Re-thinking Post-Mining Areas Reclamation in 21st Century

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Abstract. Despite the technological advancement, widespread investor pressure and the global recognition of sustainable development as a 21st century paradigm, many of the post-mining areas are still waiting for reclamation and giving them a new function. The studies that have been carried out have aroused interest in the lack of development of these areas, so numerous in many regions, where the mining industry has been driving the economy for centuries. The article posed the question of what factors determine today the formation of post-mining areas, and whether these processes are consistent. It was also considered what impact the idea of sustainable development has on the approach to post-mining areas. In order to solve such constructed problems, the research method of logical argumentation and interpretation was used. The author used research techniques such as: data query, literature research, comparative analysis as well as sketches and tabular statements. The article analyses critically the most important legal documents in this field, discusses the conditions and limitations of reclamation and changes in the function of post-mining areas, as well as outlines the context of the idea of sustainable development. During the research, the directions of reclamation were reviewed. Next, features of post-mining areas were presented, which have a decisive influence on the possibilities of their transformation. There were given more important conditions for choosing the direction and method of reclamation. In addition, in a paper a critical reference was made to the reclamation practice in Poland. What is more, the need to adjust the reclamation of post-mining areas to the concept of their subsequent development with regard to local conditions was shown. The article draws attention to the lack of full use of the potential of post-mining areas and the need to change this situation in the context of sustainable development, according to which space is one of the valuable non-renewable resources. The author suggests introducing the necessary legislative changes related to the reclamation of post-mining areas, and also states the need to refine the multi-criteria analyses of the possibilities and directions of reclamation. She also states that in the 21st century, any space development project (including mining and mine liquidation) should be based on the principles of sustainable development.

1. Introduction

The mining industry for centuries was the basis for the economic development of many regions of the world. Usually, mining activities were associated with the so-called "A robbery economy", which consists in deriving maximum benefits at the expense of depleting the deposits, with minimal costs incurred to repair the serious effects of spatial and environmental transformations. The post-mining areas created in this way, usually much larger than the extraction area itself, are areas with permanently transformed terrain, temporarily devoid of vegetation, with anthropogenic elements, remaining after the mining activity. As numerous examples show, not all areas with a post-mining operation successfully undergo reclamation processes and give them new functions. Many of them...
remain degraded. Therefore, the purpose of the article is primarily to look for answers to the questions that factors currently determine the formation of post-mining areas and whether these activities are consistent. It was equally important to examine the limitations and conditions of the change in the function of post-mining areas, as well as to determine the directions of reclamation undertaken and to refer them to the idea of sustainable development.

2. Legal conditions
Standards and legal regulations regarding mining operations vary considerably between countries, even within the European Union. The conducted analysis of legal conditions has shown that usually mining of mineral resources takes place on the basis of permits / concessions obtained by a mining entrepreneur even before starting operations. Permits are granted at various levels of administration - from regional to national, often depending on the size of the deposit and the planned volume of its extraction. Usually, already at the level of the application for the concession, the mining entrepreneur is obliged to present the deposit development plan, the mining operation plan and the analysis of the project's environmental impact. [1].

In individual countries, mining enterprises, after completion of extraction to a different extent, are obliged to reclaim the area in a way that will realistically prepare the area for new functions. Reclamation is understood here as the restoration of utility or natural values of degraded land. Unfortunately, the lack of precise provisions in legal documents and planning documents may cause that obligatory reclamation is carried out by the mine in the easiest way - the forestation. That is the situation in Poland, where reclamation is carried out without any connection to subsequent development, which is already the responsibility of local authorities or private individuals. In contrast to this, for example in Germany reclamation is directly linked to later development of the land, and the responsibilities of the mining process involves both reclamation and redevelopment. This enables a more holistic approach, better land preparation and coordination tasks. What's more, at every level of administration, German documents on reclamation contain many detailed records, which are missing in Polish documents (e.g. guidelines for shaping waste in landscape, not conical or terrace form, definition of new functions, obligation to implement a network of roads linking the transformed area with the surroundings, which are recorded in local plans) [2-4]. This approach to the last, obligatory stage of the mining company's activity seems to be much more appropriate. Otherwise, it is possible to adapt the later mode of use to the conditions left by the mining entrepreneur, instead of preparing the site and adapting the way of land reclamation by the mine to the planned, new usage.

3. Conditions and limitations of changes in the function of post-mining areas
Post-mining areas usually have a large natural potential. At the same time, land reclamation in this direction gives the possibility of later linking such a way of management with, for example, recreational, sports, etc. Despite the high strength of nature "recovering" the area after mining exploitation, it is not enough to leave this area fallow. It is necessary to perform a series of activities that adapt the habitats to the desired fauna and flora. These treatments may relate to, for example: shaping slopes, stabilizing slopes, draining, changing geochemical conditions, detoxification, soil layer fertilization, selecting already growing plants and planting new ones, etc.

Interesting aquatic habitats are formed in both retention ponds (reservoirs) in the immediate vicinity of, for example, heaps (picture 1), as well as in flooded open-cast mines, quarries, mines extracting aggregates from under water, mining hollows and floodplains. Wetland ecosystems are among the most biodiverse. These waters create the most favorable habitat conditions and show a spontaneous tendency to overgrow with aquatic plants (e.g. reed and water stick), as well as colonization by various species of birds and amphibians. The process of overgrowing this type of surface water is a continuous process and needs to be controlled so as to leave an undamaged part (according to some naturalists, a minimum of half) of the water surface. In turn, shallow retention ponds may require periodic dredging. These activities are important for creating appropriate habitat conditions for both fauna and flora.
Different environmental conditions occur in mining dumps, where for a number of years physicochemical processes take place, and the mechanical impact of the dump on the ground reaches sometimes hundreds of meters beyond its base. Initially in the upper layers of the embankment oxidized carbon causes acidification of the material (acidic pH). Over time, hydrogen ions are leached into deeper layers over the years. Nevertheless, any violation of the soil surface causes its return to acidic pH. What's more, the material of the heap can be initially heavily grained. Over time, it is crumbled. Then forms (especially on flat surfaces) a clay layer - slippery in moist periods and fossilized in dry periods. This layer closes tightly, significantly limiting the penetration of rainwater into the heap. The best conditions for plant growth occur on flat parts of the heap. In these places, the nutrients are more easily accumulated in the humus layer, which is formed over time from the decomposition of plant material (e.g. leaves from trees). On the slopes, the conditions are much worse. The habitat is dry there, and the rock is easy to weather. Rainwater flows away quickly, rinsing clay particles down the slope. Erosion processes are strong there (picture 3), and the soil dries quickly (picture 4). The southern and western slopes, which get very hot, are especially vulnerable. The eastern side is quite favorable. From the north, the slope warms up least. There, the conditions of natural plant succession are better. [5]

In general, it can be said that the environment with which we deal in the case of post-mining areas is not favorable and easy to adapt to the new function. When it comes to heaps, it is often an acidified, saline environment with limited access to compounds that are absorbed by plants. In the initial phase - natural succession - it can be colonized by pioneer plants, mainly sown by the wind, ruderal and native

**Picture 1.** Overgrowing pond at the foot of the heap in Katowice-Murcky - a habitat of valuable species of frogs (author: K. Mazur-Belzyt)
species (picture 2). The development of expansive, invasive plants of foreign origin (e.g. white robinia) that can displace native species should be avoided and controlled. [5]

![Picture 2. Natural succession of plants on the surface of a post-mining heap (K. Mazur-Belzyt)](image)

In such a specific environment, which is a dump, important for natural reasons is to increase biodiversity. A simple, cheap and quite effective operation may be pouring on the slopes heaps of plant material from the mowing of nearby roadside ditches and neglected lawns. This should of course be done when plant seeds are in the cut material. [5]

Apart from the natural potential, post-mining areas often have significant landscape potential. Landscape attractiveness requires the preservation of the post-mining area itself, possible alignments, viewing axes and role as a vertical, anthropogenic dominant in the landscape. There is also a second aspect - valuable scenic values, for example from the top of a heap or excavation. In this case, care should be taken to preserve the landscape exposure. This is done by non-developing the upper part of the slopes and the top, establishing the visibility belts, removing any high plants in them and controlling the growth of trees in the field of exposure. Otherwise, during several years, the trees could obscure valuable views.
Picture 3. Erosion of the heap slope (K. Mazur-Belzyt)

Picture 4. The surface of the heap dried up and fossilized in the dry period (K. Mazur-Belzyt)
4. Directions of reclamation
There are many opportunities to transform post-mining areas and ways to adapt them to new functions. The choice of the direction of adaptation generally depends on natural, social, cultural, economic, formal-legal, technical and technological factors [6].

The conditions discussed above are only part of a comprehensive set of factors that have a significant impact on the selection of directions for the reclamation of post-mining land, as well as on the way of composing abiotic elements with nature. When determining the direction of land reclamation, and then the possibility of giving it new functions, it should be taken into consideration at the beginning such factors as [7]:

- slope of the heap or walls of the excavation
- maximum height / depth
- insolation
- climatic zone (length of vegetation period, sum of precipitation, daily temperatures)
- material permeability for water and plant roots
- the scale of erosion
- type of soil (sand, clay, silt, loess, rock, etc.) and its grain size
- pH
- already existing species of fauna and flora (including endemic, protected species)
- other values, including, for example, historical, landscape and composition.

The weight of individual factors is different for different new, planned land use methods. The significance of selected environmental and socio-economic factors when changing the use of post-mining land is shown in table 1. Individual factors are grouped into environmental and socio-economic ones, giving them from 1 to 3 points. At the same time, it should be noted that point weights are not proportional and only in a certain simplification allow for comparisons within rows and columns. In highly urbanized areas, socio-economic factors are of decisive importance when choosing a new method of developing post-mining areas. Assigning these factors greater importance in the process of selecting the development method eliminates a certain number of potential directions.

In European countries, the most frequently undertaken direction of reclamation is the natural, forest, agricultural or water course. The analysis of resettlement of post-mining areas in Poland showed that the areas designated for forests constitute as much as 60% of all areas covered by reclamation, for agricultural land - about 20%, water - about 10%. There is only 10% left. They are developed in other directions, including industrial areas, leisure areas, housing, parks, recreation and sports areas, landscape compositions, landfills, etc. [8]. The table 2 presents a proposal to assess the suitability of the dumping grounds and excavations for new uses.

As already mentioned, the most common direction of reclamation of post-mining areas is the forest direction. As we read in the Geominero manual [9], this type of use should be used for relatively low fertile soils, with an area of at least 0.25 ha and an inclination angle of any slope up to 35°. Necessary preparatory measures include, above all, mitigation of slopes, improvement of drainage, fertilization of humus and silt, and settling of pioneer plants. In turn, the introduction of agriculture will be favored by large, open surface mines, top heaps, areas with inclination of up to 5° for arable land and up to 15° for pastures, low stony soils, ensuring good drainage, and above all non-toxic, moderate pH. In the case of this method of use, the necessary adaptation measures include: mitigation of slope, humus, sludge and limestone, fertilization, regulation of water conditions and introduction of necessary plants.
Table 1. The importance of selected environmental and socio-economic factors (based on Sweigard, Ramani 1986, Paulo 2008, modified by author)

| Type of land use | F | A | R | H | S | I | L |
|------------------|---|---|---|---|---|---|---|
| **Environmental factors:** |   |   |   |   |   |   |   |
| terrain          | 2 | 3 | 1 | 2 | 2 | 2 | 2 |
| slope            | 3 | 3 | 1 | 2 | 3 | 3 | 2 |
| relative height  | 2 | 2 | 1 | 1 | 1 | 1 | 2 |
| geographic exposition | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| rock permeability| 3 | 3 | 1 | 3 | 3 | 3 | 3 |
| temperature      | 3 | 3 | 2 | 1 | 1 | 1 | 1 |
| atmospheric precipitation | 3 | 3 | 2 | 1 | 1 | 1 | 1 |
| bearing capacity of the substrate | 2 | 3 | 1 | 3 | 3 | 3 | 1 |
| fertility of soils | 2 | 3 | 2 | 1 | 1 | 1 | 1 |
| agrotechnical properties of soils | 1 | 2 | 1 | 3 | 2 | 2 | 1 |
| **Total points - natural sensitivity** | 23 | 27 | 13 | 18 | 18 | 17 | 15 |

| Socio-economic factors: |   |   |   |   |   |   |   |
|--------------------------|---|---|---|---|---|---|---|
| location                 | 1 | 1 | 3 | 3 | 3 | 3 | 3 |
| transport accessibility  | 1 | 3 | 2 | 3 | 3 | 3 | 2 |
| size and shape of the area | 1 | 1 | 1 | 2 | 1 | 3 | 2 |
| destiny of surrounding areas | 1 | 2 | 2 | 3 | 3 | 1 | 3 |
| property                 | 1 | 1 | 2 | 2 | 2 | 2 | 2 |
| demography               | 1 | 1 | 2 | 3 | 3 | 2 | 3 |
| legal restrictions       | 1 | 2 | 2 | 3 | 3 | 3 | 3 |
| attitude of entrepreneurs | 1 | 1 | 1 | 3 | 3 | 3 | 3 |
| attitude of society      | 1 | 1 | 1 | 3 | 3 | 3 | 3 |
| **Total points - socio-economic sensitivity** | 9 | 13 | 17 | 24 | 23 | 22 | 24 |

Type of land use: F - forest, A - agricultural, R - recreation, H - housing, S - service, I - industrial, L - landfills

Table 2. The potential of post-mining land use (based on Coppin, Bradshaw 1982, modified)

| A new terrain feature | Mining dumping ground | Excavation |
|-----------------------|------------------------|------------|
|                       | graded | leveled | deep flooded | dry shallow flooded |
| return to original use | -      | +/-     | -             | -                  |
| agricultural          | +      | ++      | -             | +                  |
| forest                | +      | ++      | -             | ++                 |
| nature conservation   | +      | +       | +             | +                  |
| recreation and sports | ++     | ++      | ++            | ++                 |
| park                  | ++     | ++      | ++            | ++                 |
| fish farming          | -      | -       | +             | -                  |
| water retention       | -      | -       | +             | -                  |
| industrial / communal | -      | -       | +             | -                  |
| landfill              | +      | +       | -             | +                  |

- lack of possibilities, + small potential, ++ big potential
Leisure, recreational and sports functions are usually devoted to post-mining areas with a large area (usually above 10 ha), which are located relatively close to residential areas. Due to the fact that in this case the safety of land use is important, the necessary measures can include: removal of abandoned machines and equipment, stabilization and mitigation of slopes, strengthening structures, construction of paths and parking lots, drainage and introduction of vegetation. [9] [6]

Construction of housing estates and industrial plants requires stable soils, controlling erosion, subsidence and the possibility of flooding. The bulk soil is not suitable for heavy objects. In the case of this type of development, the potential for contamination of areas is also one of important factors. As part of the preparatory work it may be necessary to: drainage, slope change and possible strengthening and stabilizing constructions. [9] [6]

Post-mining excavations are often used to store garbage and waste. The location of the post-mining area in close proximity to the city and / or industrial plants may lead to this. This type of purpose requires particularly careful research and adaptation in connection with the need to comply with complex legal norms. Particular attention should be paid to the study of substrate permeability, sealing of the foundation and walls of excavations, internal and surface dehydration, monitoring of leachate, biogas discharge, etc. [9] [6]

The smallest requirements and necessary adaptations concern the development of post-mining areas for nature protection purposes. The most important are the preliminary tests, which will allow to identify and evaluate plants and animals that have already settled in this area. Some of them may turn out to be endemic and protected species of high ecological value. In addition, the more species of plants occur in a given area, the more animals live there. However, there are wastelands so difficult to succession of plants that even after more than 10 years no spontaneous overgrowth is observed. These require the provision of soil layers and the introduction of plants [6].

5. Reclamation and sustainable development

As already mentioned, it is inappropriate to limit reclamation only to "afforestation" of post-mining areas, although of course it is the simplest and cheapest solution. It is necessary, based on the principle of sustainable development, to ensure efficient and multifunctional development, taking into account the conditions and limitations of both these areas and their surroundings. [10] [11] [12].

The concept of "sustainable development", although it is fashionable and often appears in various documents and resolutions, still does not involve too many specific actions. It functions more in the form of a theory than a practical tool, provided with a commonly used set of indicators to monitor its effects. In theory, referring to the issue of balancing development only to urbanized areas, it can be said that it is "that all resources are used optimally for synergistic development, in which social, environmental and economic aspects are mutually reinforcing in the city space" [13]. These aspects shape the city - its form, way of functioning and even its inhabitants. This is related to the spatial policy paradigm taking into account primarily the criteria of efficiency, quality and equality. Thus, it can be said that the development of post-mining land, taking into account the assumptions of sustainable urban development, should primarily be understood as rational management of the resources of this place.

The definition of sustainable development, which can be found, inter alia, in the Brundtland Report indicates that for the benefit of future generations, who will also have the right to development, the contemporary civilizational and economic development cannot take place at the expense of exhausting non-renewable resources and destroying the environment. This has a direct reference to the discussed post-mining areas. Similarly, in Agenda 21 we read that at the current level of civilization sustainable development is possible and it is a development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs [14] [15].

In turn, the “Leipzig Charter on Sustainable European Cities”, developed at a meeting of ministers responsible for urban policy makers of the Member States of the European Union can find the rules and strategies for urban development policy. These principles can also be applied to the reclamation and re-use of post-mining areas. For example, the fundamental principle of the Charter is such land
development, thanks to which it is possible to obtain the most compact urban structure, effectively using space. Likewise, the development of post-mining areas in terms of creating attractive high-quality public spaces, improving the quality of the environment, measures to improve the quality of life of residents, or strengthening the local economy in the context of the city as a whole are in line with the principles of sustainable development [16] [17].

6. Results and discussions
The devastation of areas associated with mining activities should be temporary, and the reclamation should end the mining process. However, today there are many examples showing how difficult the process is and how often post-mining areas remain degraded.

Many factors affect this state of affairs. The most important of them is improper determination of the usable potential of the site and its limitations, including hydrogeological, physico-chemical, natural and landscape factors, as well as the wrong choice of remediation method, insufficient financial resources allocated for corrective actions and not applying appropriate technical measures. Another factor is not to use the conclusions resulting from examples of good practice. They show clearly that the process of liquidation of mine reclamation and post-mining area must be subordinated to the way of future development, because the scale of restructuring and cost make this a difficult and lengthy process.

Local governments as well as mine and post-mining landowners should decide, at the stage of mine operation, how reclamation can be carried out, by doing so as the service fronts move. After the end of activities, it is possible to give the former mining areas the landscape and functions that are often more valuable than the original state, restore the spatial order and balance the development of urbanized areas as a whole. Shaping sustainable development and the pursuit of spatial order to achieve one of the important tasks of 21st century society. It does not have to be a utopia and an empty slogan, but it requires holistic urban design and spatial planning as well as the awareness and involvement of the local self-government, mining entrepreneur and the local community.

In summary, the following conclusions can be made:

- completing legislative documents related to the subject of reclamation and new use of post-mining sites is an important and urgent task,
- it is necessary to further improve the selection procedures and tools for multi-criteria assessment of factors determining a specific direction of reclamation,
- in both cases mentioned above it is advisable to draw conclusions from examples of good practice,
- local government administration should already at the stage of the development project require a concrete and detailed determination of the method of land reclamation after the end of mining activities. For this purpose, the local government administration should commission studies and analyses as well as variant land development concepts in order to concretize their expectations in relation to the mining entrepreneur at the moment of cessation of mine extraction and liquidation,
- choosing the proper method of developing the post-mining area is of key importance for balancing the development of the city.

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