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Land Reclamation and Ecological Restoration in a Marine Area

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ABSTRACT: This paper deals with the planning of rehabilitation of spoils of asbestos mine in NW Greece with the name MABE in Prefecture of Kozani. For this purpose a detailed ecological research has taken place in the wider area in order to estimate the prevailing environmental (site) conditions. The spoils heaps are characterized by very steep slope inclination (80-90%). In order to improve the stability of the area, in cooperation with civil engineers of our scientific team, a minimization of slope inclination to 39-43% had been decided. For the avoidance of erosion hazard, broad terraces (8-12 m width) and small terraces (1.2 m width) must be constructed. After these works the whole surface of spoils will be covered by topsoil of 40 cm depth. On this topsoil the suitable trees and shrubs species will be planted. The list of these species is the result of detailed research in the mine and the surrounding area. The tree species *Pinus nigra*, *Robinia pseudoacacia*, and *Quercus pubescens* have proposed as dominant species and *Acer campestre*, *Carpinus orientalis*, *Ostrya carpinifolia*, *Fraxinus ornus*, *Celtis austalis* and *Sorbus aucuparia* as secondary tree species.

Key words: Inclination, Spoils depositions, Terraces, Topsoil, Plantings, Rehabilitation

INTRODUCTION

Minerals are significant economic resources worldwide, when they are used in rational way from financial and environmental point of view. The prevailing economic conjuncture determines if the exploitation on resource is profitable or not. For this reason the exploitation of the minerals in a country should be decided after a systematical research of the prevailing economic parameters and the environmental problems connected with this activity, because the mining causes the destruction of natural ecosystems through removal of soil and vegetation and burial beneath waste disposal sites (Saaty, 1990, Boyadziev and Boyadziev, 1997; Bradshaw, 1997). The restoration of mined land in practice can largely be considered as ecosystem reconstruction. Unfortunately, in practice, the lack of post-restoration monitoring and research has meant few opportunities to improve the theory and practice of ecological restoration in mining. (Cooke and Johnson, 2002). However, although the scale of human activities (overgrazing, deforestation, agriculture, overexploitation for fuel wood, and urban and industrial use) has become such that most of the ecosystems of the earth have been disturbed in some way (Ehrlich, 1993; Daily, 1995) the area of land directly altered by mining industries is still relatively low in terms of the global inventory of degradation, but can represent considerable quantities on an individual country basis.

The mine area land reclamation and ecological restoration research involves many research fields such as mining, geology, geography, land use, environment, landscape, ecosystem, agriculture and forestry, biology, soil science, and social economy etc. and the amount of information is huge. Therefore, reasonable organization and management of research data is needed (Huading *et al.,* 2005). The most important problems faced in the procedure of mine areas rehabilitation is the choice of future land use (Cairney, 1995). Forestry is the most usual land uses of abandoned mine areas. For the establishment of forest on those areas the following particular problems must be solved: the formation of the slopes, the finding of the necessary quantities of good quality topsoil, the selection of the suitable plant species able to survive in such extreme site conditions, the possible problems of toxicity end environmental pollution and the effective planning of rehabilitation. In this study,the rehabilitation of spoils of asbestos mine

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MABE in Kozani prefecture (northern Greece) is the research object. Specifically, the aim of this study was the land reclamation and ecological restoration of the spoils deposition in this asbestos mine area. In order to succeed this, we studied analytically the environment of the area (topography and spoils' slope, climate, soil and topsoil properties, vegetation and landscape), and based on the results obtained, we proposed the appropriate measures.

The asbestos mining area (M.A.B.E.) (in SW part of Kozani Prefecture, northern Greece) is situated eastern of mountain Vourinos and north-western of mountain Kambounia. It covers 414 ha and it is located 1 km southern of the longest Greek river 'Aliakmon'. Geo-morphologically the wider area is characterized mountainous with a dense network of streams and the elevation ranges from 400 to 700 m, while in the northern part of the study area (in the valley of Polyphyton artificial lake), the topography is characterized as very smooth and the elevation reaches 295 m. Geologically the area is located to the western border of Pelagonic Zone, which is consisting from crystalline schist substrate (gneis, schist, amphibolites, granites, ophiolite rocks) (Rassios, 2008). Phyto-sociologically the area belongs to *Quercetalia pubescentis* floristic zone (Athanasiadis, 1986).

The mean annual rainfall is 563 mm and the mean temperature is 13.3 ^{o}C, (according to the 5-year data obtained by the Meteorological station of Kozani). The bioclimatic of the area, according to Emberger diagram (Mavromatis, 1981), is meso-mediterranean, sub humid with harsh winters, 40 days < Dry season< 75 days. The landscape of the wider area is composed by the following characteristics: the artificial lake of Polyphyton, intense hilly relief, dense network of streams, the asbestos mining area with the industrial infrastructure, the excavation area and the deposition area. The mine depositions have formed an artificial hilly area with very steep slopes. For this reason a lot of landslides have been occurred. Concerning the topography and spoils depositions slope, in the north-eastern exposures the slope inclination was 80-90%, the bank's height was 180 m and the depositions mainly consisted of materials with particle size of sand gravel and sludge-clay gravel. In the south-eastern exposures slope inclination was 70-90%, the bank's height was 30-60 m and the depositions mainly consisted of asbestos spoils with coarse structure.

MATERIALS & METHODS

With the main target the land reclamation and ecological restoration of the spoils deposition in the asbestos mine, we studied analytically the topography and spoils depositions' slope, soil and topsoil properties, vegetation and landscape of the study area. In restoration, emphasis was given first to minimize slope inclination, to build soil organic matter, by adding topsoil, and vegetation cover to accelerate natural recovery process (Singh et al., 2002). Also, in order to propose the more suitable planting material for the vegetation establishment, measurements in already existed plantations were done. Finally we organized and managed the initial data of the area and proposed the most effective and economic restoration techniques. The minimization of the slope inclination of the depositions was planned by terraces construction (bench plains) of different width, in collaboration with the civil engineers of the same scientific work team, based on the most effective and economic solution. Physical and chemical properties of the soil and topsoil, which are consider as the more basic factors together with topography, for the vegetation establishment and future growth (Jafari et al., 2004; Tavilli and Jafari, 2009), were estimated after detailed soil analysis. The topsoil (the productive soil) had been deposited in two positions (covering surface area about 6 ha and having total volume 365.000 m^3) at the beginning of the mining activities. We took 4-pooled samples from topsoil and we excavated two (2) soil profiles from the neighbour undisturbed area. However, additional topsoil that should be extracted from the wider area is needed for the spoils covering of the mine. A detailed plant species inventory in the wider area (in a distance 2-3 Km around the mining area) and on the heaps of topsoil was made in order to study the vegetation and to propose the most suitable species for the rehabilitation. We also recorded the species that had been planted by the MABE Company in the undisturbed and in the rehabilitated surfaces within the mining area. The change of the visual absorptive capacity of the landscape before and after reclamation techniques was estimated. The visual absorption capacity of the landscape (VAC) is defined as the capacity of the landscape to absorb developments without its character being significantly changed or its scenic quality reduced (Amir and Gidalizon, 1990; Lucas, 1991; BCMoF, 1995).

It was estimated according to the equation: VAC= S* (SE+RD+C+L), where: S= slope, SE= Soil Erosion, RD=Regeneration Dynamics, C= Color contrast, L= Landscape diversity (Anderson, et al., 1979; Yeomans, 1979). For the selection of the suitable planting stock, field survival and growth measurements were done in the existed plantations within the mine area.

RESULTS & DISCUSSION

To rearrange the spoils depositions' geometry and to prepare the site for restoration, the specific rehabilitation study has been carried out to determine the requested terraces (bench plains) that should be constructed. Two types of terraces with different width were proposed (Fig. 1). The factors significant in the selection of broad and small terraces were to obtain suitable surface for vegetation, to avoid any erosion hazard and to keep spoils depositions permanently stable. The maximum slope angle of the spoils depositions have been chosen as 23.6° to 21.6°. Broad

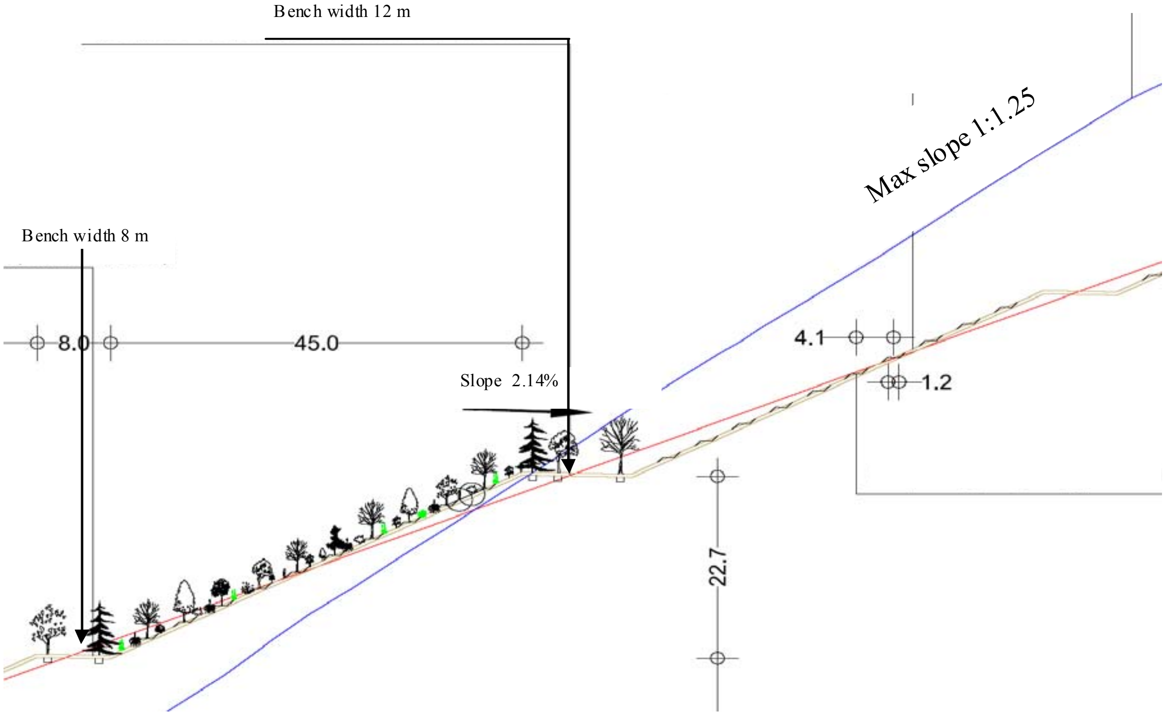


Fig. 1. Slope inclination of spoils depositions

Table 1. Physical and chemical properties of the soil and top soil.

Soil sample	α/α sample	Mechanical Analysis	Organic matter (%)	N (mg/kg)	pH	$CaCO_3$(%)
Soil	1	SL-Sand-loamy	2,04	0,09	8,51	38,72
-//-	2	SL-Sand-loamy	5,29	0,21	8,54	11,00
Top soil	3	SL-Sand-loamy	0	0,015	8,32	14,08
-//-	4	L-Loamy	0	0,012	8,75	11,44
-//-	5	LS-Loam-sandy	0	0,003	8,76	29,04
-//-	6	LS-Loam-sandy	0	0,007	8,93	46,20

Table 2. Concentrations of P, K, Mg, Fe, Zn, Mn, Cu and B in soil and topsoil.

Soil sample	α/α Sample	P ppm	K ppm	Mgppm	Feppm	Znppm	Mnppm	Cuppm	Bppm
Soil	1	4,0	92,0	120,0	1,76	0,24	3,86	0,48	0,23
-//-	2	6,0	154,0	205,0	2,14	0,30	4,32	0,38	0,59
Top soil	3	3,0	80,0	118,0	0,90	0,24	1,12	0,14	0,15
-//-	4	3,0	109,0	200,0	1,06	0,10	1,10	0,60	0,20
-//-	5	2,0	36,0	110,0	1,22	0,22	0,86	0,16	0,22
-//-	6	2,0	46,0	215,0	0,76	0,28	0,58	0,12	0,22

Table 3. Species composition of the natural vegetation of the area

No	Trees	Shrubs
1	*Platanus orientalis*	*Quercus coccifera*
2	*Quercus pubescens*	*Paliurus spina cristi*
3	*Quercus frainetto*	*Corinus coggygria*
4	*Carpinus orientalis*	*Pistacia terebinuthus*
5	*Fraxinus ornus*	*Phillyrea latifolia*
6	*Cercis siliquastrum*	*Juniperus oxycedrus*
7	*Pyrus amygdaliformis*	*Rubus canescens*
8	*Populus nigra*	*Sambucus ebulus*
9	*Ficus carica*	*Colutea arborescens*
10	*Celtis australis*	*Coronilla emeroides*
11	*Morus nigra*	*Clematis vitalba*
12	*Salix alba*	*Rosa sp.*
13	*Ulmus campestris*	
14	*Acer campestre*	
15	*Populus alba*	

Table 4. Naturally colonized species on the heap of topsoil

No	Woody species	Grasses
1	*Colutea arborescens*	*Ononis spinosa*
2	*Ulmus campestris*	*Cynodon dactylon*
3	*Rubus canescens*	*Dactylis glomerata*
4	*Pistacia terebinthus*	*Tussilago farfara*
5	*Polulus alba*	*Hypericum perforatum*
6	*Platanus orientalis*	*Epilobium sp.*
7	*Pinus nigra*	*Chamecytisus sp.*
8	*Cotinus coggygria*	*Lotus corniculatus*
9	*Juglans regia*	*Trifolium campestre*
10	*Pyrus amygdaliformis*	*Trifolium arvense*
11	*Malus sylvestris*	
12	*Vitis vinifera*	

Table 5. Visual absorption capacity (VAC) of the landscape of the study area.

Factor	Conditions	Degree before restoration	Degree after restoration
Slope Inclination	Slope 0-5 %		
	6-15 %		
	16-30 %		2.5- 3
	31-60 %		
	>60 %	1	
Landscape diversity (vegetation, topography, water sources)	Low	1	
	Medium		2
	High		
Soil erosion	High	1	
	Medium		
	Low		3
Regeneration dynamics	Low	1	
	Medium		
	High		3
Colour contrast of soil	High	1	
	Medium		2
	Low		

Table 6. Survival percentage of existed planted species in the mine area

Species	Planting stock	Survival (%)
Pinus nigra	Containerised	70
Pinus brutia	Containerised	80
Robinia preudoacacia	bareroot	95
Fraxinus ornus	bareroot	80
Populus nigra	bareroot	80

Table 7. Percentage contribution of the tree species, which are proposed for planting on the great and individuals terraces

a/a	Species	Percentage (%)	Planting stock
1	*Pinus nigra*	35	Container seedlings
2	*Robinia pseudoacacia*	35	Bareroot seedlings
3	*Quercus pubescens*	20	Container seedlings
4	*Acer campestre*	1.67	Bareroot seedlings
5	*Carpinus orientalis*	1.67	—//—
6	*Ostrya carpinifolia*	1.67	—//—
7	*Fraxinus ornus*	1.67	—//—
8	*Celtis australis*	1.67	—//—
9	*Sorbus aucuparia*	1.67	—//—

terraces (8-12 m width) must be constructed every 45m on the slope, while small terraces (grandonia 1.2 m width) must be constructed every 2.9 m on the slope. As it is shown in the Tables 1 and 2, the soil of the undisturbed area as well as the topsoil is very poor in nutrients. They belong to the category of grey forest soils with low content of clay and medium organic matter. They are very alkaline, with pH 8.3-8.9. The depth ranges from 20 cm (on the hill picks) to 60-80 cm (in small valleys). After the detailed inventory, species composition of the natural vegetation of the area is listed in Table 3 and the naturally colonized species on the heap of topsoil are listed in Table 4. The existed planted species recorded on the topsoil were: *Pinus brutia, Pinus nigra, Cupressus sempervirens, Cupressus arizonica, Populus alba, Spartium junceum, Juglans regia, Prunus cerassifera and Pyrus amygdalus.*

As it is shown in the Table 5, the visual absorption capacity of the landscape (VAC) of the study area will be significantly improved after the restoration attempts. The VAC was 4 degrees before restoration and increased to 25-30 degrees after the proposed restoration.

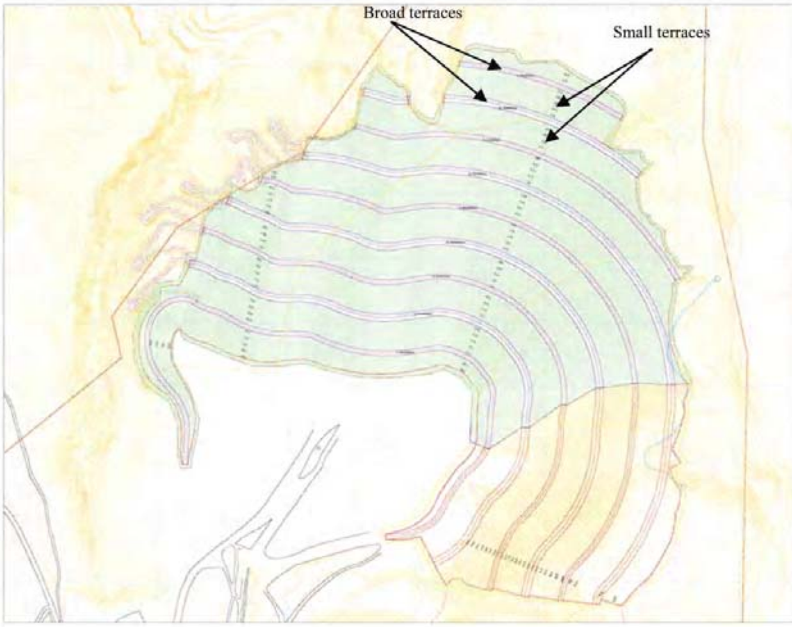
Taking into account that the vegetation cover is essential to stabilize the bare sites (Wong, 2003); the choice of appropriate vegetation and type of planting stock will be important. According to the measurements made on establishment success of existed planted species we found that the planting stock considered more suitable for the studied species is: Container stock for species: *Pinus brutia, Pinus nigra, Cupressus sempervirens and Cupressus arizonica, Quercus pubescens*; Bareroot stock for species**:** *Robinia preudoacacia, Fraxinus ornus, Populus alba, Populus nigra;* Cuttings for species**:** *Salix alba, Platanus orientalis, Robinia preudoacacia, Alnus glutinosa;* Seeding (in the declined surfaces) for**:** *Legumes species.* Some examples of the planted species survival percentages are listed in Table 6.

The environmental rehabilitation of mining areas is a difficult and complex procedure. The Society for Ecological Restoration defined ecological restoration as the process of assisting the recovery of an ecosystem that has been degraded or destroyed (SER, 2002). Although evidence has indicated that the unassisted process of natural colonization can be very powerful, restoration of a mine area often requires human assistance (Li, 2006). Special difficulties occur during the rehabilitation of spoil peals that consist of materials of different sizes which are unconnected to each-other and have a height of many tens of meters. The inclination of spoil peals surfaces are very steep (>70%) and are under continuous changes (erosion, slides) depending on weather conditions. Consequently the first step to take is the reduction of the slope inclination of spoil peals as well as the reduction of the erosive capacity of water the aiming at erosion mitigation which is succeeded by construction of wide or narrow terraces.

Another problem in this procedure is the collection of the necessary quantities of top soil in order to cover all spoil surfaces and hereupon carry out the planting and seeding of the appropriate species. According to the aim of the future land use which in the particular case is the establishment of a forest which will protect this ecologically sensitive mining area, the very important neighboring lake and the ecological and esthetic incorporation of the mining area in the ecosystem and the landscape of the wider area.

Concerning the stabilization of spoils depositions, the slopes inclination will be decreased to 21.6^o - 23.6^o (39%-43%) after the terraces construction (Fig. 2). Broad terraces (8-12 m) must be constructed every 45m on the slope. Also, small terraces (grandonia 1.2 m) must be constructed every 2.9 m on the slope. The terraces were considered to be served as the convenient specific areas for re-vegetation. The re-vegetation aims to serve both the elimination of the visual pollution and forming of the artificial ecosystem in a short period of time (Lucas, 1991; Pamukcu, and Simsir, 2006). For the minimization of erosion on the small terraces, dense-spacing plantings with trees and shrubs have been foreseen. The planting design on the terraces it is shown in Fig. 3.

For the species selection, the floristic zone of the area and the adverse soil conditions (low nutrients and soil depth) were taken into account (Table 7). Among the conifers we have selected *Pinus nigra* which is very dry resistant and very tolerant in poor soil conditions and it grows naturally in the neighbouring forests. *Robinia pseudoacacia* is an exotic species suitable for this floristic zone and the most appropriate for poor soils and rehabilitation works. *Quercus pubescens* grows in the wider area and forms stands and dominated in whole area in the past. The rest are secondary forest species that grow in the forests of the wider area and for this reason they are proposed for planting in order to improve the biodiversity of the rehabilitated mining area. For the better protection of the rehabilitated area and the improvement of biodiversity we have



: Research area with plantations

Fig. 2. The proposed plan for the formation of spoils' heaps

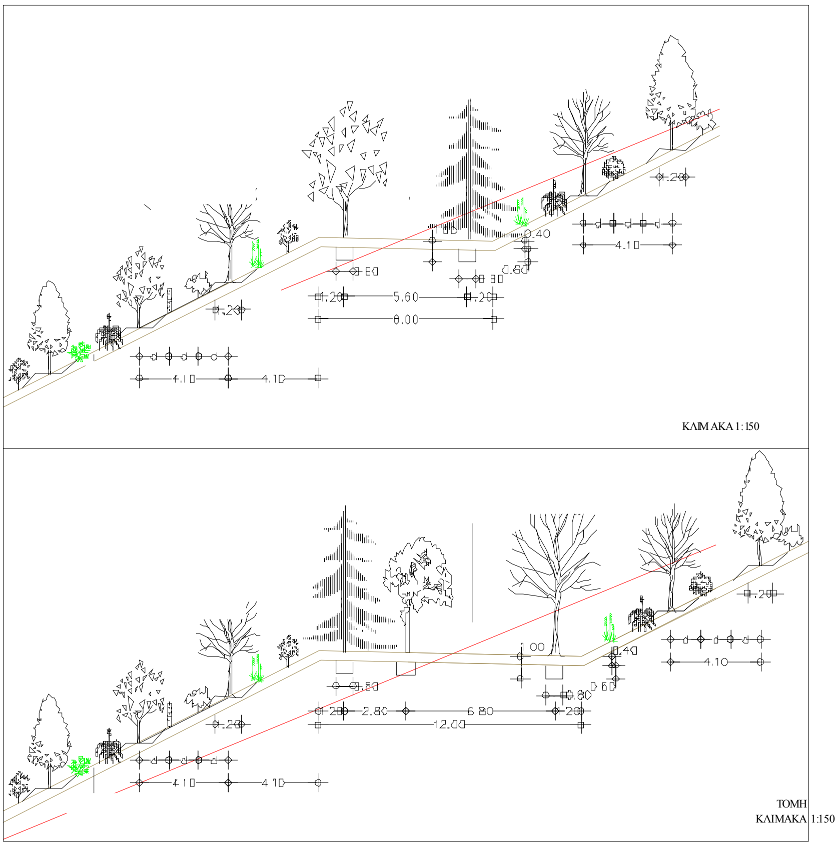


Fig. 3. The proposed planting design for the small and broad terraces

proposed also the followings: 1. Planting the shrub species: *Spartium junceum*, *Cotinus coggygria*, *Rhus coriaria*, *Colutea arborescens*, *Prunus spinosa*, *Quercus coccifera*, *Buxus sempervirens*, *Cercis siliquastrum*, *Ligustrum vulgare* and *Phillyrea latifolia*, 2. Planting species as cuttings: *Salix alba*, *Robinia pseudoacacia*, *Populus nigra*, *Alnus glutinosa*, *Platanus orientalis* and 3. Seeding of the species: *P. nigra, R. pseudoacacia, C. siliquastrum, Colutea arborescens, S. junceum, L. vulgare, C. coggygria, R. coriaria, Rosa canina, Rubus canescens, Trifolium arvence, Vicia sp., Lathyrus sp., Dactylis glomerata, Lolium multiflorum.* For the systematic irrigation of the established species on the rehabilitated area, hydraulic engineers of the same scientific team have planned a modern irrigation system.

CONCLUSION

This study proposes the forestry as the future land use of the mining area because this concentrates the most advantages and this was the previous land use of the area (degraded forest land, used for animals grazing and firewood production).

According to the results of the soil analysis, the soil as well as the topsoil of the study area is very poor in nutrients, with low content of clay and medium organic matter and very alkaline. This study proposes that the minimum depth of topsoil, which will be used for spoils covering, must be over 40 cm in order to support effectively the established species. Also, the topsoil should be enriched with organic matter (2% at least) and with the appropriate fertilizers in order to improve soil fertility and reduce alkalinity. Since the deposition peals are visible from a long distance due to the relief change and the colour contrast, the principles of landscape architecture must be applied for the ecological restoration of the disturbed land according to the visual characteristics of the landscape of the wider area.

After our restoration techniques the visual absorption capacity of the landscape will be increased from the very low class (4) to middle class (25-30).

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