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EVALUATION OF DUMP SITE RECLAMATION TECHNIQUES IN WESTERN TURKEY COAL MINES

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Abstract

The environment friendly development of mining applications progressed significantly due to the rapid increase in environmental awareness and requirement of available land. The reclamation studies of those lands, ruined during mining activities, should be evaluated and regained in the most effective and rational way. In recent years, especially in open pit coal mining, reclamation applications become crucial due to rapid spreading of mining companies on extensive lands. These applications were taken into account in feasibility studies and included in mining operations. The reclamation systematics of dump sites formed by stripping of open pit coal mines and depleted coal pits are investigated. In this study, the rehabilitation studies subsequent to mining activities are dealt technically and parameters affecting the success of these studies are determined.

Keywords: dump sites, economic evaluation, open pit mining, reclamation, technical evaluation

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1. Introduction

The reclamation of lands ruined during mining activities is reckoned and become more significant due to the increase in environmental awareness and available land requirement in recent years, regarding plantation, vegetation, etc. These rehabilitation activities are suggested and applied essentially, especially in the countries with abundant coal reserves.

The amount of ruined lands subsequent to mining activities reached a remarkable level in Turkey, since the majority of lignite mining in Turkey is being extracted by open pit mining methods (Unal et al., 1994; Unver and Kara, 1994). The reclamation of the ruined lands is a legal obligation and should be taken into account in feasibility studies regarding occupational safety and environmental impact for the benefit of society (Delibalta, 2003).

Mining is an activity that changes the structure of the land temporarily in a definite time scale by wiping out the signatures of past usage and landscaping of the field. The destruction in visual environment, landscaping, water resources, agricultural and forestry land should be considered intensely with other harmful effects such as erosion and landslide (Sengupta, 1993). Therefore, the reclamation studies should proceed during and after mining activities to avoid or minimize the negative impacts (Mallı et al., 2011).

The term of reclamation is the restoration of a depleted mining site for further usage (Ramani et al., 1990). The main scopes of reclamation in ruined mining sites are landscaping to achieve the ideal visual aspects and retrieving the initial ecologic and economic values by enhancing the land in an esthetical and suitable way.

The suitability of ruined mine sites for post-mining usage are evaluated in several studies in literature. The limiting and enhancing factors in soil have been evaluated in overburden dumps of opencast mining sites by Maiti and Ghose (2005) and Carrick and Kruger (2007). Tafi et al. (2006) have managed a post-reclamation monitoring to quantify the effectiveness of reclamation and evaluate the soil

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suitability for sustaining plant growth for several abandoned mine sites. Many other researchers have evaluated the environmental and economic factors such as climate, topography and society to discuss the further usage of mined and other disturbed lands (Hindle and Grosskopf, 2000; Hill, 2003; Gizikoff, 2004; Kanda et al., 2017; Soltanmohammadi et al., 2010). Mio and Marrs (2000) have outlined the principles and approaches to ecological restoration of several surface mines while Mchaina (2001) have discussed environmental management and technical considerations for the decommissioning, closure and reclamation of a mine sites. In addition, several special post-mining land uses have been discussed by Wisconsin (2000), Errington (2001), Paschke et al. (2003), Li (2006) and Cao (2007). Some regulations, key elements and exercised procedures have been discussed by Meech et al. (2006) based on a local town in Britannia which suits the conditions of investigated coal mine sites in this study.

Economic, technical, social and mine-site factors are effective in analysis required to determine the reclamation suitability of mine sites. The economic factors include cost, investment, governmental incomes, etc. as sub-factors. The social sub-factors can be listed as immigration, employment opportunities, land ownership, company policy, etc. The technical factors include shape and size of mined land, availability of reclamation techniques, current land-use in surrounding areas, structural, landscape quality, etc. as sub-factors. Eventually, the mine-site sub-factors are soil's physical and chemical properties, evaporation, frost free days, wind speed, air moisture and temperature, etc. (Soltanmohammadi et al., 2009, 2010).

The heavy mining equipment (excavator, truck, scrapper, etc.) used during mining operations can be benefitted from in rehabilitation of ruined lands and availability of these equipment is an important parameter in reclamation method selection (Brauer, 1997; Pamukcu, 2004). Therefore, the reclamation studies should be taken into consideration with open pit production, haulage, dumping methods and equipment selection (Köse et al., 1993). For instance, excavator + truck combination is the most suitable and widely used method in open pit and slope mining for aggregate quarries which is also classified as one of the surface mining methods. As a result of exercising this method, several benches and slopes would form. Similarly, dragline + truck and bucket wheel excavator + bent conveyor combinations supplied in strip mine operations generate dump sites in form of piles. Accordingly, the production method, therefore type of reclamation applications during and after mining operations varies.

The closure and reclamation of depleted mines should be included in mining design and planning stage, since the decisions given in that stage has long term benefits with risk estimation studies. The reclamation studies should progress concurrent to exploration, feasibility studies, design, development, mining operations and closure in sustainable reconstruction process (Düzgün, 2009).

The reconstruction of a ruined land is possible by retrieving the fertile land and its ecologic, economic and esthetical aspects. These reconstruction studies are collected under same title in four main stages (Akpınar, 1994; Düzgün, 2009). These stages are planning the land usage, rearrangements, rehabilitation and monitoring & maintenance. Planning the land usage is defined as inventorying the previous land conditions and the determination of ecologic goals for plantation. In addition, digging, soil laying, plantation, drainage applications, etc. are involved in rearrangements. The rehabilitation stage involves retrieving the previous biologic fertileness, recovering the soil and plantation. The plant growth, drainage applications, slope stability and risk assessment of erosion are covered in the monitoring and maintenance stage.

The subsequent usage of ruined lands due to open pit mining should be determined by the parameters such as the previous usage of the land, type of the ore extracted, method of production, socio-cultural groups in the vicinity and social necessities (Topay et al., 2007).

The scope of reclamation in these areas should be to economically benefit from the land in addition to achieve an ideal landscaping. For that purpose, the rehabilitation process may yield to agricultural zone (vegetation, orchard, etc.), forestry (commercial and noncommercial), recreational zone (public gardens, playgrounds, parks, etc.), wetland (public necessities, fishery, etc.), wildlife (biotope, reservation zones etc.), and constructional zone (industrial, commercial and residential zones) applications (Köse et al., 1993; Saltoglu, 1992). The fertile soil layer should be thick enough and at least 0.8-1 meters over the water table if the land would be used for agriculture. The slope of the field should be at most 1.5% to avoid the risk of erosion. The agriculturally available land (flat or low-pitched) is used for vegetation and plantation, whereas the steep slopes can be graded for agricultural usage (Fig. 1) (Görcelioglu, 2002). The land can also be used for forestry. Therefore, the plantation should be selected carefully; the recreation zones and roads should be planned prior to plantation.

2. Case study presentation

2.1. Decision mechanism

The determination of reclamation applications for the predefined goals and stages involves evaluation of four main factors; technical, economic, social and mine-site parameters in correlation. The effective sub-factors of those four main parameters are agriculture, forestry, lake or pool, intensive and non-intensive recreation, construction and pit backfilling etc. (Soltanmohammadi et al., 2009). The main decision making mechanism in reclamation is schematized in Fig. 2.

Fig. 1. The rearrangement of the field for further agricultural usage

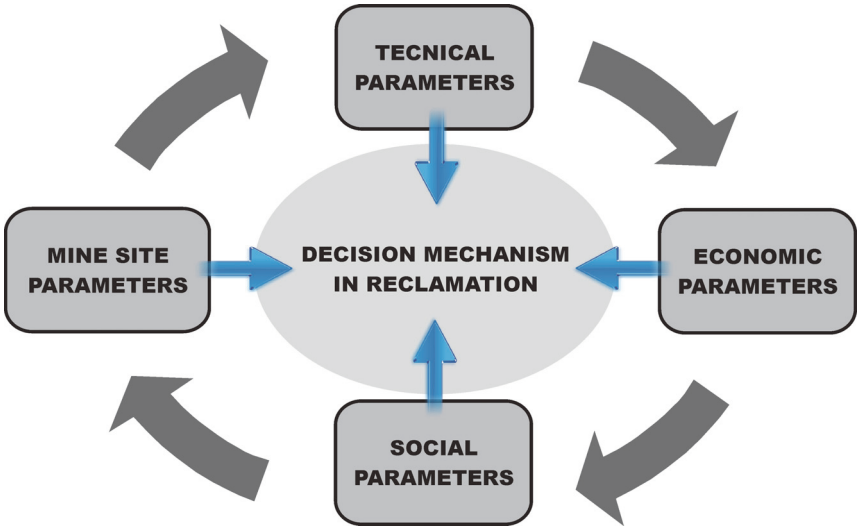

Fig. 2. The main decision making parameters in reclamation

The cost of land restoration studies covers the 90% of total reclamation cost. The total of this cost covers the 10% of annual operating cost of the mining company. The planning of reclamation applications should be made prior to mining operations since the excavating and filling costs would be a great burden economically after the mining operations finished.

Several studies including economic evaluation of reclamation applications are present. It has been mentioned that the reclamation cost of West Kentucky Basin (USA), is approximately 8% of the total operating cost. The stripping/coal ratio has been calculated as 8:1 and it has been determined that 0.2 hectares of land was ruined for every 100 tons of coal production. This yields to a reclamation cost of 0.32 $/ton that covers the 7.6% of the total costs. In addition, the rehabilitation studies in East Germany lignite mines cost 7.5 billion € to reclaim over 100.000 hectares of ruined land (Kuyumcu, 2005).

It is exceedingly hard to serve numerical values regarding cost of reclamation studies in Turkey. The first reclamation attempt in Turkey was the vegetation and plantation (542 hectares) of the coal basin of South Aegean Lignite Enterprises in Mugla in 1991 (Elcim and Atasay, 1999). Another application of reclamation studies for coal mines was in Istanbul Agacli-Kemerburgaz for the purpose of forestry. In this application, a zone of 1247 hectares was reclaimed by afforestation between 1988 and 1996 for 62.500 €/hectare. It is revealed that, the costs of reclamation studies per hectare are similar as East Germany lignite mines when compared.

2.2. Methodological study

The cost of reclamation in ruined lands subsequent to mining is calculated with regard to the volume of affected soil and ton of ore produced. This cost is expressed in terms of $ or € per hectare commercially. The systematic of the reclamation studies is listed in Fig. 3. The reclamation systematic in Fig. 3 involves many parameters and these parameters need to be briefly defined. The production capacity is specified as day-month-year in

open pit mines. The production amount is dependent on operating parameters of the mine with a definite stripping ratio. The stripping amount depends on the stripped volume and defines the expropriation territory. The method of dumping is also important regarding internal or external dumping. The internal dumping is suggested in open pit mines since the distance of haulage is shortened by that method.

The cost of reclamation is very sensitive upon transportation distance and haulage system. Therefore, the effect of transportation distance on reclamation cost should be specified by the location, position and geometry of the dump site. The further expropriation of land is dependent on the necessity of new land. The expropriation may include forestry land, public domain or owned land.

The applications of land restoration such as dumping, filling, terracing, soil laying and rearrangements should be achieved after stabilization of the land. The terracing, filling, soil laying and slope stabilization should commence regarding the visual aspects and safety (Fig. 3). The stability problems can be avoided by slope and soil stabilization applications at that stage.

The scope of soil stabilization is to enhance the endurance and burden of the ground by concreting, supporting, chemical and geosynthetic applications. The durability of the ground would be enhanced due to these applications in endurance, cohesion, compaction and resistance to erosion. The fertile soil should be laid 30 cm in thickness to provide suitable platform for plantation and support plant growth. This thickness is crucial for the development and holding of plant roots (Kun et al., 2012). Other than, the climate and ecology parameters such as humidity, amount of rainfall, temperature, wind direction, wind force, physical and chemical characteristics of soil should be considered prior to reclamation applications.

The plantation selection mainly depends on other parameters; soil properties, climate and ecology.

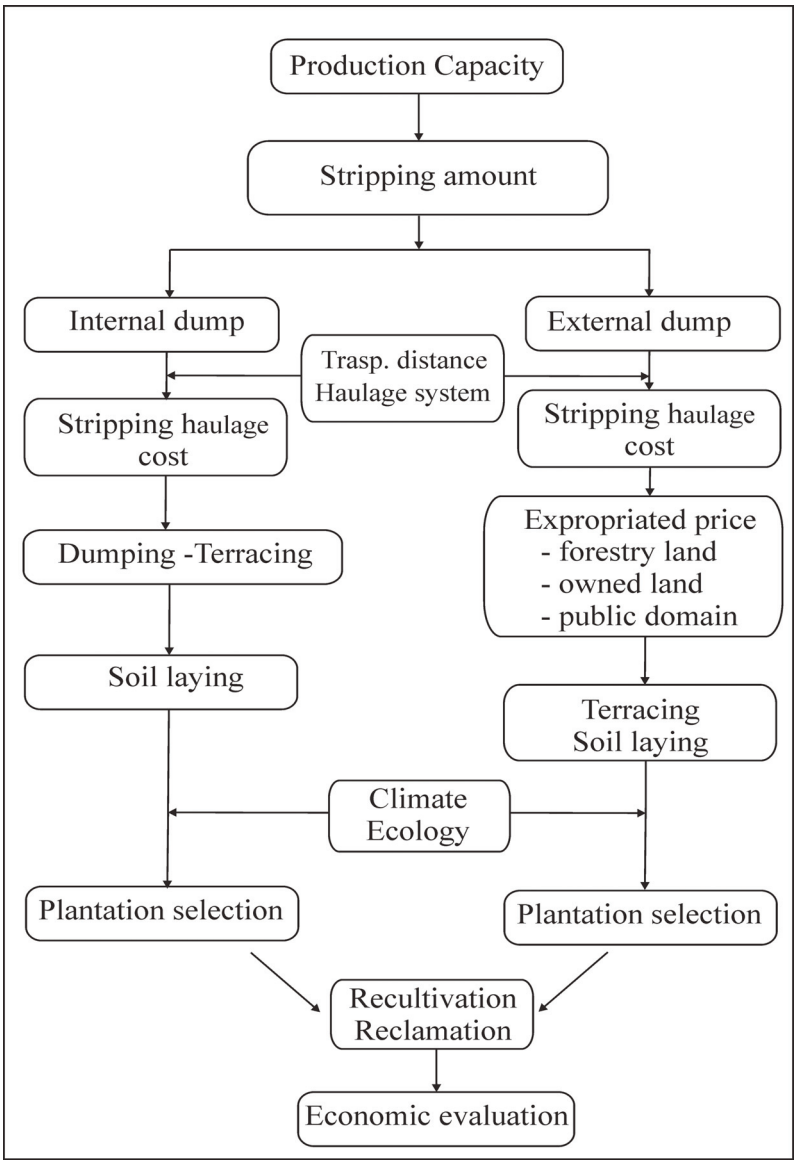

Fig. 3. The systematic of reclamation studies

The subtopics to be considered with economic evaluation are latitude, elevation, climatic conditions, soil properties, distance to seashore and natural vegetation of the land. These criterions also affect the chance of survival for plantation. One of the most important factors in plantation is humidity. The annual rainfall should be over 254 mm to achieve a successful seeding (Pamukcu, 2004).

The rough climatic conditions also affect the plantation, since steep slopes, loose soil, high wind force, low rainfall and potential of toxic plant growth should be taken into account. The esthetical perspective of the reclaimed land is another factor and the visual integrity of plantation with neighboring flora is notable. The economic evaluation of reclamation studies ruined lands subsequent to mining is determined by the volume of affected soil and ton of ore produced and expressed as cost per hectare.

2.3. Field study

The field of study is located on the western part of Aydın in Turkey and 15 km far from the city center. The coal mine was operated as an underground mine till 1984 and after that year, both underground and surface mining operations were held. The total lignite production of the company is 6.1 million tons from underground and 4.5 million tons from open pit mine. The amount of dumped overburden is 130 million cubic meters till today. The area and samples of reclamation studies are illustrated in Fig. 4.

The altitude of the coal mine is approximately 300 m. The surrounding vegetation is mainly formed by olive trees, scrubs, acacia and other agricultural farm zones. The base formation involves schist and gneiss zones and conglomerates of these zones under the coal seam according to the general geology of the area. Above the coal seam; argillaceous marl, sandstone, sand and thin layers of limestone are observed. Eventually, the surface formation is formed by loose sand and aggregates. These aggregates are originated from schist and gneiss zones and have abundant amount of mica content (Karakurt and Altun, 2000).

The overburden of the lignite mining zone, extracted by excavator + truck combination was stored to be used in plantation and soil laying activities. The suitable tree species to be planted were decided upon the soil properties and regional climate. The plantation was applied on the zones of the dump sites restored by loaders and bulldozers depending on the topography. Based upon these applications, commercial income from the reclaimed zone is aimed.

The plantations of acacia and olive trees over a land of 890 decares for soil conservation and commercial income have been observed in the same region in previous years. The adaptations of the mentioned trees have been evaluated as successful (Karakurt et al., 2009). In addition, the possibilities of various different reclamation application types (agriculture, lake and pond, forestry, recreational, sports, etc.) are evaluated. However, the alternative ways of reclaiming the dump sites are not possible due to the distance to nearest urban zone, inadequate soil specifications for farming, insufficient labor force, difficulties in irrigation and above all; noise and dust due to ongoing mining activities nearby.

The annual climatic conditions in the city of Aydın are listed in detail in Table 1. The highest and lowest temperatures measured in the region are 43.6 and -11^{o}C respectively. The highest rainfall is in December and January lading to annual rainfall of 656 mm in 2012. The amount of rainfall (656 mm) in the region exceeds the minimum rainfall amount sufficient enough to perform a successful seeding (254 mm). Besides, the level of humidity is also sufficient for plantation with an average humidity of 62% annually.

3. Results and discussion

In the past few years, trial zones for plantation were generated in the open pit lignite mine. The five different species as Pinus Brutia Ten, Folium Elaeagni, Robinia Pseudoacacia, Rolium Olivarum and Amygdolus Communis were planted in dumping area and the survival statistics were investigated after 5 years. As a well known fact, the most accurate method to determine the difference between groups when there are two or more groups is analysis of variance (ANOVA).

The determination of difference between groups and the group that originates the difference should be well mentioned in this kind of variance analysis. The analysis of such situations can be accomplished by methods such as Duncan, Turkey HSD, Scheffe, Newman-Keuls and Dunnett etc. The most common method among those is Duncan method (Kesici and Kocabas, 1998) which was applied to calculate and evaluate the survival statistics of tree species. The variance analysis applied in this study was based on the tree species, area of the dump site, fertilizer and watering criterion. The “multiple comparison test” principles were applied and the interactions between the criterion of area of dumpsite-fertilizer, area of dumpsite-watering, tree species- area of dumpsite, tree species- area of dumpsite-watering were evaluated with respect to group and individually (Karakurt et al., 2009). Similarly, Yongwen and colleagues were investigated the affect of multi-level nitrogen addition on plant and soil by determining the interactions between fertilizer, plant and soil by Duncan multiple comparison test successfully (Yongwen et al., 2013). Depending on the results of Duncan multiple comparison test there observed notable differences in survival statistics of the tree species in this study. Rolium Olivarum (98.33% survival) and Robinia Pseudoacacia (94.17%

survival) were the most adoptable and enduring species in that habitat. The other species; Pinus Brutia, Folium Elaeagni and Amygdolus Communis, had survival chances of 77.5, 82.5 and 80.83% respectively (Table 2) (Karakurt et al., 2009). The effect of soil and dump quality on survival statistics of tree species was investigated.

In addition, the fertilizing and watering operations have brought positive impact on chances of survival at this stage. The results stated that the success of plantation depends on the suitability of the soil for the rapid root growth. The properties of the soil used in plantation application are listed in Table 3 (Karakurt et al., 2009).

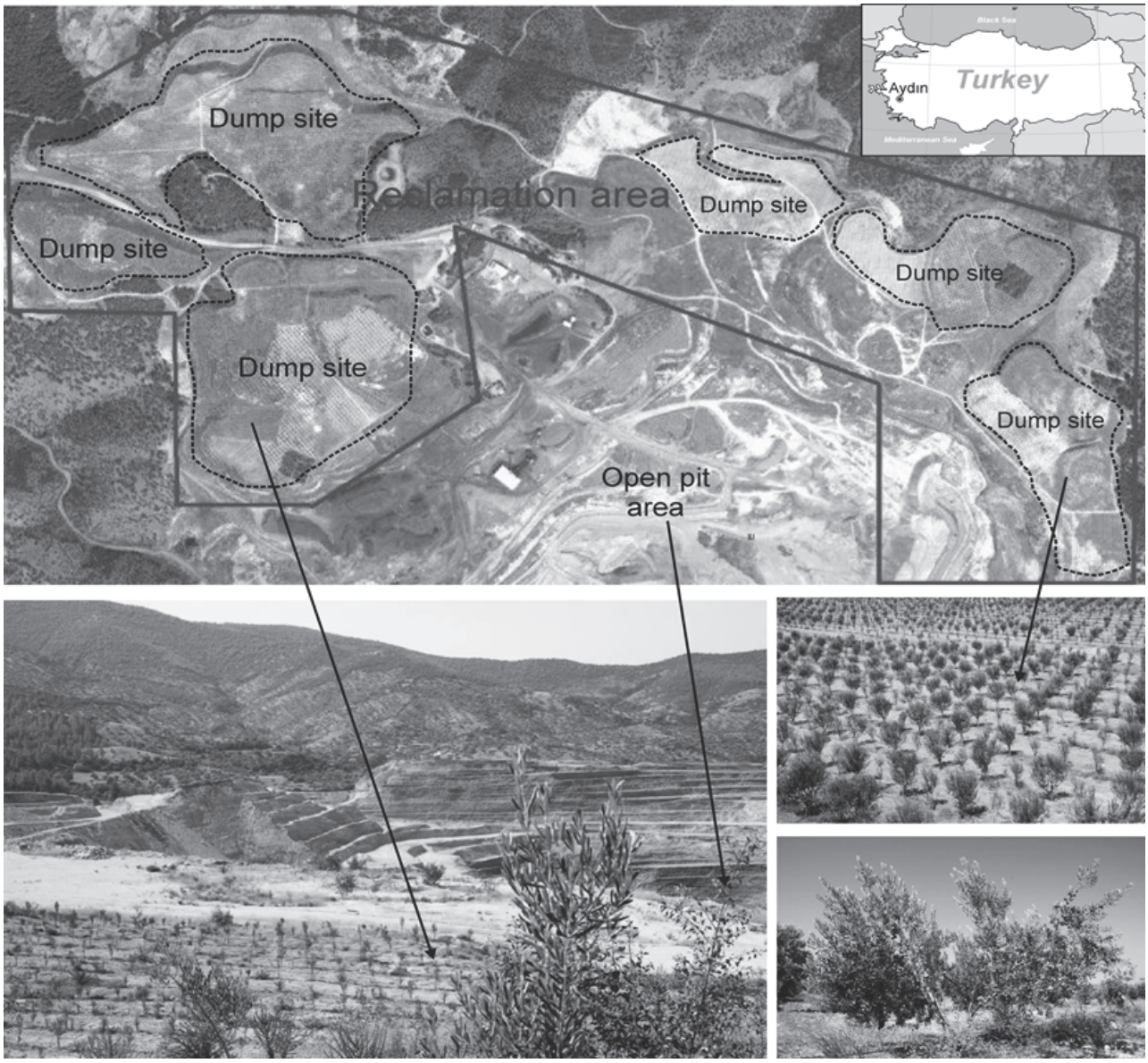

Fig. 4. The reclamation area and samples of plantation

Table 1. The annual climatic statistics of Aydın, Turkey (MGM, 2012)

Condition	*Month*												*Annual*
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	
Highest Temp. (ºC)	23.2	25.2	31	33.8	40.2	41.7	43.6	43	40.2	38	30.5	25.9	43.6
Lowest Temp. (ºC)	-11.0	-5.4	-4	0	4.9	10.2	13.4	11.8	7.6	1.6	-4.7	-5.3	-11
Avr. Temp. (ºC)	7.8	9.2	11.2	15.7	20.7	25.4	28.1	27.3	23.3	17.8	13.6	9.5	17.5
Avr. Rainfall (mm)	121.2	94.1	69.6	46.8	30.7	14	4.2	2	15.7	48.4	74.4	135	656
Avr. Humidity (%)	77	73	67	65	55	46	53	49	54	59	70	70	62
Wind Velocity (m/s)	2.3	2.5	2.9	2.2	2.6	2.7	2.6	2.2	2.4	1.8	2.0	1.8	2.3
Wind Direction	E	WSW	E	W	WSW	W	WSW	WSW	W	WSW	W	E	E

Table 2. Survival statistics of several tree species (%)

Tree Species	*Chance of Survival %*
Rolium Olivarum	98.33
Robinia Pseudoacacia	94.17
Folium Elaeagni	82.50
Amygdolus Communis	80.83
Pinus Brutia Ten	77.50

Table 3. The characteristics of soil used in plantation

Characteristic	*Value*
Texture	Sandy Loam
Sand (%)	54.56
Dust (%)	38.56
Clay (%)	6.88
$CaCO_3$ (%)	9.98
pH	6.92
Organic Subs. (%)	2.59
N (%)	0.08
P (mg/kg)	3
K (mg/kg)	156
Ca (mg/kg)	2700
Na (mg/kg)	75
B (mg/kg)	3.22

The successful plantation trials can be applied to sites with similar soil and climate conditions if there are no other restrictions. However, the species with similar biologic specifications (need of humidity, growth duration etc.) should be planted together in groups. In addition, organic fertilizing and watering (for the first two years) should also be considered and applied professionally. Today, plantation is applied to the reclamation area by 50.000 olive trees with both ecologic and economic benefit such as olive and olive oil production. It is intended to gather an average of 20 kg/tree olive product which leads to 1.000 tons of olive per year.

4. Conclusions

The four main factors (technical, economic, social and mine-site), directly effecting the decision making mechanism are discussed in correlation to select the most suitable type of reclamation for post-mining land usage in a coal mine dump site. The possibilities of various different reclamation application types are evaluated and the alternative ways of reclaiming the dump sites are eliminated due to discussed reasons except plantation.

The positive correlation of the plant species selected with the current flora is significant in consideration of ideal soil and climatic conditions. The chances of survival were investigated for several different tree species to determine the adoptability for current habitat.

In this study, an alternative post-mining land usage method is revealed. The plantation of trees with commercial income possibilities brings out the opportunity of employment and earning money together with the reclamation of mine site (olive, olive oil etc.). The legal obligation of reclamation studies for environmental awareness would bring economic advantages if the reclamation area is suitable for plantation and agricultural use.

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