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# Review of the Global Experience in Reclamation of Disturbed Lands

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**ABSTRACT**
The article deals with the global experience related to the reclamation of land disturbed due to mining. The experience of Ukraine in carrying out the biological reclamation of disturbed lands as a result of mining operations was analyzed. The directions of land reclamation in the world were defined. The plant species best used for biological reclamation of disturbed lands were determined.

**Keywords:** mining industry; afforestation; growing crops; quarries.

## INTRODUCTION

Extraction of minerals, and such human activities as the creation of landfills, ash dumps, tailings, construction of industrial and residential purposes, lead to the withdrawal of land suitable for agricultural and forestry from use. In a global scale, about 6–7 hectares of fertile land is allocated annually for the above-mentioned purposes. As a result of disturbance of the Earth's surface due to mining operations, the hydrological and hydrogeological regimes of the surrounding area, crop yields and wood growth decrease, and so on. Therefore, in many industrialized countries, land reclamation becomes of great economic and socio-economic importance.

According to the literature, reclamation is understood as a complex of engineering, biological and other measures aimed at restoring the productivity and economic value of the areas affected by industry, as well as improving the environmental conditions in accordance with the interests of society (Zabaluiev et al., 2017; Nadtochii et al., 2007; Kupchyk et al., 2010). In foreign literature, reclamation is understood as the process of restoring or providing useful values to degraded or devastated lands through appropriate land modeling, as well as improving the physical and chemical properties of soils (Lima et al., 2016; Kazmierczak et al., 2017).

In the interest of environmental safety and sustainable development, a number of industrialized countries have started adopting the laws and programs aimed at protecting and restoring the environment from the effects of mining activities. Much attention to reclamation has been paid in the United States, Germany, Poland, Great Britain, and later in other countries (Legwaila et al., 2015; Pietrzyk-Sokulska et al., 2015; Antwi et al., 2014; Citizen's guide …, 2007).

The direction of reclamation in each country is selected for each case separately, based on complex natural and economic factors. For example, in Great Britain, Germany, and Hungary, the agricultural approach of reclamation is preferred, whereas in the United States, and Turkey – the forestry approach. The first land reclamation work in the United States was conducted in 1926 in Indiana (Citizen's guide …, 2007). According to (Burger, 2011; Schladweiler, 2018), surface coal mining disturbed approximately 2.5 million hectares of land from 1930 to 1977 in the USA. Therefore, in 1977, the Surface Mining Control and Reclamation Act (SMCRA) was adopted, which led to significant changes in reclamation practices and established federal control over coal mining, reclamation and environmental standards (Schladweiler, 2018; Sloss, 2013).

The mining industry in the US spread almost across the entire territory, so the direction of biological reclamation is chosen according to the soil properties and weather conditions. For example, in the Eastern States forest reclamation dominates, in the Western US – disturbed lands are used for pasture, and in the Midwestern – for farmland (Burger, 2011).

The forestry reclamation is characterized by a large variety of tree types (Table 1) (Davis et al., 2017; Skousen et al., 2014).

Most often, the restoration of disturbed areas for forestry use is carried out in winter and spring (Ivanov et al., 2017). Much attention in the United States is paid to the agricultural approach of reclamation. Lucerne, oats and corn are grown on the disturbed lands. According to Trofymova et al. (2015), when growing corn on reclaimed land, the increase of yield was twice greater than before mining. Pastures are created in the dumps formed due to the mining operations. In Kansas, about 80% of all pastures are located on reclaimed coal dumps, orchards and vineyards are grown on restored lands. In Pennsylvania, Ohio and Indiana, parks are created on reclaimed dumps (Trofymova et al., 2015).

In Turkey, the land disturbed by mining is commonly used for afforestation. According to (Kuter, 2013), between 1991 and 2011, about 7.3 million trees were planted in 4,455 hectares of abandoned quarries. Black locust (*Robinia pseudoacacia*), stone pine (*Pinus pinea*), black pine (*Pinus nigra*), cedar (*Cedrus* sp.), horse chestnut (*Aesculus hippocastanum*), tree of heaven (*Ailanthus altissima*), oak (*Quercus* sp.), maple (*Acer* sp.) and other species grow well in the spent brown coal quarry Agacli (Fig. 1) (Kuter, 2013; Ender et al., 2011).

In Bulgaria, reclaimed land is used for growing crops. Cereals, technical and some horticultural crops – oats, corn, sunflowers and grapes are cultivated in the restored lands. Forest reclamation in the areas disturbed by the mining industry in Bulgaria has been carried out since the 1970s. The type of forest stands is chosen taking into account the natural diversity of the area. In addition, forest stands must be resistant to the newly created ecological conditions of the Earth's surface (Lukina et al., 2015).

**Table 1.** Types of trees used for mine sites reclamation

| Common name | Scientific name | Site type |
|---|---|---|
| American sycamore | *Platanus occidentalis* | For wet soils |
| Black oak | *Quercus velutina* | For dry soils |
| White oak | *Quercus alba* | For different types of sites |
| Yellow poplar (tuliptree) | *Liriodendron tulipifera* | For fine textured soils at the bottom of the slope |
| Sugar maple | *Acer saccharum* | For moist soils |
| Bristly locust | *Robinia hispida* | Fixes nitrogen on moist soils |

**Fig. 1.** Afforestation in Agaclı, İstanbul (Kuter, 2013)

Significant experience in forest restoration in Bulgaria gained in the area of Maritsa Iztok and Pernik quarries. Common oak, red oak, downy oak and smooth-leaved elm are successfully used for forest reclamation. Common ash, silver linden, silver birch, European crab apple and other were used as additional species. Austrian pine is planted on the dumps with high sand content and looser substrate, whereas white acacia on faintly acidic or neutral soils (Kirilov et al., 2016; Kirilov et al., 2017).

Pastures are created on the dumps of mining lead-zinc ores. Red clover (*Trifolium pretense*), white clover (*Trifolium repens*), red fescue (*Festuca rubra*) and bird's-foot trefoil (*Lotus corniculatus*) are grown on the reclaimed lands. According to (Tsolova et al., 2012; Banov et al., 2020), they are resistant to the climatic conditions of the region and are not very demanding about the soil environment.

In Bulgaria, the following woody plant species are used in the forest reclamation of quarries and dumps for copper mining : Scots pine, European beech, sycamore, hornbeam, red oak, European crab apple, etc.; in addition, the following shrub species are used: yellow acacia, white dogwood, Judas tree, barberry and others (Lukina et al., 2015).

The predominant direction of disturbed land reclamation in Estonia is forestry. Extensive experience has been gained in landscaping dumps after extraction of oil shale, ash dumps of thermal power plants and phosphoritic dumps. Reclamation of shale quarries in Estonia began in 1960, when Scots pine and larch were planted on the leveled area. Coniferous trees such European larch (*Larix decidua* Mill.), green spruce (*Picea pungens* Engelm.) and European spruce (*Picea abies* (L.) Karst.) are the species that grow well on leveled shale dumps, in addition to Scots pine, according to (Lohmus et al., 2007; Kuznetsova et al., 2010; Korjus et al., 2014). In the case of deciduous trees, species such as birch (*Betula pendula* Roth.), black alder (*Alnus glutinosa* (L.) Gaertn.), maple (*Acer platanoides* L.), common and green ash (*Fraxinus excelsior* L. and F. *viridis Michx*.), linden (*Tilia cordata* Mill.), Scots elm (*Ulmus glabra* Huds.) and others are grown with good results. According to studies (Kaar, 2010), the decomposition of birch and alder leaves has a good effect on the process of soil formation on shale dumps. In the agricultural direction of shale dumps reclamation, barley, rye, and potatoes are grown on disturbed lands, and the thickness of the humus layer should be approximately 50 cm (Kaar, 2010).

Haymakers are created on the ash dumps of thermal power plants. Studies show that red fescue (*Festuca rubra* L.), orchard grass (*Dactylis glomerata* L.), smooth brome (*Bromus inermis* (Leyss.) Holub.) and white clover (*Trifolium repens* L.) grow well under such conditions (Kaar, 2010). Significant success has been achieved in Estonia in the reclamation of phosphoritic dumps. Scots pine (*Pinus sylvestris* L.), black alder (*Alnus glutinosa* (L.) Gaertn.), Siberian larch (*Larix sibirica* Ledeb.), Swedish whitebeam (*Sorbus intermedia* (Ehrh.) Pers.) and others, among shrubs – caragana (*Caragana arborescens* Lam.), sea buckthorn (*Hippophae rhamnoides* L.), silverberry (*Elaeagnus commutata* Bemh, ex Rydb), etc. are well adapted to the extreme conditions that occurred in phosphoritic dumps (Kaar, 2010).

About 82 thousand hectares of agricultural land have been disturbed as a result of lignite mining in Germany, according to (Quinkenstein et al., 2012). Extraction of lignite in Central and East Germany, which has been carried out for 200 years, led to significant changes in the landscape (Fig. 2).

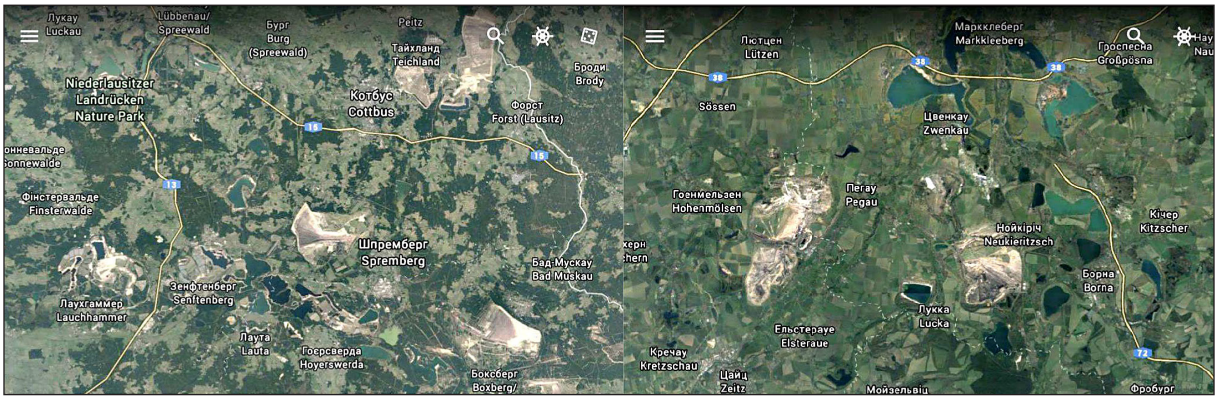


**Fig. 2.** Post-mining landscapes: A – East Germany; B – Central Germany (Geobasis-DE/BKG) (Schlenstedt, 2017)

In Germany, the reclamation of lignite quarries and dumps began in the early twentieth century, but the rate of such activities was very slow compared to the ever-increasing rate of formation of new disturbed areas. In this regard, the Federal Mining Law (Bundesberggesetz, BBergG) was adopted in 1980, which began to regulate the relations in the field of mining, from the extraction of raw materials to the closure of quarries and their reclamation (Hildmann et al., 2019; Sloss, 2013).

Special attention in Germany is paid to the agricultural reclamation of disturbed lands, as there is a large shortage of agricultural land. Rye (*Secale cereale* L.), wheat (*Tritium aestivum* L.), barley (*Hordeum vulgare* L.), rapeseed (*Brassica napus* L.), lupine (*Lupinus*) and others are grown on brown coal dumps. Melioration has an important role on providing: application of lime and mineral fertilizers, household waste, brown-coal ash, etc. (Quinkenstein et al., 2012; Krummelbein et al., 2012).

These types of trees and shrubs, which can transfer the specific properties of disturbed soils, are used for forest reclamation in Germany. Pine (*Pinus*), oak (*Quercus*), birch (*Betula*), larch (*Larix*) as well as other conifers and deciduous species trees are well accustomed to reclamation work on heaps of lignite containing a large amount of sulfur in the region Lusatia (Krummelbein et al., 2012).

Extensive experience in the reclamation of lands disturbed by lignite mining has been gained in Poland. According to (Pietrzykowski et al., 2018), 3,830 and 2,270 ha, were reclaimed for agricultural purposes at the Konin and Adamów mines, respectively. As a result of complex melioration works, wheat, lucerne, corn, sunflower, beets and clover are grown on the restored lands (Fig. 3).

**Fig. 3.** Lucerne crops on the dumping ground of the Konin mine (Kasztelewicz, 2014)

Significant progress was made in Poland for the reclamation of sand pits. The lands disturbed due to sand mining in most cases are used for afforestation. In the places with poor soils, Scots pine (*Pinus sylvestris*), silver birch (*Betula pendula*), black alder (*Alnus glutinosa*) and oak (*Quercus petraea*) are well established, whereas in the areas with more fertile soils – larch (*Larix decidua*), English oak (*Quercus robur*) and sycamore (*Acer pseudoplatanus*) (Pietrzykowski et al., 2018; Dulias, 2010).

Considerable attention in Poland is also paid to the creation of parks and recreation areas on the developed quarries: park H. Bednarskiego in Krakow created on limestone quarries; 640-hectare culture and recreation park in Chorzów created on coal mining dumps; Kadzielnia Park in Kielce created in open quarries for limestone mining, etc. (Pietrzyk-Sokulska et al., 2015; Uberman et al., 2012).

In Ukraine, the greatest experience has been gained in land reclamation due to lignite mining. Here, the main attention is paid to the agricultural direction of reclamation with the subsequent cultivation of perennial grasses. A lot of experience has been gained in the reclamation of lands disturbed due to the extraction of ferrous metals. At the Komish-Burunskyi metallurgical plant, as a result of reclamation, more than 600 hectares of land – on which wheat and corn are grown – have been returned for agricultural use. In addition, this plant has the experience in the reclamation of used dumps for planting gardens (Panas, 2008).

At the «Ordzhonikidze Mining and Processing Plant», a phased system of reclamation was carried out on the disturbed lands, as a result of which the lands were returned for agricultural use. Currently, perennial and annual grasses, wheat and corn are grown in this location. Reclamation of dumps in Kryvbas has also been successful. Maple, acacia, poplar and other trees were planted on the dumps, which took root well. The average growth of trees was 0.36–0.60 m/year. Black alder and perennial lupine are recommended to plant on the dumps of Polissya and the Forest-Steppe of Ukraine to increase the productivity and stability of forest stands (Ivanov et al., 2017, Segin et al., 2020).

Extensive experience in forest reclamation of dumps has been gained in Ukraine. According to (Brovko, 2012), 825 and 196 ha were afforested in the Zhytomyr region at the Stryzhivka ilmenite ore deposit and the lignite deposit, respectively;

in the Cherkassy region, 640 and 50 ha of brown coal and kaolin clays were afforested, respectively; in the Kirovohrad region, 1,407 hectares were afforested at the lignite deposit; 834 and 409 ha were afforested at nickel and iron ore deposits in the Dnipropetrovsk region etc.

Today in many countries of the world, reclamation of disturbed lands is being carried out by applying a fertile or potentially fertile layer of soil and applying fertilizers, lime, ash and industrial waste, followed by planting perennial grasses. In recent decades, great importance has been attached to «non-traditional» types of fertilizers (sewage sludge, peat, etc.), the use of which reduces the costs required to create a fertile soil layer and increase the productivity of reclamation works (Kozhevnikov et al., 2017). In our opinion, special attention should be paid to the research on the use of the spent activated sludge from municipal wastewater treatment plants and landfill leachate as a component of substrates for the reclamation. This spent activated sludge is formed in large quantities during treatment and uncontrolled accumulation, polluting the environment (Malovanyy et al., 2016, Malovanyy et al., 2019, Tymchuk et al., 2020). Such problem is especially relevant for Ukraine.

## RECAPITULATION

Thus, given the existing scale of the man-made human impact on the biosphere, the measures to eliminate the damage to nature are becoming relevant. Therefore, there is a need for the transition from the modern industrial to the environmental production. In solving this problem, biological land reclamation is of great importance. Restoration of disturbed lands through the use of biological reclamation is an essential part of the problem of rational use of natural resources and environmental protection.

In many industrialized countries of the world it is important to choose the direction of reclamation of disturbed lands. For example, in Germany, where there is a shortage of agricultural land, the agricultural areas are preferred, in the United States the main focus is placed on forest reclamation, whereas in Poland many disturbed areas are used for recreational purposes (creation of gardens, parks, etc.).

Owing to the right approach to biological reclamation, hundreds of thousands of hectares of degraded land can be returned to agriculture and forestry. Choosing the right direction of reclamation of disturbed lands is an important issue for Ukraine as well. When carrying out biological reclamation, namely when applying fertilizers, attention should be paid to the involvement in this process of man-made waste of organic origin, the use of which will reduce the reclamation costs and dispose of the accumulated waste, but the use of such waste requires a detailed study.

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