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THE DETERMINATION OF RECLAMATION PARAMETERS AND COST ANALYSIS IN MINING SITES

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Abstract: The rapid expansion and industrialization in major metropolises increases the demand for some raw materials (cement, iron, ceramics, etc.) in recent years. These raw materials are usually provided by the nearest quarries (stone quarries, limestone quarries, etc.) in economical point of view. Thus, this demand causes a rapid development and growth in quarries and raw material processing plants. The uncontrolled growth of these industries causes noticeable temporary and permanent environmental impacts. The minimization of environmental impacts due to mining activities and reinsuring the ecological balance in the mining site is achieved by rehabilitation or reclamation (restoring the site to an intended condition) practices. The reclamation studies were accomplished by plant selection and plantation geometry depending on the geological structure, climate and local flora and fauna. In this study, the parameters and cost analysis of the reclamation practices applied on a limestone quarry near Izmir are introduced. The success and the details of application are observed concurrent to the cost analysis. Moreover, the studies in the mining site are compared to similar reclamation studies in different sites regarding engineering practices such as planning, applications and unit costs.

Keywords: Rehabilitation, reclamation, limestone quarry, cost analysis, plantation

1. INTRODUCTION

The term "reclamation" or "rehabilitation" is the restoration of a depleted mining site for further usage (Ramani et al., 1990). However, the reclamation studies should take place simultaneously with the mining activities, not after the mining activities as in description. The reclamation is restoring a field after an industrial usage including the mining activities in a favorable manner and it depends on many different parameters according to Down and Stocks (Down & Stocks, 1977).

The rapid expansion and industrialization in major metropolises increases the demand for some raw materials in recent years. These raw materials are usually provided by the nearest quarries in economical point of view. Thus, this demand causes a rapid development and growth in quarries and raw material processing plants. The uncontrolled growth of these industries causes noticeable temporary and permanent environmental impacts (Kun, 2011).

The existing mining quarries continue to get near to the residential areas owing to the municipality who let the growth of zoning areas in a short period of time due to rapid urbanization (Köse & Pamukçu, 2003). The reclamation of open pits and quarries has become obligatory depending on many different restrictions such as approaching the residential areas. That fact becomes compulsory within the laws in Turkiye as the world today.

Mining activities that were revolutionized by developments in mining techniques and the application of steam engines since 19th century, like other industrial activities, cause temporary or permanent environmental impacts. The stabilization of an industrially destroyed field is obligatory to achieve a healthy environment with ecological balance. However, achieving the ecological balance takes quite some time for a left alone destroyed field. Rehabilitation of these fields in a favorable time period needs human assistance (Simsir et al., 2007 and Lorant, 2008).

2. MATERIAL AND METHODS

The recovery of a destroyed field in ecological and esthetical aspects can be achieved by reclamation practices. The reclamation practice involves planning of field usage, restoration, rehabilitation and maintenance. The main cost elements of reclamation are removal of topsoil, bench and slope restoration, ditching, soiling, stopping (if necessary) and plantation. A limestone quarry near Izmir was chosen as a model, later, the reclamation parameters, the condition of the quarry before and after reclamation and the cost analysis were investigated and stated in this study. The method applied is schematized as the steps of the reclamation practice and cost analysis in figure 1.

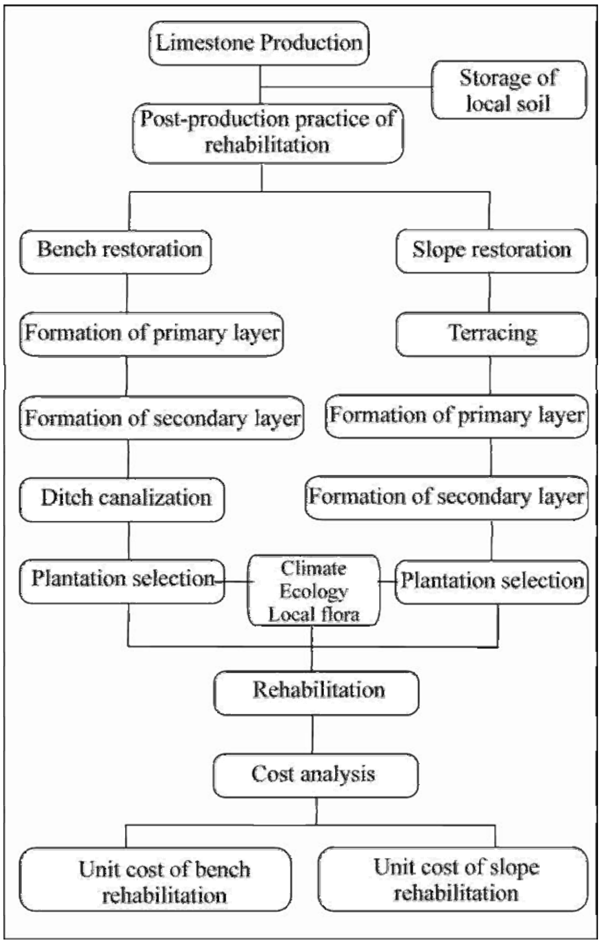

Figure 1. The flowsheet demonstrating the steps of the reclamation practice and cost analysis.

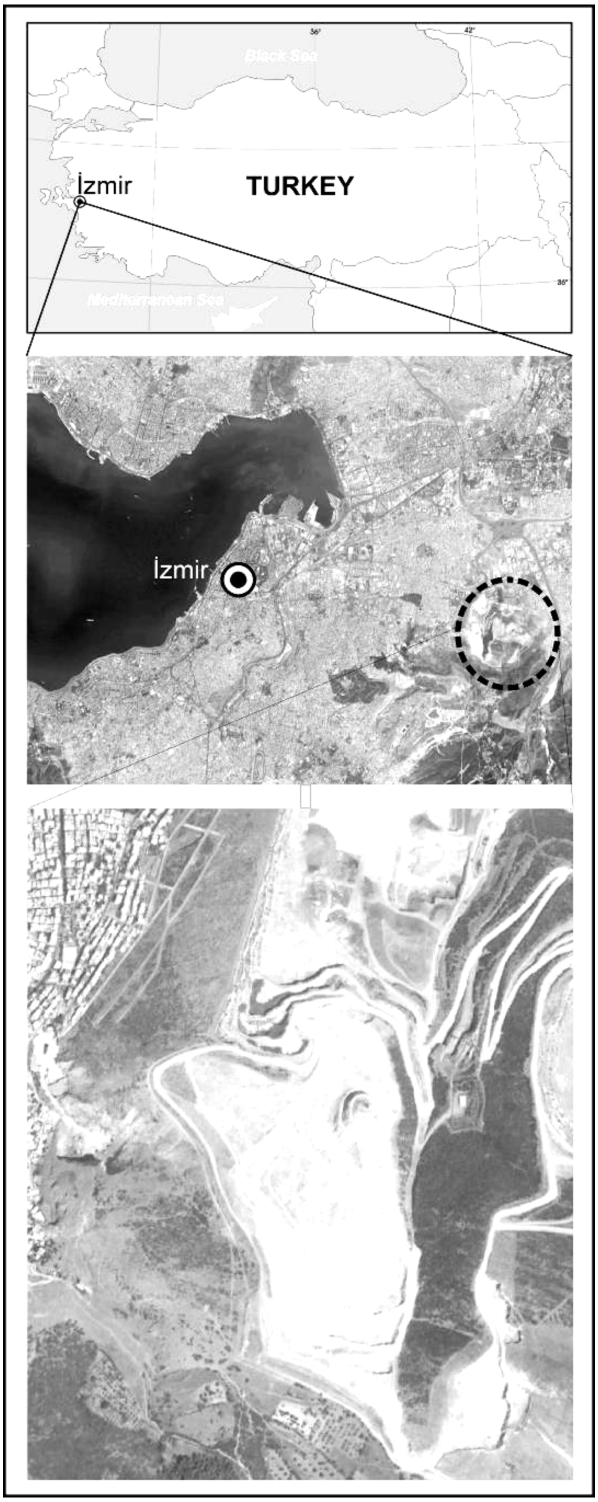

Figure 2. The geological location of the study area.

2.1. Study Area

There are three different geological formations in Western Anatolia, Turkey. These formations significantly differ in their geologies, tectonics and rock formations (Kun, 2006). The study area is located on the western part of Izmir-Ankara zone, 6 km south of Bornova county of Izmir and east of Altındag village (Fig. 2). The mining quarry is quite close to the residential areas of metropolis Izmir. That fact states the significance of reclamation practices in similar mining sites.

The investigated limestone zone is dominantly formed by limestone and neocene precipitates. The limestones in the region are massive highly durable. The limestone zones are mainly characterized by steep topography and maquis flora with scrubs. The interface is grey in color and massive in structure. Limestone zones frequenly have jointed structures and host abundant internal cracks. These cracks may be secondary calcite filled. The age of limestones is estimated as Cretaceous Era regarding the fossil formations of Rudists, Orbitoides sp, Algae and Globotruncanna sp. The older neocene structures over limestones formed by a tectonic touch are aggregates, clay stones and sandstones. The aggregates are mainly calcites and rarely volcanites such as andesite or basalt. A matrix in form of a thin clay layer can be observed between aggregates.

Ten different faults (over 3 m in height) are located in the fault zone by tectonic investigation of the site (Fig. 3). The endurance of the rocks are loosened due to percolation of water through these cracks hence, a stabilization problem emerges.

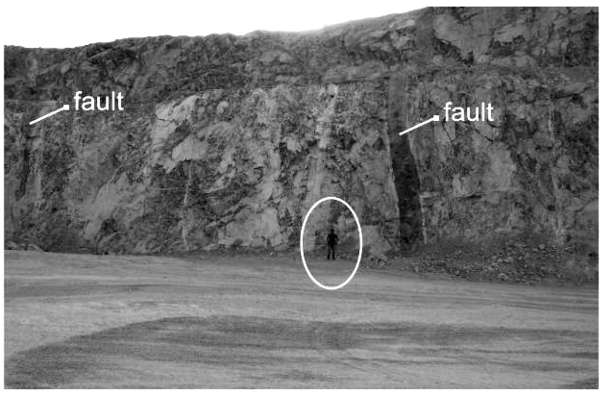

Figure 3. The overview of the limestone quarry and east-west oriented faults.

2.2. General Structure of the Field Soil

A bench extraction is applied as an open pit mining method on the limestone quarry to be reclaimed for the recreation of natural living habitat. There exists no local flora and fauna except the unextracted regions in the quarry (Fig. 4). These regions, due to the weak development and sparse planting of trees, do not exhibit an important vegetation to cover the ground. The continuous mining activities and destruction in the other regions restrain the flora to be regenerated. The inactive fauna cannot accomplish its duty as a source of nutrition for the flora due to the noise around the quarry.

Even though bench extraction method is applied in the quarry, the steep ground slope and impermeable ground lets the rain water flow over the surface easily. The extended and steep slopes cause erosive water flow over the slopes particularly in December and January, when the average amount of rainfall is high (Table 1). Consequently, the resultant water erosion hinders the formation of soil. In addition, during periods of heavy rainfall, undesired water ponds have occurred in the bottom regions of the quarry. The natural soil and flora have been observed on the unexcavated top regions. It has been noted that, similar soil formation and local flora had occurred in the unexcavated neighboring hills of limestone deposition. The local flora on those hills has a maquis formation which consists of Quercus coccifera, Pistacia lentiscus, Cistus creticus, Cistus salvifolius, Sarcopoterium spinosum and Juniperus sp (Fig. 5).

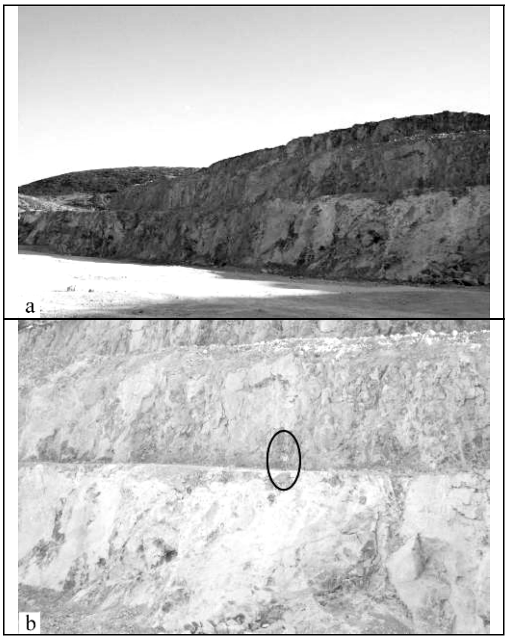

Figure 4. The general structure of the limestone quarry (a), the steep and high slopes of the quarry (b).

Table 1. Average meteorological statistics of Izmir (MGM, 2012).

Unit / Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Ann
Avr. Temp. (^{0}C)	8.7	9.3	11.3	15.6	20.6	25.3	27.7	27.3	23.4	18.7	14.0	10.4	17.7
Avr. High. Temp. (^{0}C)	12.3	13.4	16	20.7	25.9	30.6	33.0	32.7	29.0	23.9	18.4	13.9	22.5
Avr. Rainfall (kg/m^2)	130.2	98.5	74.4	45.2	30.7	7.7	2.0	2.6	11.4	38.0	94.4	150.9	686.0
Avr. Humidity (%)	71.0	68.4	65.7	63.4	59.8	52.8	50.6	52.0	56.7	63.7	69.5	72.1	62.1
Avr. Evaporation (mm)	-	-	-	3.7	5.6	7.8	8.8	8.1	5.9	3.5	1.8	-	45.1

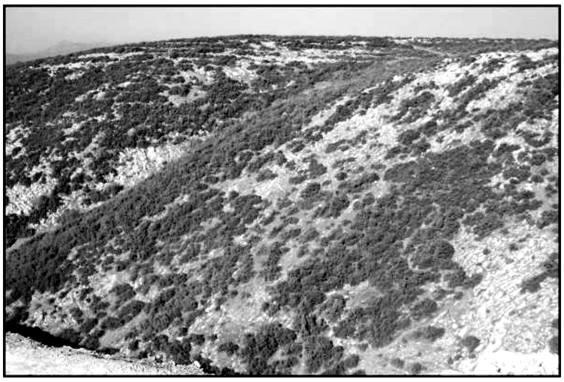

Figure 5. The untouched local flora in the limestone mining site boundaries.

2.3. Bench and Slope Parameters, Reclamation Studies

The required parameters in bench and slope restoration and the details of the reclamation studies were covered in this section. The individual studies for benches and slopes such as digging, soiling, terracing, plantation of tall trees and scrubs with regard to plantation geometries were completed. The calculations of unit costs were imposed upon the information given in figures 6, 7 and 8.

2.3.1. Bench Restoration

The limestone quarry was investigated in terms of geology, soil structure and climate. The benches of this quarry are 8 m in width, 12 m in height and have an approximate slope angle (α) between 55 and 60^o (Fig. 6a). The abbreviations "L" for length and "H" for height would be used for the existing benches and high bench faces in the further cost analysis of the applied reclamation practice (Fig. 6).

The most important phase in reclamation studies is the restoration of benches. The success of the applied reclamation practice depends on the design parameters of bench top geometry. A few of these parameters can be listed as, bench slope, soil thickness, stoppings at the bench ends and drainage ditches. The slope of bench faces were adjusted to 0.5% and 50 cm of stopping was applied as the design parameters were taken account. The primary soil layer, stored before the mining operations initiated, was laid in 30 cm of thickness. The mentioned topsoil was scraped and stored prior to the mining activities.

The significant parameter in soiling is the thickness of the soil to be laid. Some weaknesses can be observed on the bench top stability if the soil is laid above the required thickness. On the contrary, if the soil thickness is not sufficient, the required root depth for plantation and essential conditions for natural soil formation would not be provided. Besides, the primary soil layer thickness should meet the requirements to keep in sufficient rain water in warm periods of the year. Secondary soil layer was laid in 30 cm of thickness. A drainage ditch was built on every bench to prevent the destruction of the bench face by reason of the overflow of water from the slopes. After all, the bench top design was completed (Fig. 6b).

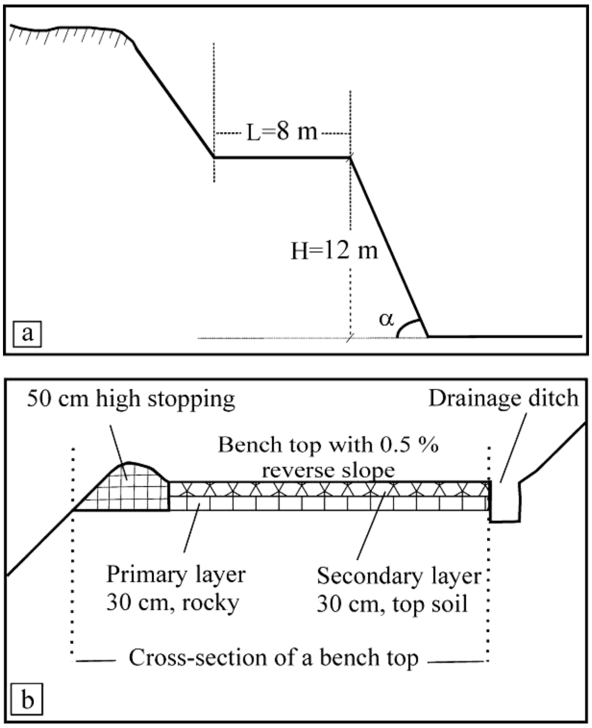

Figure 6. Simple bench geometry of the limestone quarry (a) and cross-section of the bench top (b)

The next step after soiling was digging tree holes with dimensions of 1x1x1.5 m for tall trees on bench bottoms and for scrubs on bench ends (Fig. 8). The prepared tree holes were provided with appropriate materials as perlite, fertilizer and plant nutrition. The following step was to build the drainage ditches with a cross-section area of 1 m^2 on bench bottoms and the stoppings with 50 cm of height at bench ends (Fig. 6b). The stopping built would stabilize the newly laid soil. The method and the plantation geometry applied on bench tops are schematized in figure 7.

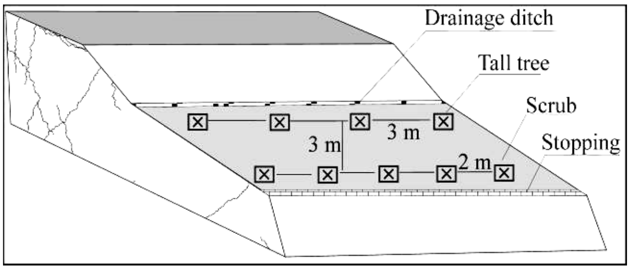

Figure 7. The plantation geometry of the benches.

The tree plantation is not sufficient for the vegetation of bench and slope faces. The selection of trees to be planted should include tree types that root in rocky, loose soil and easily adapt on arid climate conditions. The seed mixture should be prepared with 2/3 proportion of legumes and 1/3 proportion of poaceaes (Gençkan, 1978).

2.3.2. Slope Restoration

The existing slopes of the limestone quarry are quite steep (Fig. 4). It has been planned to build narrow terraces in every 5 m for the slopes with 10 m of height or above. Excavators have been used to build these terraces with 1.5 m width and 30 cm thickness approximately (Fig. 8). These durable terrace structures would be a suitable host for scrubs and ground covering plants in high slopes.

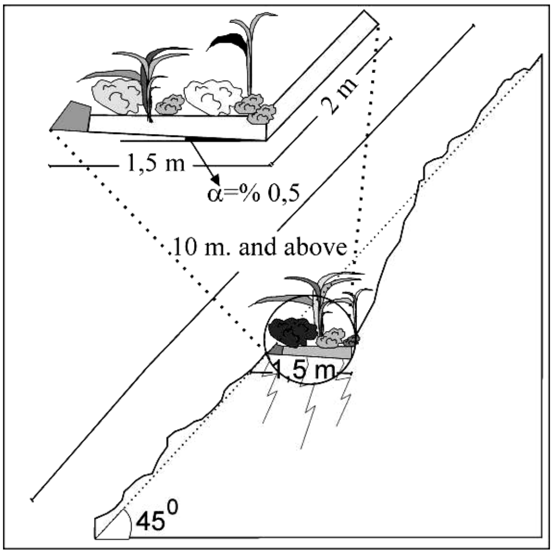

Figure 8. The plantation geometry of the slopes.

These structures, especially applied to the faces of the high slopes would reduce the water flow rate, prevent the damage to be occurred on the bench tops and also let the water flow through the cracks and joints. The reclamation of the limestone quarry, continuing the mining activities simultaneously, including the vegetation, plantation and soiling has been achieved by preconcerted parameters. The sight of the benches and slopes after reclamation is shown on figures 9a and 9b. In figure 10, the previous reclamation practices on the same limestone quarry are exemplified.

3. RESULTS AND DISCUSSION

The costs of environmental protection for the industries have become compulsory to be taken into account with the increasing environmental concerns in each passing day. The most correct approach is to consider the environmental costs within the operation costs prior to initiate the industrial activities (Coskun & Karaca, 2008). Especially, the reclamation cost of the destructed field due to mining activities should be considered within the planning and feasibility study stages and should be included in the operation costs. These costs should be calculated depending on the volume of soil layed, and should be represented in terms of the cost of 1 m^2. Besides the operational parameters such as the capacity of mining activities, the volume of overburden removed, distance of haulage and method of dumping, the total cost consists of the restoration, vegetation and plantation costs (Mallı et al., 2011).

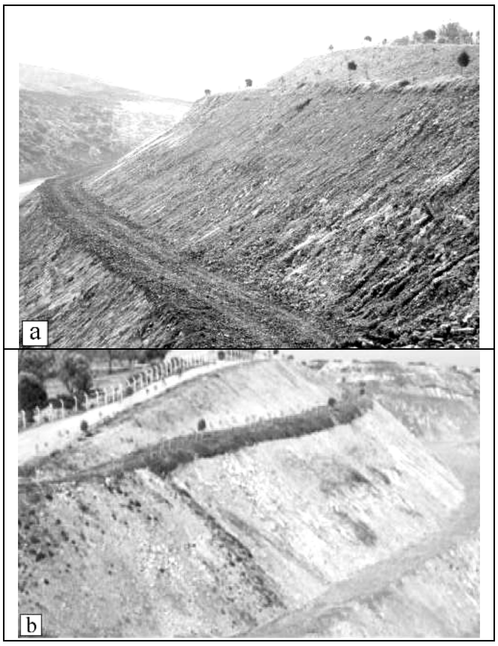

Figure 9. The benches and slopes after reclamation.

Figure 10. The top view of the benches after reclamation.

The reclamation studies in a mining site can be categorized into two main topics. These are bench restoration and slope restoration. The bench restoration cost for the related limestone quarry consists of soil laying, hydraulic breaker, building of stoppings, treehole digging, ditching, soil loading and haulage. Likewise, the slope restoration cost consists of hydraulic breaker, terracing, dumping and laying of soil. The descriptions and cost analysis are given in tables 2–8.

A bench width of 8 m and bench height of 12 m has been used in cost calculations. The unit costs of sodding, tree planting, digging, soiling and haulage has been normalized by assuming the total cost of 100 m zone of benches and slopes and calculated the average costs for the restoration of 1 m^2 of units. The fluctuating labor costs due to national conditions have been neglected in calculation of unit costs. The cost of 1m^2 of bench and slope has been calculated respectively. Nevertheless, a 10% of unexpected costs were included in the estimated operation cost. The cost analysis for the formation of primary and secondary soil layers has been calculated by assuming 100 m of height, 8 m of width and thickness of 0.3 m in soil layering. Similarly, the cost of tree hole digging has been calculated by 100 m distance to be taken into account regarding the plantation geometry in figure 7.

The plant species decided to be used in reclamation studies of the related quarry were selected depending on visual and esthetic impact alongside with functional and ecologic characteristics (Hope et al., 2003, Acar & Sarı, 2010). Tall trees for the bottom of the benches, scrubs for the bench ends, maquis or ground covering plants on the terraces and scrubs or maquis plants on the slopes were decided to be used in the plantation of benches and slopes respectively (Table 5). The different plant species given in tables showing the average costs were selected upon the adaptability of the species to the mining site.

The costs of tall trees, scrubs, maquis plants, ground covering and spreading plants, fertilizers and seeds were calculated for a 100 m long bench as the reclamation geometry and unit costs were considered. The cost of sodding on the bench tops was calculated including the seed and fertilizer costs for 1 hectare of area (Table 6).

The necessity of planting at least 1 maquis plant or scrub and 5 ground covering and spreading plants was determined by analyzing the reclamation cost of slopes. The total cost of these two different plant species was estimated to be 4.10 €/m^2.

Table 5. The cost of trees to be planted on benches

Tall Trees Description		**Unit Cost, (€)**
Pinus Pinea	2 years old	0.55
Pinus Brutia Ten	2 years old	0.36
Cupressus Sempervirens	2 years old	0.45
Prunus Dulcis	2 years old	0.45
Schinus Molle	3 years old, 1.5 m	2.93
Blatanus	4 years old, 1.5-2m	9.91
Robinia Pseudoacacia	2 years old	0.45
Juglans Regia	3 years old, 100 cm	1.72
Quercus	2 years old	0.26
Casuarina Equisetifolia	2 years old	1.00
Total		17.46
Average Tall Tree Cost		***1.75***
Scrubs		
Acacia Cyanophylla Lindley	2 years old, 50cm	0.32
Acacia Dealbata	4 years old, 1.5 m	2.48
Elaeagnus	2 years old	1.35
Total		3.83
Average Scrub Cost		***1.28***
Cost of mulch		***9***

The mulch with seeds to be laid with 30 cm of thickness was applied on each terrace. The cost of each terrace with dimensions of 100x1.5x0.3 m (total of 45 m^3) was estimated as 405 €. In addition, the cost of slope restoration was calculated according to geometric plantation pattern (Tables 7 & 8). The success of the reclamation practices was determined in comparison to similar practices.

Table 2. The cost of bench restoration.

Description	**Dimensions (m)**	**Volume (m^3)**	**€ / m^3**	**Total Cost**
Primary soil layer	100 x 8 x 0.3	240	0.45	108
Secondary soil layer	100 x 8 x 0.3	240	0.45	108
Hole digging by hydraulic breaker (25 holes)	1 x 1 x 1.5	25	16.58	414.50
Hole digging by hydraulic breaker (34 holes)	1 x 1 x 1.5	34	16.58	563.72
Ditching by hydraulic breaker	100 x 1 x 1	100	13,65	1365.00
Stopping	100 x 1.5 x 0.5	75	1.33	99.75
Soil loading and haulage (4 km)		315	1.35	425.25
Total				3084.22
Cost of bench restoration (1 m^2)				3.84
Unexpected costs (10 %)				0.38
Total				***4.22 / m^2***

Table 3. The cost of slope restoration.

Description	Dimensions (m)	Volume (m^3)	€ / m^3	Total Cost
Terracing with hydraulic breaker	100 x 1.5 x 2.5	188	16.58	3117.04
Terrace soiling	100 x 1.5 x 0.5	75	0.45	33.75
Total				3150.79
Cost of slope restoration (1 m^2)				2.63
Unexpected Costs (10%)				0.26
Total				***2.89 / m^2***

Table 4. Bench vegetation and sodding cost

Material	Description	Amount	Unit Cost	Cost of a Decare (€ / hectare)
Mixed Seed	A seed mixture of suitable seeds	100 kg / hectare	2.70 € / kg	270.00
Fertilizer	Fertilizer and nutrition over the seeds (CIF)	250 m^3 / hectare	2.25 € / m^3	560.25
Total				***830.25***

* The haulage or transportation costs were calculated assuming a maximum distance of 5-8 km.

Table 6. The cost of tree hole filling materials

Material	Amount	Unit Cost, (€)	Cost of Tree Hole Filling, (€)
Perlite	1/3 bag / hole	4.73 /bag	1.57
Soil (CIF)	1 m^3 / hole	7.21 /m^3	7.21
Fertilizer	1 / 10 m^3	2.25	9.01
Total			***17.79***

* The haulage or transportation costs were calculated assuming a maximum distance of 5-8 km.

Table 7. The cost of maquis and scrubs for the bench ends

Maquis & Scrubs	Unit Cost, (€)
Daphne	0.320
Spartium Junceum	0.450
Juniperus sp	1.130
Thuja orientalis	0.110
Total	2.010
Average Cost	***0.503***

Table 8. The cost of ground covering and spreading plants on terraces

Species	Description	Unit Cost (€)	Cost for 100 m, (€)
Ground covering, Spreading plants	2 per meter for a 100 m terrace and 200 for inner side of the terraces	0.72	144

The plant species selected in the reclamation practices in a coal mine in the north of Çatalca Peninsula, formed of limestone and Paleozoic shale, were rapid growing Pinus Pinea, Pinus pinaster and Robinia Pseudoacacia to conserve the ecologic balance (Keskin & Makineci, 2009). Hence, the erosion due to rain water and wind was minimized and natural soil formation was initiated. The selection of Robinia Pseudoacacia in similar mining site plantations relies on the high stabilization, a characteristic of Robinia Pseudoacacia (Kantarcı, 1988).

The survival statistics of plantation species selected for reclamation were investigated in a lignite mine in Aydın. The results concluded that Robinia Pseudoacacia (93.33% survival) and Olea europaea (97.50% survival) were the most adaptable and enduring species. In addition, species with rapid growing and root development characteristics were named as preferable in the study (Karakurt et al., 2009). A study on the plantation of Soma and Denis reclamation practice sites was conducted by Aegean Lignite Enterprises and 4 main species (Pinus Pinea, Pinus Brutia Ten, Robinia Pseudoacacia and Cupressus Sempervirens) with a sum of 500.000 were selected among 617.000 of total plants to be used. Similarly, in a study conducted by Southern Aegean Lignite Enterprises, a sum of 771.200 trees among a total of 795.580 were decided to be Robinia Pseudoacacia, Pinus Pinea and Cupressus Sempervirens.

The reclamation studies during and after the mining activities in Aegean Region of Turkey state that species of Pinus Pinea, Pinus Brutia Ten and Cupressus Sempervirens are suitable for plantation considering the soil structure and climate.

4. CONCLUSIONS

The reclamation studies should take place simultaneously with the mining activities. The cost of these reclamation studies is 9.8% of the total operation cost. The 90% of the reclamation part is the restoration of the field (arrangement, digging, stopping, etc.) (Kartallıer, 2006).

The determination and investigation of the reclamation parameters with the cost analysis for a depleted mining site was practiced on a limestone quarry. Especially, the bench top geometry and reclamation of the high slopes were studied in detail.

In this type of surface mining operations, it is necessary to provide a safe general slope angle (Lorant, 2008). The reclamation of high slopes was aimed to be achieved with limestone quarry activities concurrently. The reclamation and rehabilitation studies on an empty field with none flora and fauna habitat were investigated.

Accordingly, the design and geometry of slope and bench plantation were concluded and cost analysis of the total reclamation practice was calculated. The variable labor costs due to national conditions were ignored. Nevertheless, a 10% of unexpected costs were included in the estimated operation cost. Eventually, the costs were found to be 4.25 €/m^2 for bench rehabilitation, 1.38 €/m^2 for bench plantation, 2.88 €/m^2 for slope rehabilitation and 3.82 €/m^2 for slope plantation respectively.

The reclamation studies of the limestone quarry were accomplished with detailed investigation of geological structure, climate, local flora and fauna, application details and cost elements depending on the rapid growth of plantation, soil formation, ecological and economical criterion. As for that, several significant criterions were determined to be affective on plant selection such as the adaptability of plantation, soil and air humidity, maximum and minimum rainfall, total amount of rainfall and annual heat distribution.

After all, the reclamation cost of the destructed field due to mining activities should be considered within the planning and feasibility study stages and should be included in the operation costs. It is conceived that, the results of investigated reclamation and rehabilitation studies regarding the mining site specifications, geological structure, climatic parameters and application details of the limestone quarry would guide similar studies in this research area.

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