimal condition for reclamation success, biological reclamation needs to be strongly adjusted to the technical part of ground preparation.

Non-selective deposition of overburden material is a common practice in Serbian mining basins (e.g. Bor, Majdanpek, Kostolac, Kolubara). In his way, the surface ground remain heterogeneous, creating a variety of different conditions over a relatively small surface that often compromises the biological reclamation efforts and success. Physical, chemical and biological properties of extracted material are main obstacles for a successful reclamation. If the topsoil layer has been preserved, soil cover preparation is more efficient than in the case of non-selective deposition. However, Ličina et al. (2017) suggest that preserved surface soil layer, used for topsoiling in biological reclamation, should be previously tested on the excess of heavy metals, especially if the agricultural reclamation is going to be applied.

Biological reclamation of mine wastes can be described in terms of three different basic approaches (Hester and Harison, 1994):

a) agricultural / silvicultural - agricultural crops or forest plantations are established using conventional or specialized techniques.

b) ameliorative - achieving optimum conditions for plant growth by improving the physical and chemical nature of mine wastes using organic matter, fertilizers or specialized industrial products. The most suitable species commercially available are sown on to the wastes with modified properties.

c) adaptive - selection of the most suitable species and cultivars to meet the extreme conditions of mine wastes. This approach is simple but is constrained by the availability of the seed banks and lead-time in producing commercial seed from promising natural or artificially selected plant material.

The objective of this paper is to present a review of the reclamation methods used in practice and the outcomes of biological reclamation activities in some of the most important mining basins in Serbia. The outcomes reflected in Technosol development, microorganism and vascular plant diversity indicating a degree of ecosystem function and productivity, which are highly influenced by prevailing abiotic and biotic conditions of specific mine basin.

This paper also aims to answer following questions: What is the prevailing type of biological reclamation in most important Serbian mining basins? What are the main changes that arise upon the biological reclamation? Are there any new directions emerging in nowadays reclamation practice in Serbia?

Summarizing the findings of diverse researches and reports on biological reclamation state and process creates a base of which the basic guidelines and directions for the adequate management measures can be given in order to enhance the successful outcomes in future reclamation activities.

MATERIAL and METHOD

Identification of relevant publications, technical reports and unpublished sources was undertaken prior to their systematic review. The results and the conclusions of relevant studies are summarized and interpreted in order to answer the research questions.

RESULTS and DISCUSSION

Reclamation practice in Serbia has been developing in last couple of decades, reaching its peaks during 80`s of previous century. Reclamation practice was closely connected with economic development and it was also heavily influenced by economic crisis in the country. So far, rather low percentage of reclaimed area out of total deposited area has been obtained in Serbian large mining basins (Table 1).

Table 1
Total deposited area, reclaimed area and percentage of reclaimed area out of total deposited area in Serbian mining basins (according to Vujić et al, 2005 and National Strategy for Sustainable Use of Natural Goods and Resources, 2012)

Mining basin	Total deposited area (ha)	Reclaimed area (ha)	Percentage
Kolubara	3 580.6	1150.8	32.14
Kostolac	1 435	462.1	32.20
Bor	827.7	112.7	13.6

Reclaimed land is managed either by the operational units within the mining companies, either by separate companies (public entities) with a purpose of land reclamation and managing. The organizational type influences the way reclaimed land is managed and treated. In Kolubara mining basin special operational units are conducting reclamation work and they also permanently manage post-exploitation land. In Kostolac mining basin this role belongs to a public company „Reclamation and greening". The reclaimed land is in a public ownership, and state and local governments has obligation to provide financial support and other measures for effective land management and other management measures based on the sustainable development of the area (Živanović- Miljković and Džunić, 2013).Operational unit within Mining Basin Bor and Institute for Mining and Metalurgy Bor as a public institution are currently managing the mine waste and flotation tailings areas in Bor. There is no special treatment of reclaimed areas in this mining basin, which largelz influence their size, quality and effectiveness.

The reclamation works and post-mining land use change in largest mining basins in Serbia needs to be accompanied with ownership transformation, e.g. returning the land to the previous owners, transfer of land for profit or non-profit purposes (Živanović- Miljković and Džunić, 2013).

Kolubara coal mining basin

The first reclamation efforts in Kolubara mining basin began in the 1950's (Šmit and Veselinović, 1997). A total of 845.14 ha of deposited area in Kolubara mining basin has been reclaimed by the end of 2016., out of which 738.24 ha underwent forest reclamation, and 106.9 ha agricultural reclamation (Report on the state of the environment in MB Kolubara d.o.o., 2016). Few decades of experimenting with crops, fruits and forest plantations, as well as application of diverse agro-technical measures, has nowadays brought to a valid recommendations for successful reclamation of Kolubara deposits.

Agricultural reclamation process consists of substrate preparation, fertilization, sowing and care measures. However, if preserved surface soil layer is going to be used in agricultural reclamation, Ličina et al. (2017) suggest a prior metal assessment as a component of a future rehabilitation policy for topsoil in food and fodder production in Kolubara mining basin. First phase of agricultural reclamation consists of grass and legumes, which improves fertility of Technosols. In later phases diverse crops (wheat – *Triticum* sp., corn – *Zea mays*, alphalpha – *Medicago sativa*, and sunflower – *Helianthus* sp.) and fruits (apples – *Maluspumila*, pears – *Pyrus* sp., and plums – *Prunus* sp.) are planted. Agricultural products from Kolubara mining basin are annually sold on market. However, evaluation of economic parameters for success of agricultural reclamation showed that high level of agricultural profitability cannot be expected in the case of Kolubara mining basin, according to the investigations of Zlatić et al (2000). Forest reclamation in Kolubara mining basin started in 1957, but intensive reclamation efforts began from 1973, when first forest nursery was formed on the Technosol in Baroševac (Šmit and Veselinović, 1997). The technology of establishing forest plantations consisted of adding peat in a planting hole, or using seedlings with baled roots in order to provide favourable conditions for the development of root system. First tree species used in reclamation of this area were the species previously used in similar programs: Austrian pine (*Pinus nigra)*, lime (*Tilia* sp.), ash (*Fraxinus* sp.), larch (*Larix europaea)* and black locust (*Robinia pseudoacacia).* At later stages, other tree species such as oak (*Quercus* sp.), alder (*Alnus glutinosa*), Douglas fir (*Pseudotsuga menziesii),* maple (*Acer* sp.) etc. were used. Results of multidisciplinary research on this forest stands showed that great number of autochthonous deciduous species and fast-growing conifers can be used in reclamation of Kolubara mine deposits (Šmit and Veselinović, 1997). Technosol soil texture is one of the major factors that determine the choice of tree species (Šmit and Veselinović, 1997). The profitability of wood production in Kolubara Technosols depends upon tree species and site quality (Zlatić et al, 2000). According to Resulić et al, 2013, agrochemical properties of tested Technosols under different forest cultures showed increased pH, lower humus and total nitrogen content, higher level of available phosphorous and similar or lower value of available potassium compared to the control pseudogley soils, which represents natural autochthonous soils of Kolubara basin (Table 2).

Table 2
Agrochemical properties of Technosols and pseudogley soil under different forest cultures (taken from Resulić et al. 2013)

Locality	Species	pH	Humus (%)	N (%)	P2O5 (mg/100g)	K2O (mg/100g)
Technosol 1	*Pinus nigra*	5.5	1.48	0.1	8.2	15.4
Technosol 2	*Quercus robur*	6.5	1.26	0.13	6.8	22.6
Technosol 3	*Alnus incana*	6.5	2.1	0.05	2.1	13.6
Technosol 4	*Pseudotsuga menziesii*	5.75	1.35	0.12	3.7	27.8
Technosol 5	*Larix decidua*	5.9	2.67	0.10	3.6	16.5
Technosol 6	*Tilia* sp.	5.9	1.12	0.06	2.5	15.2
Control site - pseudogley	*Pinus nigra*	4.55	3.15	0.16	2.7	23.4

According to Miletić (2004), one of the main limiting factor for the growth and development of the forest trees on the reclaimed mine soils in Kolubara mining basin is the lack of nitrogen. Consequently, the best improvements of Technosols characteristics were achieved by nitrogen-fixing species *Alnus glutinosa* and *Robinia pseudoacacia* (Miletić, 2004; Miletić et al, 2009). Based on the results of a various investigations on the reclaimed areas in Kolubara, it is recommended that the future reforestation works should be based on formation of mixed deciduous-coniferous or mixed deciduous forest stands, in order to enhance their ecological values and effects they produce on the surrounding environment (Šmit and Veselinović, 1997).

Investigation of soil microorganisms in Technosols under forest stands showed that biochemical processes and organic matter turnover has been established. The higher content of soil microorganisms by their main physiological groups has been obtained under deciduous stands compared to the coniferous stands at the reclaimed areas (Miletić et al, 2005). Similar results are obtained by Đorđević et al. (2014), which have found increased number of soil microorganisms in the 7 year old birch tree stands, compared to a 16 year old silver pine tree stands. Total number of soil microorganisms in the investigated Technosols has been reached the average levels for natural soils.

New approaches to biological reclamation in Kolubara mining basin are confined to the individual scientific studies on small plots. Research on short-rotation forest plantations for biomass production was established in Kolubara mining basin in order to revile proper species and optimal solutions for the establishment of short-rotation plantations that may produce the greatest amount of biomass for energy production. In 2006.experimental plots with *Larix europaea (larch)*, *Pseudotsuga menziesii (*Douglas fir*)* and *Populus* sp. seedlings were established at Field "D"(Dražić et al, 2008), while in 2008. experimental plot with *Robinia pseudoacacia* seedlings was established at Field "B" (Danilović et al, 2013). Preliminary results showed that deciduous species, especially poplar, achieved better growth compared to the coniferous trees at current stage of development (Dražić et al, 2011; Dražić, 2017). However, continuous monitoring until the end of rotation period is needed for the proper conclusions to be made. These investigations have been partially coupled with amelioration measures, where waste sludge (generated in the process of coal processing) and ash (product of the wood combustion) were successfully used as manure for tree plantations (Dražić et al, 2017).

Similar approach has been undertaken by creating experimental plots with perennial grass *Mischantus x giganteus.* In 2011.experimental fields of *Mischantus x giganteus* for biomass production emerged in "Tamnava West Field". The results of this experiment suggested that the development and production rate of *Mischantus x giganteus* highly depends on fertility of Technosol and application of adequate agrotechnical measures. When properly applied, it becomes possible to achieve results on degraded Technosols close to the ones obtained on natural soils (Aranđelović et al, 2014).

Kostolac coal mining basin

Reclamation works in Kostolac mining basin started in 1970`s. Up to 2011th, total of 704 ha has been reclaimed, out of which 432 ha have been afforested, while 235 ha were under agronomic cultures (Miloradović-Đorđević et al.,2014).

Forest reclamation was predominantly undertaken at the landfill slopes of open-pit mines "Ćirikovac", "Kostolac", "Klenovnik" and "Drmno" (Figure 1). Main tree species used for afforestation at this mining basin are *Robinia pseudoacacia*, *Populus* sp. and *Pinus nigra*. Agricultural reclamation is confined to flat areas, and is sporadically been coupled with topsoiling (Figure 2). First phase of agricultural reclamation includes sawing of rapeseed (*Brassica napus*), which is afterwards used as a green manure in process of soil preparation for supporting cultivation of grasses and crops. Investigations of potential of annual agricultural species for reclamation of mine waste deposits at “Drmno” reflected the accumulation of heavy metals (especially Ni and Cr) in underground and aboveground parts of plants (*Lactuca sativa*, *Fragaria vesca*, *Brassica napus*, *Zea mays*, *Medicago sativa*) and the possibility for their transfer to animals and humans via food chains, which makes them unsuitable for reclamation of this area (Ličina et al, 2007).

Figure 1. Two-year old black locust plantations on landfill slopes of „Drmno“ mine

Figure 2. Topsoil placement upon preparation for agriculture reclamation in „Drmno“ mine

Technosols reclaimed with poplar become richer in nitrogen and potassium, followed by formation of humus-accumulative horizon. After 5 years of reclamation with rapeseed, legume and grasses initial acidity of Technosols decrease, contents of humus and nitrogen increase, as well as the contents of available potassium. State of 25 year-old forest and agricultural Technosols in “Ćirikovac” mining field showed increased content of humus and total nitrogen, as well as the decrease in content of $CaCO_3$ in comparison to a non-reclaimed deposits (Table 3).The highest differences in terms of humus, total nitrogen and available phosphorous and potassium content were obtained under agricultural areas as a consequence of fertilization application and other agrotechnical measures.

The best condition and health status so far have been achieved by usage of black locust (*Robinia pseudoacacia*). Technosols of older black locust stands are characterized by regular turnover of organic material with formation of humus (Đorđević—Miloradović et al, 2014). Increased biogenity and development of ecosystem processes on reclaimed areas has regularly been followed by increased biodiversity. Over 300 species of herbaceous plants was found to inhabit reclaimed areas in mine “Ćirikovac” (Đorđević—Miloradović et al, 2014).

Table 3
Agrochemical characteristic of non-reclaimed mine waste deposits and 25 years old Technosols under different reclamation types (according to Đorđević—Miloradović et al, 2014)

Reclamation type	pH_{KCl}	Humus (%)	$CaCO_3$ (%)	N (%)	P_2O_5 (mg/100 g)	K_2O (mg/100 g)
Non-reclaimed area	7.5	1.67	4.99	0.02	5.4	27.9
Spontaneously revegetated area	7.4	2.28	4.18	0.09	5.36	21.3
Forests of *Pinus nigra*	6.9	2.31	4.11	0.11	5.12	19.1
Forests of *Populus sp.*	7.1	3.15	4.05	0.13	5.31	18.5
Agricultural areas	7.2	3.71	4.1	0.185	7.81	26.3

New approaches to biological reclamation in Kostolac Mining Basin have been implemented in previous years. Amelioration of Technosols by zeolite and coal dust prior to agricultural reclamation has been proved to improve it's characteristics by introducing new amounts of organic carbon, nitrogen, phosphate and potassium (Grubišić, 2011; Đorđević—Miloradović et al., 2014). In 2016.a plantation of fast- growing *Paulownia tomentosa* was established on 3.5 ha of landfill slopes at "Drmno" mine in order to investigate the potential of this species for the biomass production.

Bor copper mining basin
Reclamation of mine wastes and flotation tailings in Bor copper mining basin has started in late 1970's. Due to the severe heavy metal and metalloid pollution of air, soil and water in Bor area, forest reclamation has been predominantly applied for the purpose of environmental protection and erosion control. Afforestation efforts have been carried out on mine wastes and flotation tailings in mines "Bor" and "Veliki Krivelj" during 1979-1986. and 1992-1997., with species *Robinia pseudoacacia* (Figure 3), *Betula pendula*, *Quercus* sp., *Pinus nigra*, and *Carpinus* sp. (Milijić, 1997). Agricultural reclamation has been carried out during 1994-1995. on flotation tailings in Veliki Krivelj with rapeseed (*Brassica napus*) and rye (*Secale cereale*).

Table 4
Chemical characteristic of Site 1 - Non-reclaimed mine waste sites with native vegetation, Site 2 - Afforestated Technosols on mine wastes under *Robinia pseudoacacia* stands, Site 3 - Afforestated Technosols on flotation tailings under *Robinia pseudoacacia* stands (according to Ranđelović et al, 2014)

Mine wastes	pH_{H2O}	C (%)	N (%)	P_2O_5 (mg/100g)	K_2O (mg/100g)
Site 1	3.91 - 8.32	1.35	0.03	6.1	15.8
Site 2	5.6 - 7.85	1.04	0.6	7.6	19.5
Site 3	4.5 – 7.55	2.57	0.2	13.3	20.4

Technology for biological reclamation on deposited mine wastes consisted of providing favourable conditions for the development of roots by adding peat in a planting holes. Biological reclamation was preceded by topsoiling on flotation tailings sites in mines "Bor" and "Veliki Krivelj" (Figure 4). Investigation of Ranđelović (2010) showed that initial stages of pedogenesis, represented by accumulation of organic material and nitrogen in surface layers of Technosols occurred under black locust stands,but also in the non-reclaimed areas colonized by spontaneous native vegetation (Table 4). However, there is no formation of humus-accumulative layer neither a formation of structural aggregates in surface in investigated areas (Lilić, 2015), except in flotation tailing sites that have been topsoiled prior to biological reclamation. However, due to the constant exposure to aeropollution, Technosols of flotation tailings show degradation of soil structure in comparison to the surrounding natural soils (Lilić, 2015).

Despite the fact that the total content of soil microflora is generally low due to the presence of metal pollution, especially copper and arsenic (Ranđelović, 2010; Lilić, 2015), the transformation process of organic matter under the black locust stands has been established. The ratio of the number of soil microorganisms in diverse physiological groups (fungi, actinomyces, oligonitrophiles, ammonifiers and total microbes) reflects that the major part of the organic matter decomposes to the end-products. Synthesis of humus out of the inter-products of organic matter decomposition is slow and the further decomposition of the synthesized humic substances to the end products is either very slow, or was not identified (Ranđelović, 2017). Total of 105 vascular plants, which count as approximatelly 3.3% of total flora of Serbia, have been identified in black locust stands at Bor mine wastes and flotation tailings (Ranđelović, 2009).

Figure 3: Black locust stand on Bor mine waste slope

Figure 4: Reclaimed flotation tailings with topsoil and herbaceous species

Recent reclamation efforts have been made in 2008. at “Veliki Krivelj” mine wastes, where 10 ha were planted with black locust and Siberian elm *(Ulmus pumila).*Evaluation of reclaimed surfaces in “Veliki Krivelj” reviled that Siberian elm was not able to survive present environmental conditions, while the black locust showed different survival rates (16-95%), depending on a site conditions and reclamation technology (Žikić et al, 2017). In the area of Bor copper mine wastes, species selection and maintaining measures have proved to be a very important question for success of biological reclamation.

New approaches to biological reclamation in Bor mining basin include selection of plant species for future reclamation and investigations for the purpose of phytoremediation. During 2008. and 2009. experimental plots at Bor flotation tailings were tested with with meliorated and sterile substrates and chosen tree and grass species. The best results in a first year upon establishment were achieved with the species planted in the fertile soil layer placed upon the flotation deposit, and on the mixture of soil and flotation tailings deposit. Black locust, European ash *(Fraxinus excelsior)* and sycamore (*Acer pseudoplatanus)* showed the best survival rate, growth, and physiological vitality (Dožić et al., 2010). This research has confirmed that it is possible to use a wider number of tree species in the reclamation of the Bor mine basin. Investigations of phytoremediation potential of native and cultivated species in the area of Bor mine wastes have also been conducted. Marić (2014) and Ranđelović (2015) concluded that certain native and cultivated plant species show possibilities for significant uptake of main pollutants in the area, such as copper, arsenic or lead in their underground or aboveground parts. Species such as *Dactylis glomerata*, *Vicia sativa*, *Festuca ovina*, *Taraxacum officinale*, *Calamagrostis epigejos* and *Agrostis stolonifera* can therefore be used in future reclamation projects dealing with phytoremediation issues.

CONCLUSIONS

Although wider biological reclamation of mine wastes in Serbia started six decades ago, there is still not enough attention paid to this process, which largely depends on the economic and political trends. Prevailing attitude is that a reclamation is consider to be a long-term and costly solution, and not an legal obligation to return the land into previous or similar to previous state prior to excavation. After the processes of reclamation, the issue of further land management and land use is often not properly solved.

Agricultural and silvicultural approach to biological reclamation of mining sites largely dominates in Serbia, sporadically being coupled with ameliorative approach. Adaptive approach is still not considered as a viable alternative in reclamation of Serbian mining basins.

Content of nitrogen and organic matter in Technosols generally increase in reclaimed areas and the content and diversity of soil microorganisms has also been improved, aiming at enhancing organic matter turnover and nutrient cycling in artificially created ecosystems. Diversity of herbaceous species follows the development of forest- or agroecosystems on reclaimed areas.

Scientific institutions carry out experiments in order to find efficient and cheaper, or even profitable reclamation solutions. Modern reclamation efforts are directed toward gaining biomass for energy production (coal mining basins Kolubara and Kostolac), or investigating a potential for phytoremediation (metalliferous mining basin Bor).

In order to create stable foundation for the application of biological reclamation, certain recommendation and guidelines can be met:

●Landfill practice and technical reclamation solutions should be closely related and more adapted to biological reclamation process, and this conjunction should become usual in project practice. Selective deposition of overburden would significantly influence the success of biological reclamation, improving the starting condition for vegetation development.

● Systematic monitoring of reclaimed areas is needed in order to gain comprehensive information on soil and vegetation development, which will lead to new knowledge and directions for successful reclamation. Adaptive management, which synthesizes scientific and management approach through continual monitoring and iterative project cycle is often a proper method for sustainable management of reclaimed areas.

● Further researches with ameliorative approach are needed in order to gain cost-effective and more productive reclamation solutions. Phytoremediation experiments should be directed toward practical application in selected mining basins. Species selection and maintenance measures of artificially created ecosystems on reclaimed areas should be carefully planned, having in mind future resilience and adaptation of these ecosystems to ongoing climate changes.

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