LANDFILL SITE SELECTION AND LANDFILL LINER DESIGN FOR ANKARA

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APRIL 2010

LANDFILL SITE SELECTION AND LANDFILL LINER DESIGN FOR ANKARA

A THESIS SUBMITTED TO
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

GÖZDE PINAR YAL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEOLOGICAL ENGINEERING

APRIL 2010

Approval of thesis:

LANDFILL SITE SELECTION AND LANDFILL LINER DESIGN FOR ANKARA

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ABSTRACT

LANDFILL SITE SELECTION AND LANDFILL LINER DESIGN FOR ANKARA

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April 2010, 116 pages

The main scope of this thesis is to select alternative landfill sites for Ankara based on the growing trends of Ankara towards the Sincan and Gölbaşı municipalities and to eventually select the best alternative. Landfill site selection was carried out utilizing Geographic Information System (GIS) and Multi-Criteria-Decision-Analysis (MCDA). A number of criteria were gathered in a GIS environment. Each criterion was assigned a weight value by applying the Pairwise Comparison Method (PCM). “The Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)”, was applied and the best landfill site alternative was determined.

The geotechnical properties of the clay samples, obtained from selected locations in Gölbaşı and Sincan were determined in order to design a landfill liner system using compacted “Ankara Clay” as the liner material. The permeability values for the clay samples were determined by performing falling head tests and consolidation tests. The coefficient of permeability value of the compacted clay was determined to be in

the order of 10^{-10} m/s for the Gölbaşı samples and 10^{-11} m/s for the Sincan samples for both of the tests performed. These tests indicated that the native clay was suitable to be utilized as a landfill liner material. The HELP and POLLUTE was employed for the purpose of landfill design and predicting the landfill hydrological processes. The landfill profile with a double lining system composed of geomembrane/compacted clay composite top and bottom liners with a drainage layer was determined to show the best performance amongst the others.

Key Words: Landfill Site Selection, GIS, MCDA, Compacted Clay Liner, Geomembrane Liner, Composite Liner, Double Lining System.

ÖZ

ANKARA KATI ATIK SAHASI YERİ SEÇİMİ VE TASARIMI

Yal, Gözde Pınar
Yüksek Lisans, Jeoloji Mühendisliği Bölümü
Tez Yöneticisi: Prof. Dr. Haluk AKGÜN

Nisan 2010, 116 sayfa

Bu çalışmada Ankara için uygun atık sahaları belirlenmiştir. Ankara'nın büyüme yön ve miktarları göz önünde bulundurularak Sincan ve Gölbaşı ilçeleri atık sahası yeri seçmek üzere belirlenmiştir. Atik sahası yeri seçiminde coğrafi bilgi sistemleri (CBS) ve çok kriterli karar analizi kullanılmıştır. Atık sahası yeri seçiminde etkin olabilecek kriterler CBS ortamında bir araya getirilmiştir. İkili karsılaştırma ve analitik hiyerarşi yöntemleri kullanılarak her bir kritere bir ağırlık değeri verilmiştir. En iyi alternatifi belirleyebilmek için ise bir ideal nokta yöntemi olan TOPSIS kullanılmış böylece en uygun alternatif tespit edilmiştir.

Gölbaşı ve Sincan'da seçilen alanlardan alınan kil numunelerinin jeoteknik özellikleri tespit edilerek "Ankara Kili"nin dolgu tabakası maddesi olarak kullanıldığı bir atık sahası tasarımı yapılmıştır. Sincan ve Gölbaşı'da seçilen atık sahası için uygun görülen yerlerden alınan kil numuneleri üzerinde yapılan jeoteknik analizler sonucunda elde edilen plastik limit ve plastisite indeks değerleri, kil numunelerinin atık sahası yalıtım malzemesi olarak kullanımının uygun olduğunu göstermiştir. Geçirimsizlik değerleri ise düşen seviyeli geçirimsizlik ve konsolidasyon deneyleri ile tespit edilmiştir. Geçirimsizlik değerleri Sincan ve Gölbaşı numuneleri için sırasıyla 10^{-10} ve 10^{-11} m/s seviyesinde tespit edilmiştir. Yapılan bu deneyler sonucunda Ankara kilinin dolgu malzemesi olarak kullanımının uygun olduğu doğrulanmıştır. Atık sahası tasarımınının yapılmasında ve atık sahası hidrolojik sürecinin incelenmesinde HELP ve POLLUTE modeli kullanılmıştır. HELP modeli ile elde edilen tasarım sonuçlarına göre atıkların depolanmasında en

iyi performansı, diğer yalıtım sistemleri ile kıyaslandığında, drenaj tabakası içeren jeomembran/sıkıştırılmış kil kompozit alt ve üst yalıtım tabanlarından oluşan çift tabakalı sistem sunmaktadır.

Anahtar Kelimeler: Katı Atık Sahası Yer Seçimi, Coğrafi Bilgi Sistemleri, Çok Kriterli Karar Analizi, Sıkıştırılmış Kil Tabakası, Jeomembran Yalıtım Tabakası, Kompozit Jeomembran/Sıkıştırılmış Kil Yalıtım Tabakası, Çift Tabakalı Yalıtım Sistemi

ACKNOWLEDGEMENTS

It is a pleasure to thank those who made this thesis possible. First of all I would like to express my sincere appreciation to Prof. Dr. Haluk Akgün for his guidance, support and patience. It was a highly rewarding experience for me to work with him.

I would like to thank all my committee members being Prof. Dr. Asuman G. Türkmenoğlu, Prof. Dr. Erdal Çokça, Asst. Prof. Dr. Nejan Huvaj Sarıhan, and Inst. Dr. Zeynep Gülerce for their kind and constructive criticisms.

I am indebted to many of my colleagues and friends for supporting me. First I would like to thank Selim Cambazoğlu for his technical and moral support during this thesis and for accompanying me in my field trips. I also would like to thank Arif Mert Eker for generously sharing his expertise and knowledge. I would like to thank Kıvanç Okalp for his significant contributions to this study.

I would like to thank Tanju Ökten and Selin Ökten from Form Jeoteknik for making the laboratory experiments possible and for sharing their expertise.

I would like to thank my family, Erdal Yal, Merih Yal, Ural Yal, and Lauren Yal for their continuous support and love.

I would like to thank Erkan Önder for his support. He helped me sustain my courage and aspiration throughout this thesis.

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CHAPTER ONE

INTRODUCTION

1.1. Purpose and Scope

Landfills are engineering structures for safe deposition of solid waste in long-term that requires a rigorous site selection and construction process. The safe deposition of solid waste residues are assured by regulatory laws varying between countries including but not limited to location restrictions, operating criteria, design criteria, closure and post closure care and financial assurance criteria. In designing a landfill site uttermost care should be given in order to minimize its impact on the environment. This can first be achieved by recycling. Minimizing the waste amount to be deposited into the landfill site increases the lifespan of the landfill site and decreases the amount of harmful non biodegradable waste deposited. Solid wastes that remain after processing the materials at a recovery facility are called the solid waste residues. This remaining waste is deposited into the landfill sites.

Ankara is the capital and second largest city of Turkey with an ever-growing population. The Mamak open dump landfill site is the first waste deposition facility of Ankara which possesses serious environmental risks. These risks arise initially from improper site selection, namely, serious slope stability problems caused from situating the landfill on a steep slope (i.e., the accumulated waste pile occasionally reaches a height of 10-15 m along the steep slope and poses slope stability problems). The second risk arises from the lack of a proper containment system where the leachate water is being deposited to a close-by valley, creating serious environmental risks to the adjacent residential areas. The third risk arises due to operational problems, namely improper information on the amount and type of waste deposited, compacting the old wastes that lies below the recently deposited wastes and uncontrolled biodegradation that increases the possibility of methane explosions

(Güngör et al., 2000). In order to meet the needs of the city an alternative landfill site was selected in Sincan-Çadırtepe with an estimated total waste capacity of 57,523,125 m^3 and a life span of approximately 20 years (Chamber of Enironmental Engineers , 2009). However, this landfill site not only has a limited capacity, but it also has both operational and infrastructural problems. The primary problem of the Sincan-Çadırtepe landfill site is that after the construction of the bottom liner system the site has been left idle for 4 years causing the clay liner to lose its moisture, which in turn led to the formation of secondary fissures and cracks thus causing the liner to lose its integrity and its impermeability function in general. Since municipal and hospital wastes have been periodically deposited to the landfill site following the idle period, any lining system remediation process would require that all previously deposited waste be relocated somewhere else during the period of remediation, which would not be deemed environmentally or economically feasible. Another problem is that the landfill is not used on a regular basis because of the high transportation costs facing the municipalities that attempt to dispose their municipal wastes to the Sincan Çadırtepe landfill site. The municipal wastes of close by counties along with hospital wastes are accepted by the Çadırtepe landfill site; however these wastes are not properly disposed of. The site lacks the daily spread of the soil cover material and sterile deposition of the hospital wastes. In advance of the regular usage of a landfill site, technical and administrative discrepancies should be resolved, including the construction of interim waste deposition sites along with transfer stations and a trailer system. Even if the discrepancies of the Çadırtepe landfill site were to be resolved, considering the high population growth rate in the area (21.4% annually, partially due to high immigration rates), it is inevitable that additional landfills will be required in the area in the near future in order to sustain the needs of the city.

From a city planning point of view, the early planning of the landfill site location is crucial in order to prevent residential and commercial development at those sites that are suitable for landfill siting since many factors need to be taken into consideration in finding a suitable site, the most important one being vacant property that is at a reasonably distant to residential and commercial development. In order to assure a suitable landfill site with sufficient capacity for the city of Ankara in the long-term, landfill site selection is conducted in the scope of this study since as mentioned above an additional landfill will be needed for Ankara in the near future.

Two counties, Sincan and Gölbaşı were selected to conduct the landfill site selection procedure, after taking population growth trend, wind direction, geology, transportation costs and expropriation into consideration. Ankara has a development trend towards west–northwest. Since Sincan and Etimesgut have the highest rate of population growth followed by Yenimahalle and Gölbaşı in the metropolitan area (Table 1.1), landfill site selection was initiated in the area covered by the Sincan–Etimesgut–Polatlı–Ayaş and Gölbaşı counties.

Ankara and its vicinity especially during the summer months, receives winds directed from south-southeast which causes unwanted odors and carry hazardous waste particles to the city from the Mamak landfill site. The landfill site needs to be selected towards the west-southwest-northwest of the city center in order to prevent bad odors from the waste spreading to the city. Since Sincan and Gölbaşı are located towards the northwest and southwest of Ankara, respectively, they are determined to be good candidates for landfill sites when wind directions are considered as well.

Another factor that makes the Gölbaşı and Sincan sites advantageous for landfill site selection is the widespread surface exposure of the “Ankara Clay” with low permeability at these sites. Greywacke and andesite which are widely observed in the Ankara region may be regarded as impermeable but are pervious in reality when compared to “Ankara Clay” due their secondary impermeable zones caused by the presence of discontinuities.

The expropriation costs for Gölbaşı and Sincan including many government owned lands are lower, compared to the other municipalities of Ankara.

Table 1.1. Population Growth Rates of Municipalities of Ankara per thousand 1990-2000 (2023 Ankara Metropolitan Municipality, 2006).

Municipality	Growth Rate (per thousand)
ÇANKAYA	7.42
ALTINDAĞ	3.75
YENİMAHALLE	45.38
KEÇİÖREN	22.77
MAMAK	4.81
ETİMESGUT	88.33
SİNCAN	105.26
GÖLBAŞI	36.34

The transportation costs of waste from Gölbaşı to the the Mamak landfill site has been a problem due to the fairly long distance between Gölbaşı and Mamak. A separate landfill site for both Gölbaşı and Sincan is also necessary in order to prevent illegal dumping due to high waste transportation costs. Figure 1.1 shows a view of illegal dumping in Sincan.

Figure 1. 1. View of illegal waste dumping in Sincan

In scope of this project, a landfill site that is located reasonably close to the settlements, with a convenient transportation access, underlain by an impermeable layer and having desirable hydrogeological conditions was searched.

Landfill site selection was conducted utilizing GIS and multi-criteria decision analysis. Several GIS layers were created and compiled in selecting a landfill site for municipal solid waste (MSW) disposal. These layers were geology, distance to faults, settlement, land use, drainage, slope, surface water, distance to highways, distance to rural roads, vegetation, environmental protection areas, suitability for agriculture and erosion susceptibility. These criteria were normalized and weighted using the Pairwise Comparison Method, Analytical Hierarchy Method and the most suitable landfill site was selected using "The technique for order preference by similarity to the ideal solution (TOPSIS)" method both for the Gölbaşı and Sincan sites.

After selecting a suitable site, in order to check whether the native clay was suitable to be used as a compacted clay liner, geotechnical analyses were performed on the clayey soil specimens collected from the selected sites. The plasticity index and the permeability values determined from the laboratory tests appeared to be in a range that is suitable to be used as the compacted clay liner. The HELP and POLLUTE models were employed in order to determine the leachate head and leakage amounts through assuming a 30 year life span for the landfill. Four different profiles from least conservative to most conservative were created. The first profile, from top to bottom consisted of a topsoil layer, a waste layer, and a geomembrane/compacted clay composite liner. A compacted clay liner was added to the cap below the topsoil for the second profile. The second profile, from top to bottom consisted of a topsoil layer, a compacted clay liner, a waste layer and a geomembrane/compacted clay composite liner. A lateral drainage layer in order to collect leachate was added below the waste layer for the third profile. The third profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner. The fourth profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane/compacted clay composite top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner. The fourth profile selected was the one with the least environmental impact (Figure 5.7).

1.2. General Information on Ankara

1.2.1. Population

Ankara after being selected as the capital of Turkey in 1923 has experienced a rapid population growth. Long term population estimates of the city of Ankara between 2008 and 2023 (Ankara Büyükşehir Belediyesi İmar ve Şehircilik Dairesi Başkanlığı, 2006) can be seen in Figure 1.2 where concurrent with the increasing population, the waste amount per capita is expected to increase. The continuing increase in the expected waste amount justifies the need for new landfill sites. The selected counties

Gölbaşı and Sincan, both being close to the city, have the highest rates of population growth in the metropolitan area (Ankara Metropolitan Municipality, 1992).

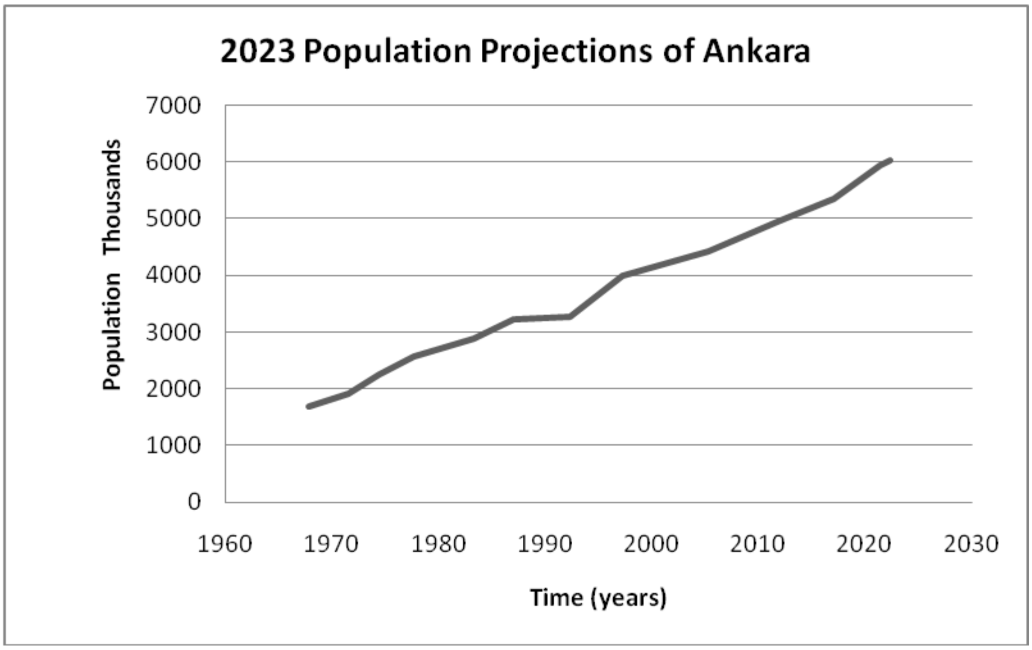

Figure 1. 2. Population Projection of Ankara until 2023

1.2.2. Hydrogeology

Ankara is located in the middle of the Hatip plain that extends from Hasanoğlu in the east, to Sincan in the west. The main river in the area is the Ankara creek. Ankara creek originates from the plains at the west of Sincan, and discharges to Sakarya river. Formations, containing groundwater are Permo-Triassic limestones, Jurasic-Cretecaous limestones, Pliocene lake sediments and alluvial deposits. Among these water bearing formations Permo-Triassic limestones, usually discharge their water through their cracks and fractures. Also the Jurasic-Cretecaous limestones, only contain water at the junctions of their joint systems. Furthermore, since the Pliocene lake sediments are composed mostly of clay, they are not capable of retaining water as well. The only formation that can be regarded as an aquifer is the alluvial deposits (State Hydraulic Works, 1975).

1.2.3. Weather

The study area is located in central Anatolia. The long term mean, highest mean and lowest mean annual temperatures are shown in Table 1.2. The long term mean annual rainfall in Ankara is determined to be 404.5 mm (Turkish State Meteorological Service, 2010).

Table 1. 1. Mean Temperature Values of Ankara from 1975 to 2010 (°C) (Turkish State Meteorological Service, 2010).

ANKARA	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean Temperature (°C)	0.4	1.9	6	11	15.9	19.9	23.4	22.9	18.5	13	6.6	2.3
Highest Mean Temperature (°C)	4.3	6.5	11.6	17	22	26.3	30	29.8	25.9	20	12.3	6.1
Lowest Mean Temperature (°C)	2.9	2.2	0.8	5.7	9.6	12.9	16	15.8	11.7	7.3	2.2	0.8
Mean Precipitation (kg/m^2)	40	32.1	36.1	51.7	49.4	32.8	14.4	12.2	17.8	30	37.6	41.1

1.2.4. Wind

The dominant wind direction varies depending on the local topography. The dominant wind direction in Ankara (city center), Esenboğa, Çubuk, Ayaş and Yenimahalle is northeast, in Haymana (İkizce), Sincan, Dikmen and Nallıhan is west, in Polatlı and Şereflikoçhisar is north, in Etimesgut and Elmadağ is southwest, in Kızılcahamam is southeast, and in Beypazarı is north-northeast. Strong winds are observed during March and April (Turkish State Meteorological Service, 2010).

1.2.5. Vegetation Cover

Generally two different types of vegetation covers are observed in Ankara, namely, step and forest, where step is the most common type. Step type of vegetation can be found on plateaus and valleys, where there is only sparse precipitation. Willow, elaegnus, and poplar trees can be seen inside the step along the river beds. Due to the discrete mountains that rise on the plateaus in the vicinity of Ankara and the mountain range that lies in the north of Ankara, denser vegetation (forest) can be observed.

1.3. Previous Studies

Many researches employed GIS-based MCDA for site selection over the years. The most common MCDA methods are Simple Additive Weighting (SAW) (e.g., Chou et al., 2009), Weighted Product Method (WPM); Analytical Hierarchy Process (AHP) (e.g., Şener, 2005; Wang et al., 2008; Wong and Li, 2007; Moeinaddini, 2010), Preference ranking organization method for enrichment evaluation (PROMETHEEE, e.g., Briggs et al., 1990; Khalil et al., 2004), The Elimination and Choice Translating Reality (ELECTRE, e.g., Norese, 2006), The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS, e.g., Huang and Yoon, 1981; Sadi-Nezhad and Damghani, 2009; Ekmekçioğlu et al.,2010; Pohekar and Ramachandran, 2003). Several criteria need to be selected for the MCDA analysis with regards to the goal of the analysis and in many cases restricted by the availability of the data. Şener, 2005, performed landfill site selection for Ankara, using a total of 16 criteria, by employing the AHP and SAW methods. In the context of this study, landfill site selection was performed in an area that is located towards the mid-west of Ankara including the Sincan, Yenimahalle, and Etimegut municipalities.

The geology of Ankara has been studied by Chaput (1931); Erol (1956); Akyürek et al. (1980, 1982 and 1984). The major rock types observed in the Ankara region are greywacke, andesite, and Upper Miocene-Pliocene clay bearing deposits named as “Ankara Clay” first by Birand (1963) and later by Çokça (2000). The geology and geotechnical characteristics of Ankara Clay with a thickness that reaches up to 200 m at some places has been studied by many researchers (e.g., Kasapoğlu, 1982; Koçyiğit and Türkmenoğlu, 1991; Sezer, 1998). Met (1999), Met et al. (2005), Met and Akgün (2005) and Sezer (1998) have investigated the suitability of “Ankara Clay” as a compacted clay liner (CCL) material. Sezer (1998) has studied the mineralogical and sorption capacity characteristics of Ankara Clay. Met (1999) has investigated the engineering geological properties and the compaction permeability characteristics of clayey soil samples collected from the Ankara region to study the suitability of Ankara Clay as a compacted landfill liner material. Met (1999) has also studied the effect of different landfill liner profiles on the leachate head and leakage by using the HELP model.

CHAPTER TWO

REGIONAL GEOLOGY

2.1. Stratigraphy

The geological units observed in the Ankara region are sedimentary, metamorphic and igneous rocks, with ages ranging from Paleozoic to Quaternary. The Ankara basin is underlain by Triassic rocks in the south, Jurassic-Cretaceous carbonates in the west, Upper Miocene-Lower Pliocene volcanics and fluvial-lacustrine clastic rocks in the north. The Triassic basement consists of dark brown greywacke, black shale, diverse sized carbonate blocks (Koçyiğit and Türkmenoğlu 1991). The basin fill of the Ankara region is called Yalıncak formation. (Koçyiğit, 1991). The generalized cross-section of Ankara Region can be seen on Figure 2.1. The Yalıncak formation consists of three main lithofacies from bottom to top, namely, debris flow conglomerate, braid plain conglomerate and sandstone and clay bearing finer clastics of floodplain origin. The debris flow conglomerates are composed of sub-rounded to angular pebbles of different origin, age and facies. These pebbles are mostly greywacke, quartzite, marble, schist, crinoidal limestone, volcanics and sandstone. This layer is overlain conformably by a yellow-reddish wedge to trough cross-bedded conglomerate and sandstone layer. The finer clastics of the floodplain which is the uppermost layer of the Yalıncak formation consist of cross-bedded conglomerates and red shale, siltstone and clay bearing mudstone alterations, from bottom to top. The uppermost finer reddish brown finer clastics are referred to in geotechnical studies as preconsolidated, stiff and fissured clay known as “Ankara Clay” (Ordemir et al., 1965).

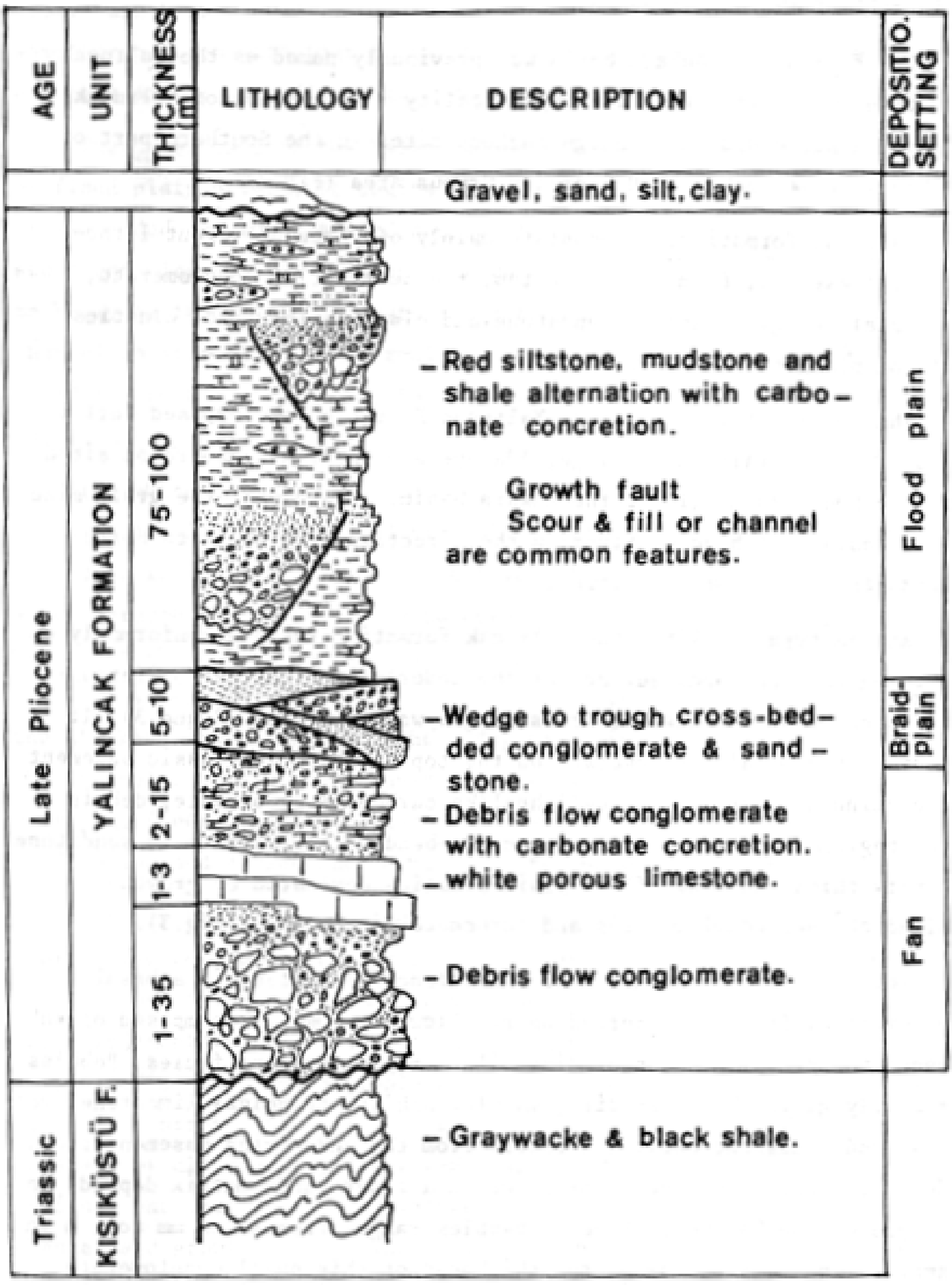

Figure 2. 1. The generalized stratigraphic column of the Ankara region (Koçyiğit and Türkmenoğlu, 1991)

Ankara Clay is composed of clayey, sandy and gravely levels in variable thicknesses, exceeding 200 m (Erol, 1973). At shallow depths it locally contains very thin lime levels, lime nodules, lenses and concretions within clayey levels with no lateral continuity. Sezer (1998) describes Ankara Clay as stiff, fissured, highly plastic, preconsolidated material which includes carbonate concentrations in the upper horizons. The source of inherited clay and non-clay mineral assemblages of the red clastics of Ankara Clay is determined to be the greywacke and limestone based on the fact that the composition of greywacke and limestone bedrocks is found to be similar to the gravel and sand sized particles observed in Ankara Clay (Met et al., 2005). Andesitic rock fragments and their weathering products in the sand fraction of the brownish clay from the Ankara basin clearly indicates that this clay was derived from andesitic source areas surrounding the city from its north and east (Aras, 1991). The preconsolidation of these clays are due to overburden caused by erosion, a consequent depression in the groundwater level, followed by sedimentation and finally a desiccation (Ordemir et al., 1977).

2.2. Geology of the site

The 1/100,000 scale geological maps were gathered and digitized from the geological maps prepared by the General Directorate of Mineral Research and Exploration. Figures 2.2 and 2.3 present 100,000 scale geological maps of the .Sincan and Gölbaşı regions, respectively. The general descriptions of the formations that outcrop out in the area of investigation are given below (General Directorate of Mineral Research and Exploration, 1997).

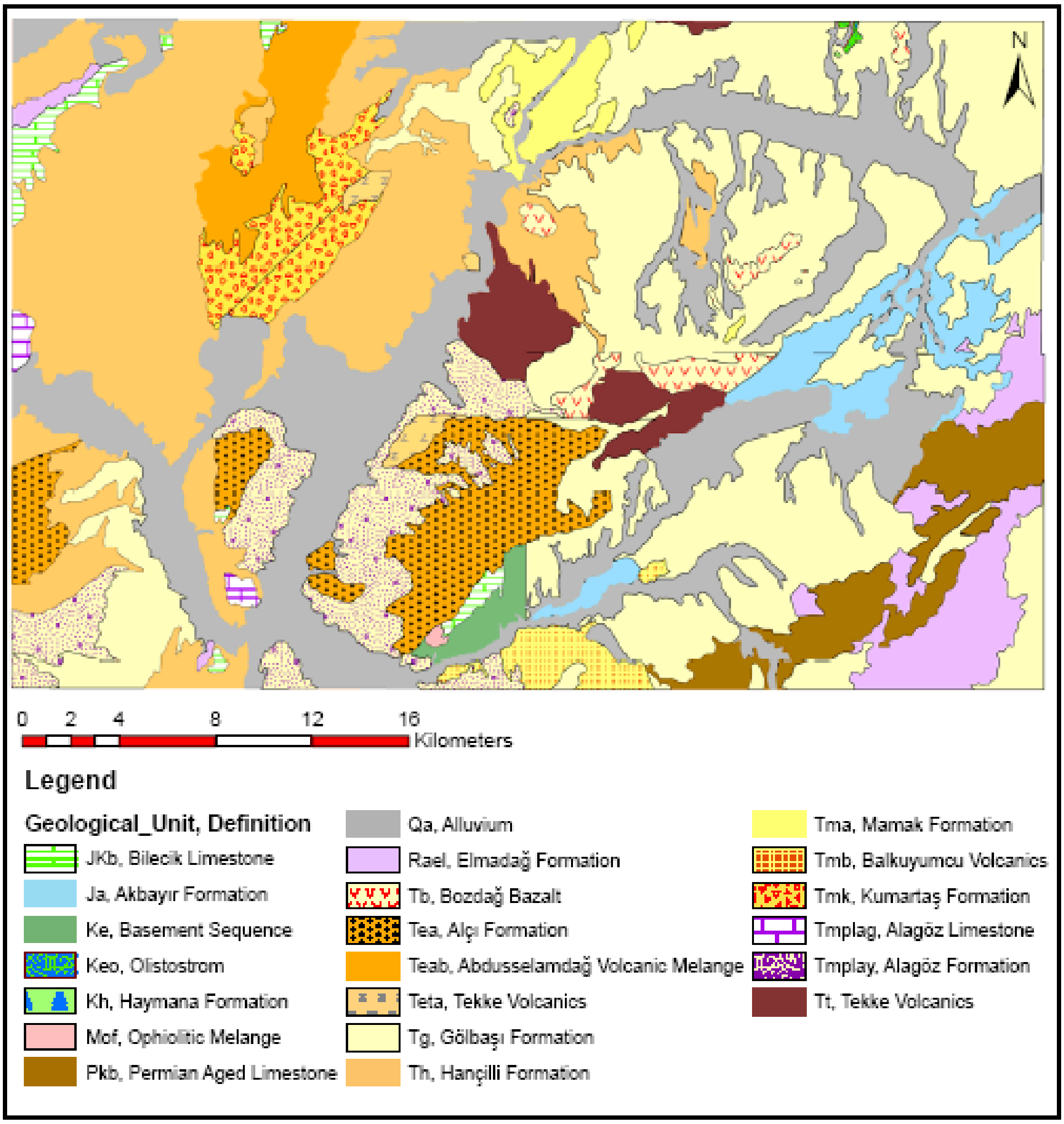

Figure 2.2. 1/100,000 Scale Geological Map of Sincan Site (General Directorate of Mineral Research and Exploration, 1997).

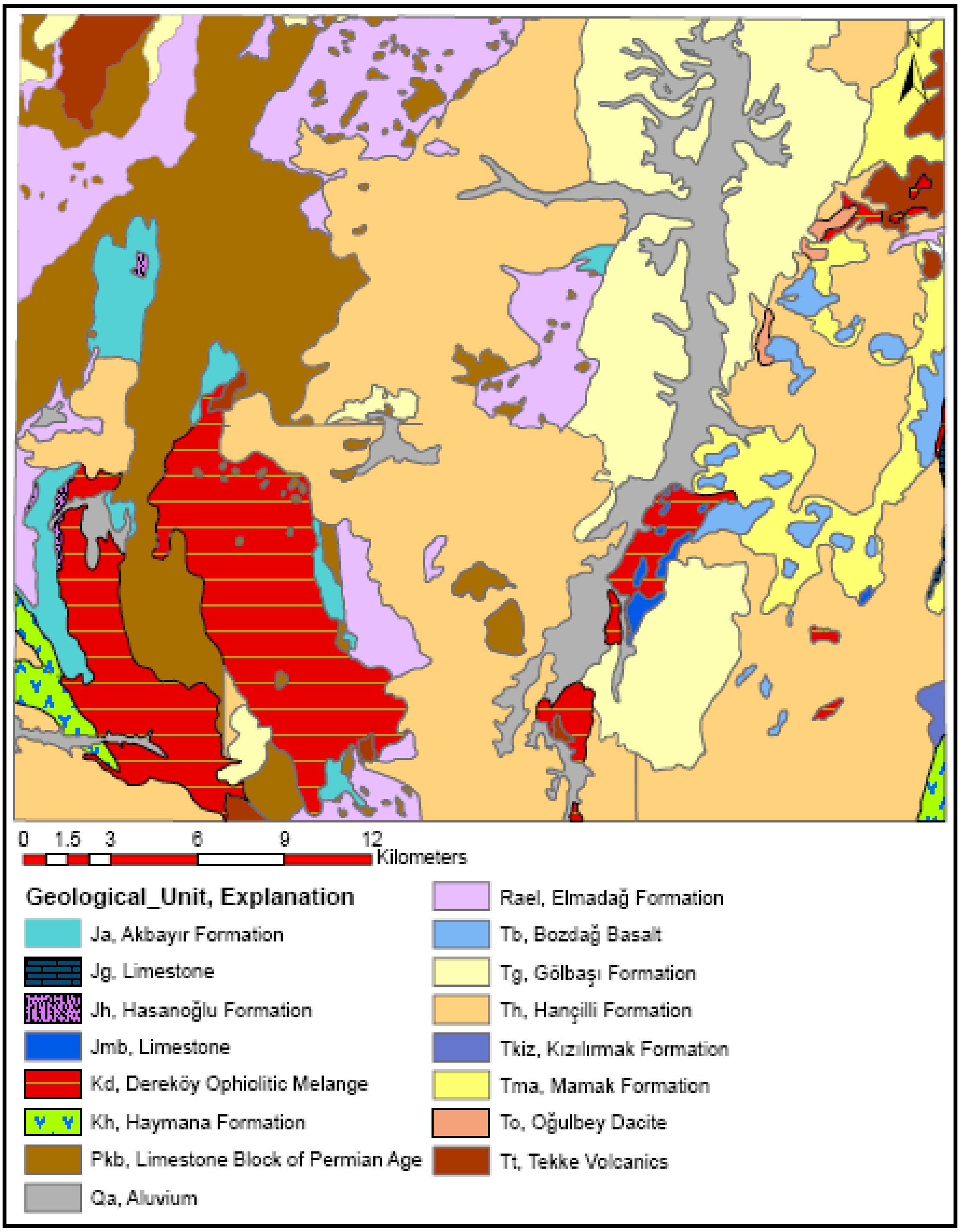

Figure 2.3. 1/100,000 Scale Geological Map of Gölbaşı Site (General Directorate of Mineral Research and Exploration, 1997).

2.3.1. Gölbaşı Formation (Tg)

Gölbaşı formation, first defined by Akyürek et al. (1982, 1984) is made up of gray, grizzly, red colored conglomerate, sandstone, mudstone with differing height and origin. The formation is horizontally bedded at places, but typical bedding cannot be observed. Conglomerates can be found between sandstones and mudstones, formed with the debris flows. The grains and the aggregates of the sandstone and conglomerate are mainly basalt where various limestone, diabase, metamorphic rock fragments along with radiolarite, serpentinite and gabbro are also present. The matrix is comprised of calcite and clay. Weathering is observed at most parts of the Gölbaşı formation. It overlies the Bozdağ Basalts and older formations unconformably. The age of the formation is widely accepted in the literature as Pliocene. Gölbaşı formation is composed of alluvial fan and lake deposits. It is correlated by "the talus unit" (Çalgın et al., 1973) and the Büyükyakalı unit (Akyürek et al., 1980).

2.3.2. Ortaköy Formation (Trao)

Ortaköy formation was first defined by Akyürek et al. (1982, 1984). The formation is composed of basalt (that has partially preserved its initial condition and partially exposed to low order metamorphism), diabase type of rocks and tuffs, sandstone with volcanics, and aglomerates. The limestones that are common in Ortakoy formation are a member of Imrahor, the rare radiolaritine are Radiolorite member and the diabase are referred as diabase dyke. Splits appear with apparent orientation in consistency with the local folding. The Permian aged limestones are observed in blocks in varying sizes. Ortaköy formation is composed of the products of the volcanism that occurred during the deposition of Elmadağ formation and Keçikaya formation. Ortaköy formation is laterally transitional with Elmadağ and Keçikaya formations at lower elevations. The lower boudary of the formation is not apparent. It is covered by the upper elevations of the Keçikaya formation.

Ortaköy formation is formed during the volcanism, started with the deposition of Elmadağ formation and continued until the deposition of the Keçikaya formation. Due to the faulting that occurred during the deposition of Elmadağ formation, Permian aged limestones can be observed in the Gölbaşı formation. Ortaköy formation is the lava portion of the oceanic ridge formed during Mid-Upper Triassic.

2.3.3. Keçikaya Formation (Trak)

Keçikaya formation is first defined by Akyürek et al. (1982, 1984). The formation is composed of gray and white limestones and sandy limestones and it is dolomitic and crystalline in character from place to place. Due to the fact that the formation is medium to thick layered with many joints and cracks and is easily erodible, layering cannot be observed everywhere in the formation. Keçikaya formation is translational with the Ortaköy formation and Elmadağ formation at lower elevations. Limestone layers exist at the transitional zones. The sandstone and gravel levels of the Hasanoğlu formation unconformably overlies Keçikaya formation. The age of the Keçikaya formation is determined as Mid-Upper Triassic.

Keçikaya formation is formed by the shoaling and simmering occurred after the deposition of flysch type rocks. At the transitional zones sandy limestone, sandstone, siltstone intercalations and limestones can be observed.

2.3.4. Permo-Carboniferaous Aged Limestone (Pkb)

These are gray, white colored, partially crystallized, mid-thin layered limestones. At the outcrops of the limestone Carboniferous and Permian aged fossils can be found.

2.3.5. Hasanoğlu Formation (Jh)

Hasanoğlu formation is first defined by Akyürek et al. (1982). Hasanoğlu formation is usually observed in small scale outcrops below the Akbayır formation. Hasanoğlu formation starts with gravels with poor gradation at the bottom. It continues towards the top with a sandstone, mudstone, and sandy limestone intercalation. At the top, it constitutes yellow, black, dark green and red colored fragments and white colored limestones. Also, lenses of sandy limestone are observed in the formation.

At the bottom, the gravels of the Hasanoğlu formation overlie the Elmadağ formation unconformably while at the top, the Hasanoğlu formation is transient with the Akbayır formation. At the transitional zone, red colored marl and clayey limestones are present. Lateral wedging is observed on the rocks forming the Hasanoğlu formation.

The gravels with poor gradation are deposited at the alluvial fan environment. These gravels are comprised of angular metasandstone, circular granite gravels and blocks. Oceanic transgressive piling that overlies the gravels deposited as alluvial fan starts with sandstone at the coast and gravel in the canals.

2.3.6.Elmadağ Formation (Trael)

The formation lies with a southwest-northeast trend. Elmadağ formation from bottom to top with decreasing metamorphism is composed of conglomerate, sandstone, mudstone, sandy limestone, agglomerate, volcanite and tuff (Akyürek et al., 1982, 1984). Carboniferous and Permian aged limestone blocks can be found inside the formation. Elmadağ formation is usually yellow, gray and brown in color and is transitional with the Emir formation at the bottom and with Keçikaya formation at the top. The age of Elmadağ formation is determined as Lower, Mid-Upper Triassic. The formation is composed of rock types deposited as sandstone and shale intercalations and gravelly canal deposits. The volcanism and its products, developed during the deposition of this formation, participated in its deposition. As the deposition and volcanism proceeded, Carboniferous and Permian aged limestone with blocks varying in size participated in the deposition of the Elmadağ formation. Elmadağ formation can be regarded to be equivalent to the Karakaya formation.

2.3.7. Akbayır Formation (Ja)

Akbayır formation is represented by thin to medium bedded biometric limestones (Akyürek et al., 1982). White, beige, and red colored, the Akbayır formation is composed of clayey limestone that includes chert nodules and bands. The lower levels of the Akbayır formation starts with yellow, brown-green colored marl, siltstone and clayey limestone intercalations. These clayey and silty levels are overlain by the biometric limestone of the Akbayir formation. Tectonic deformations (cracks and folds) and primary sedimentary structures (slamps, etc.) can be observed in this limestone.

2.3.8. Eldivan Ophiolitic Mélange (JKe)

Eldivan ophiolitic mélange was first defined by Akyürek et al. (1980, 1982). Being an oceanic ridge material, the Eldivan ophiolitic mélange is one of the ophiolitic mélanges observed in Central Anatolia that preserved its inner succession. Eldivan ophiolitic mélange rock formations are distinguished as map units. These are ultramafics, gabro-diabase, volcanite, limestone with chert.

2.3.9. Kumartaş Formation (Tmk)

Kumartaş formation is first defined by Akyürek et al. (1980). It is mainly composed of conglomerate, sandstone, siltstone intercalations, and marginally of marl, tuff and silty limestone. The poorly graded conglomerates are red and gray in color. Grading and cross bedding can be observed in some sections of the conglomerates and sandstones. Kumartaş formation lies unconformably above formations that are older. At the top it is laterally transitional with Hançilli formation and Tekke volcanites. It is of Miocene-Pliocene age.

2.3.10. Hançilli Formation (Tmh)

Hançilli formation is first defined by Akyürek et al. (1980). The formation is composed of limestone, marl, siltstone, sandstone, conglomerate, and tuff intercalations. Andesite sills can also be observed. Clayey limestone and marl in white, yellowish white color are intercalated with siltstone-sandstone. Hançilli formation is laterally transitional with Kumartaş formation and Mamak formation at the bottom. It is overlain by the Mamak and Gölbaşı formations at the top. The Hançilli formation is determined to be Serravalien-Tortonien in age.

2.3.11. Tekke Volcanites (Teta)

The formation is first defined by Akyürek et al. (1982, 1984). The formation is composed of andesite, basalt, tuff, agglomerate and dacite. Andesites are red, pink, gray and black in color. Flow traces can be observed in the andesites. Fine grained tuffs in white and gray in color can be observed in layers between andesites and agglomerates. Tekke volcanites are usually intercalated with the Mamak formation. The formation is accepted to be Upper Miocene in age.

2.3.12. Mamak Formation (Tma)

Mamak formation is observed where volcanism is common. It is composed of lava with agglomerate, tuff, andesite and basalt. Distinct bedding can be observed at places. Mamak formation is intercalated with the Kumartaş formation. It is laterally transitional with the Tekke volcanites and the Hançilli formation. Mamak formation is accepted to be the same age with the formations that it is intercalated with, being Upper Miocene.

2.3.13. Bozdağ Basalt (Tb)

The formation is first defined by Akyürek et al. (1982, 1984). Bozdağ basalt, dark black in color, is intact and solid. The air voids present in the formation are filled with calcite. Bozdağ basalt can be observed above Miocene aged volcanics and sedimentary rocks. The age of the formation is determined to be Pliocene since it is located above the Miocene aged formations.

2.3.14. Alagöz Formation (TmPla)

The formation is composed of, dark red, brown, beige, yellow and gray colored sandstone, marl and gravel. The gravels with varying origins are not well graded and they are fairly circular. The matrix is composed of clay and carbonates. The age of the formation is determined to be Upper Miocene-Pliocene.

2.3.15. Alcı Formation (Tea)

The formation is first defined by Koçyiğit and Lünel (1987). The formation is composed of fore-arc basin deposits. Alci formation lies above the Kapıkaya limestones conformably however angular unconformity is observed at places. The formation involves carbonate fragments, gravelly sandstone, a shale sequence and contemporaneous volcanism products.

CHAPTER THREE

GEOGRAPHIC INFORMATION SYSTEMS AND MULTI-CRITERIA DECISION ANALYSIS

3.1. GIS and MCDA Methodology

Geographic Information Systems (GIS) is proven to be a useful tool in site selection, thus many researchers have employed GIS in landfill site selection over the years. In constructing the GIS model for landfill site selection, a number of evaluation criteria are selected which are restricted with the availability of the data. The main considerations given in selecting the set of the attributes to be used in the study are that each attribute should be

- Comprehensible,
- Measurable,
- Complete-cover all aspects of the problem,
- Operational-can be used meaningfully in the analysis,
- Decomposable-can be broken into parts to simplify the process,
- Non- redundant-avoid problems of double counting, and
- Minimal-possess minimum number of attributes.

Each attribute is represented by a criterion map. A criterion map displays the spatial distribution of an attribute that measures the degree to which its associated objective is achieved (Malczewski, 1999). These maps entail the information that will be advisory for proper landfill site selection.

3.1.1. Standardization

In order for the attributes to be defined by a variety of measurement scales, in preparation for the multi-criteria decision analysis, each attribute must be transformed into a comparable scale. The map layers employed in this study are deterministic maps where a single value is assigned to each pixel. There are two main approaches in scale transformation, namely the linear-scale transformation and the value/utility function approach. The value/utility function approach relates attribute to a scale by a function and is appropriate for decision making under uncertainty. Since uncertainty is not an issue for this study, linear scale transformation has been employed in standardizing the layers.

3.1.2. Linear Scale Transformation

The two common procedures in linear scale transformation are the maximum score and score range procedures. Detailed information on these procedures are presented in the following paragraphs.

Maximum Score Procedure: Each raw score is divided by the maximum value for a criterion by employing Eqs. (1.1) and (1.2):

$$x'_{ij} = \frac{x_{ij}}{x_j^{max}} \tag{1.1}$$

$$x'_{ij} = 1 - \frac{x_{ij}}{x_j^{max}} \tag{1.2}$$

Where x'_{ij} is the standardized score for the ith object and the jth attribute, x_{ij} is the raw score, and x_j^{max} is the maximum score for the jth alternative. Higher score values denotes more attractive criterion values. Eq. (1.1) is the benefit criterion where the criterion is to be maximized. Eq. (1.2), on the other hand is the cost criterion where the criterion is to be minimized meaning the lower the score, the better the performance. This method that allows linear transformation of the data has a shortcoming in the interpretation of the least attractive score due to the fact that the lowest standardized score does not necessarily equal zero.

In standardizing the attributes score range procedure is employed.

$$x'_{ij} = \frac{x_{ij} - x_j^{min}}{x_j^{max} - x_j^{min}} \tag{1.3}$$

$$x'_{ij} = \frac{x_j^{max} - x_{ij}}{x_j^{max} - x_j^{min}} \tag{1.4}$$

Where x_j^{min} is the minimum score for the jth attribute, $x_j^{max} - x_j^{min}$ is the range of a given criterion, and the remaining terms are as defined previously. Here Eqs. (1.3) and (1.4) are benefit and cost criterion respectively. Score measures ranges from 0 to 1, 1 being the most attractive and 0 being the least attractive score (Malczewski, 1999).

3.1.3. Criterion Weighting

There are several methods in the literature for criterion weighting including rating, ranking, pairwise comparison and trade-off analyses. The comparisons between these methods are shown in Table 3.1 (Malczewski, 1999). In the ranking method, each criterion is ranked in the order that is determined by the decision maker and these rankings are used to generate numerical weights using several procedures such as rank-sum, rank reciprocal, and rank exponent methods (Stillwell et al. 1981). This method fails to produce trustable results with large number of criteria and it lacks a theoretical foundation (Voogd, 1983).

In the rating method, a scale such as 0 – 100 can be used to assign weights to each criterion. This method is criticized by Malchewski, 1999, for the lack of theoretical foundation since the meaning of the weights assigned to each criterion could be difficult to justify.

In the trade-off method, the decision maker assesses trade-offs between pairs of alternatives, in other words, the decision maker determines if one alternative is preferred over the other or indifferent between the two alternatives. The weakness of this method is that it is highly dependent on the judgment of the decision maker.

Table 3. 1. A comparison between the criteria weighting methods of Kleindorfer et al. (1984), Schoemaker et al. (1982) and Pitz et al. (1984) as quoted by Malczewski (1999).

Feature	Ranking	Rating	Pairwise Comparison	Trade-off Analysis
Number of Judgments	n	n	n (n-1)/2	< n
Response Scale	Ordinal	Interval	Ratio	Interval
Hierarchical	Possible	Possible	Yes	Yes
Underlying Theory	None	None	Statistical/heuristic	Axiomatic/deductive
Ease of use	Very easy	Very Easy	Easy	Difficult
Trustworthiness	Low	High	High	Medium
Precision	Approximations	Not precise	Quite Precise	Quite Precise
Software Availability	Spreadsheets	Spreadsheets	EXPERT CHOICE (EC)	LOGICAL DECISIONS (LD)
Use in a GIS Environment	Weights can be imported from a spreadsheet	Weights can be imported from a spreadsheet	Component of IDRISI	Weights can be imported from LD

The Pairwise Comparison Method is implemented in this study due to its relatively high precision and trustworthiness. The Pairwise Comparison (paired comparison) Method allows to determine the relative importance of an entity by comparing all entities in pairs. This method is developed by Saaty (1980) as a part of Analytic Hierarchy Process (AHP). The process consists of three major steps being, development of the pairwise comparison matrix, criterion weights computation, and the consistency ratio estimation.

Development of a pairwise comparison matrix requires a judgment phase where a scale of 1-9 is used to express judgments in making paired comparisons; 1 being equal importance and 9 being extreme importance (Saaty, 1980).

In order to construct the pairwise comparison matrix, the criteria are inserted to the left hand side and on top of the matrix and the values on the matrix represents the relative importance of each criteria among each other. If the criterion on the left is more important than the criterion on the top of the matrix a numerical value greater than one should be used, on the contrary the reciprocal of that value should be used in constructing the matrix.

Criterion weights are computed by pursuing the following 3 steps:

1. Summation of the values in each column of the pairwise comparison matrix,
2. Division of each element in the matrix by its column sum forming the normalized pairwise comparison matrix,
3. Computation of the average of the elements in each row of the normalized matrix.

The weight of each criterion is determined at the end of this process; however, the consistency of the comparisons still needs to be checked. For this purpose consistency ratio is estimated. Initially consistency vector is determined, by dividing the weighted sum vector by the criterion weights. Then two terms; lambda (λ) being the average value of the consistency vector and consistency index (CI) (Eq. 1.5) are determined.

$\lambda = n$ if the pair wise comparison matrix is a consistent matrix where n is the number of criterion thus $\lambda = n$ can be defined as measure of degree of inconsistency.

$$CI = \frac{\lambda - n}{n - 1} \tag{1.5}$$

Also consistency ratio (CR) can be determined in order to measure the level of consistency by dividing the consistency index (CI) by the random index (RI). RI depends on the number of elements being compared. $CR < 0.1$ indicates an acceptable level of consistency, where $CR \geq 0.1$ indicates inconsistency.

3.2. Multi Criteria Decision Making Methods

Multi-Criteria Decision Making is a decision making process, which includes multi-objective and multi-attribute decision-making. Multi-attribute decision problems have a predetermined limited number of alternatives that are to be evaluated against a set of attributes (Pohekar et al., 2004). Multi- attribute decision making (MADM) is a selection process, where multi-objective decision making (MODM) is a design process (Malczewski, 2006). In MODM alternatives are not predetermined but only defined in terms of relationships and set of constraints. There are several methods in the Multi Criteria Decision Analysis (MCDA) which can be categorized as priority based, outranking, distance based, ideal point and mixed methods. These also can be classified as deterministic, stochastic, and fuzzy methods.

In the scope of this thesis "The technique for order preference by similarity to ideal solution (TOPSIS)" was selected as the ideal point method. TOPSIS method is determined to be suitable for landfill site selection since it selects the alternative that is closest to the ideal solution and farthest from the negative ideal solution. By this way, a landfill site alternative that is closest to the best and farthest from the worst can be selected with regards to the defined criteria.

In ideal point methods, the separation in terms of metric distance from an ideal alternative, being the most desirable weighted standardized levels of each criterion, is measured. The ideal point decision rule is:

$$s_{1+} = \left[\sum w_j^p (v_{ij} - v_{+j})^p\right]^{\frac{1}{p}} \tag{1.6}$$

where s_{+j} is the separation of the i[th] alternative from the ideal point, x_{ij} is a weight assigned to the j[th] criterion, v_{ij} is the standardized criterion value of the *i*[th] alternative, v_{+j} is the ideal value for the j[th] criterion, and p is a power parameter ranging from 1 to .∞. Higher p values minimize the maximum separation from the ideal.

TOPSIS method is developed by Hwang et al. (1981). Subsequent to the standardization and weighting processes which are described previously, the TOPSIS method entitles the following steps as described by (Malczewski, 1999):

1. Determination of the maximum value for each weighted standardized map layer-ideal point,
2. Determination of the minimum value for each weighted standardized map layer-negative ideal point,
3. Calculation of the distance between the ideal point and each alternative,

$$s_{1+} = \left[\sum w_j^p (v_{ij} - v_{+j})^p\right]^{\frac{1}{p}}$$

4. Calculation of the distance between the negative ideal point and each alternative,

$$s_{1+} = \left[\sum w_j^p (v_{ij} - v_{-j})^p\right]^{\frac{1}{p}}$$

5. Calculation of the relative closeness to the ideal point (c_{i+}),

$$c_{i+} = \frac{s_{i-}}{s_{i+} + s_{i-}}$$

As c_{i+} approaches to 1 alternative is closer to the ideal.

The layers used in this study are described in Chapter 4.

CHAPTER FOUR

DECISION CRITERION AND LANDFILL SITE SELECTION

4.1. Geographic Information System (GIS) Layers

The criteria layers used in the analysis are suitability for agriculture, slope, distance to flow lines, erosion susceptibility, geology, roads, vegetated lands, land use, distance to settlement which are explained below in detail.

4.1.1. Suitability for Agriculture

The suitability for agriculture data map is gathered from the General Directorate of Rural Services (General Directorate of Rural Services, 2009). In this deterministic map, three distinct regions defining the current agricultural use and suitability for agriculture are present (Figure 4.1). Standardized suitability rank for landfill siting is assigned to each region (Table 4.1).

Table 4. 1. Standardized suitability rankings of suitability for agriculture for landfill siting (General Directorate of Rural Services, 2009).

Region No	Description	Rank
I	Cultivated lands suitable for agriculture	0
II	Cultivated lands not suitable for agriculture	0.5
III	Lands not cultivated and not suitable for agriculture	1
	No data	0

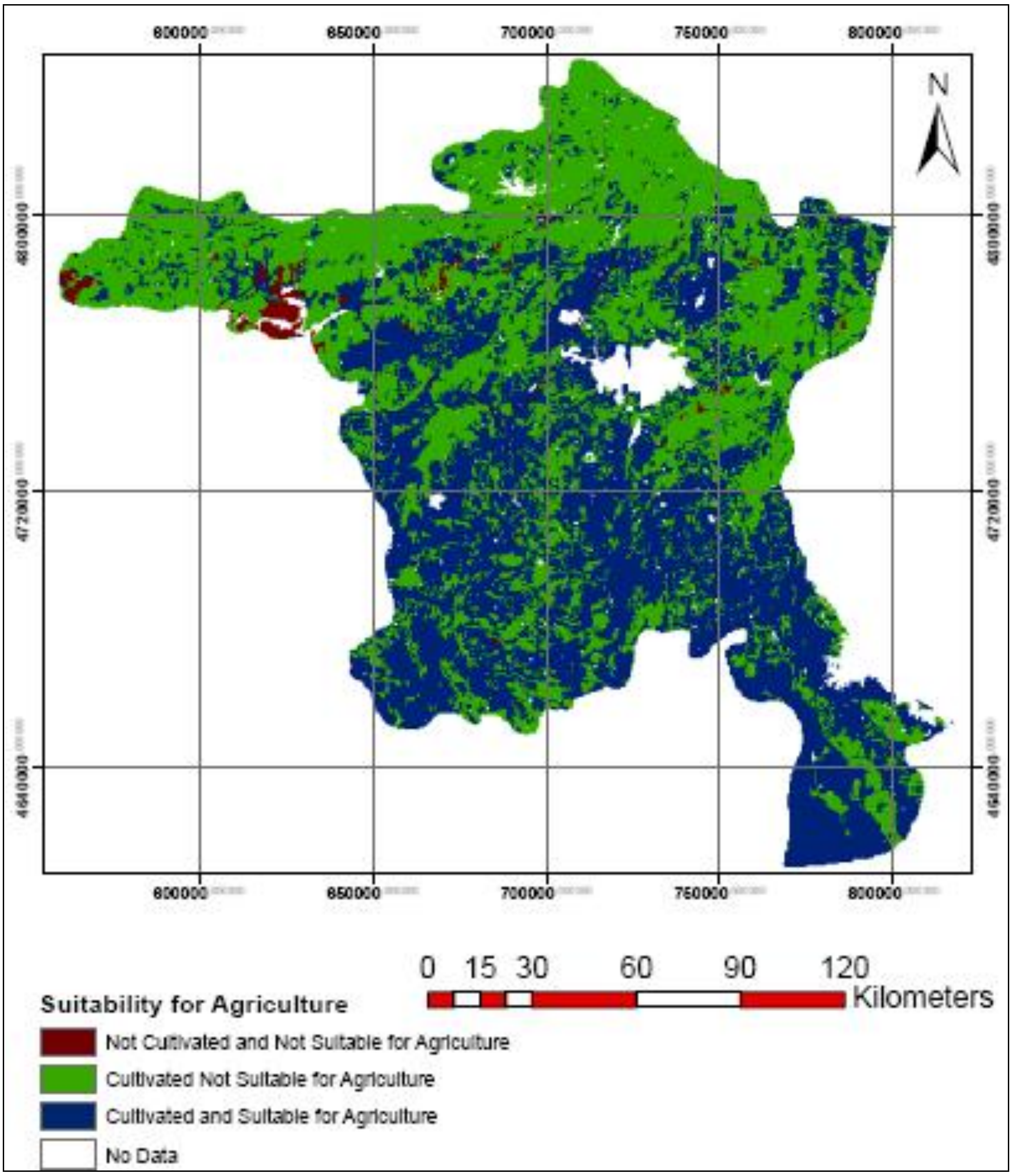

Figure 4.1. Map showing current agricultural use and suitability for agriculture. (General Directorate of Rural Services, 2009)

4.1.2. Digital Elevation Model (DEM)

The digital elevation model (DEM) of the area was gathered from the publicly available “Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Digital Elevation Model (ASTER GDEM)”. The ASTER GDEM covers land surfaces between 83°N and 83°S and is composed of 22,600 1°-by-1° tiles. The ASTER GDEM is in GeoTIFF with geographic lat/long coordinates and a 1 arc-second (30 m) grid of elevation postings. GDEM is referenced to the WGS84/EGM96 geoid. Estimated accuracies are 20 meters at 95% confidence for vertical data and 30 meters at 95 % confidence for horizontal data.

A DEM was created from a portion of the topographic contour map prepared by the Turkish General Command of Mapping. First, the topographical contours were digitized and a DEM is created by using the surface modeling tool offered in TNT Mips software. The minimum curvature method was employed in creating the DEM. Figure 4.2 (a) is the DEM created from the digitized contours and Figure 4.2 (b) is the ASTER GDEM for the same location. The DEMs are almost the same, with an approximately 5 m error, except for some noisy areas Figure 4.2 (a) due to missing contours that led to errors in modeling. The ASTER GDEM used for this study can be seen on Figure 4.3.

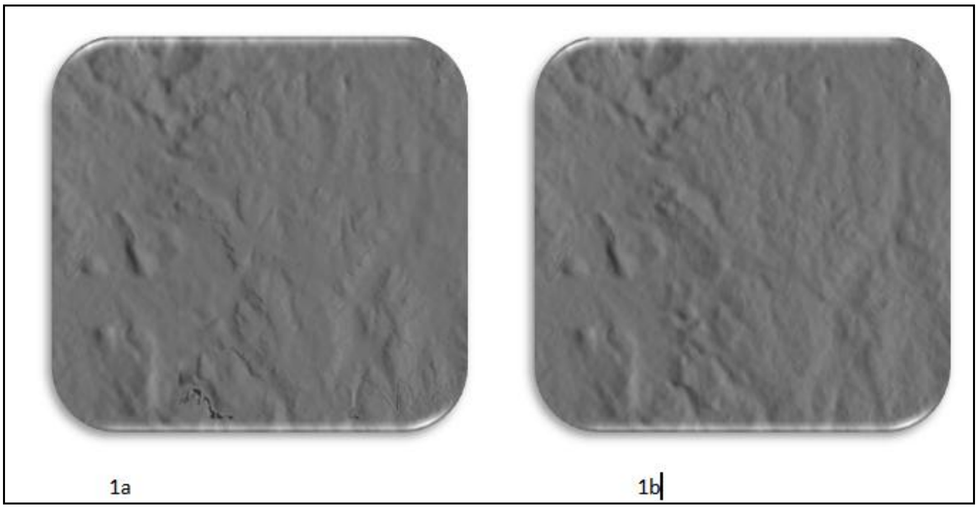

Figure 4.2. (a) the DEM created from the digitized contours (b) is the ASTER GDEM for the same location.

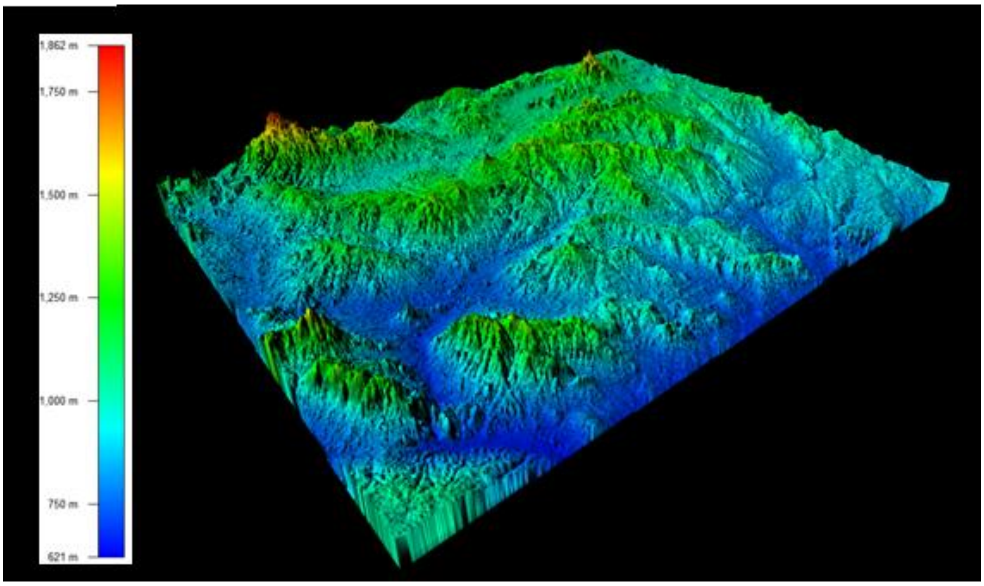

Figure 4.3. 3D view of the Digital Elevation Model (DEM).

The DEM is used to create drainage and slope layers of the project, where each process is described in the paragraphs below.

4.1.2.1. Drainage

Drainage analysis is performed utilizing TNT Mips software. In order to check the accuracy of the drainage analysis, the map gathered from The Turkish General Command of Mapping, including rivers (blue) is overlain by the flow lines (red) produced by the drainage analysis (Figure 4.4). A distance raster is produced from the flow lines created by the drainage analysis (Figure 4.5). The continuous distance dataset is converted into a discrete data set. Landfill site suitability rankings are assigned to each discrete region (Table 4.2), with regards to the distance from the flow line, by using the distance values suggested by Sharifi et al., 2009 (Figure 4.6).

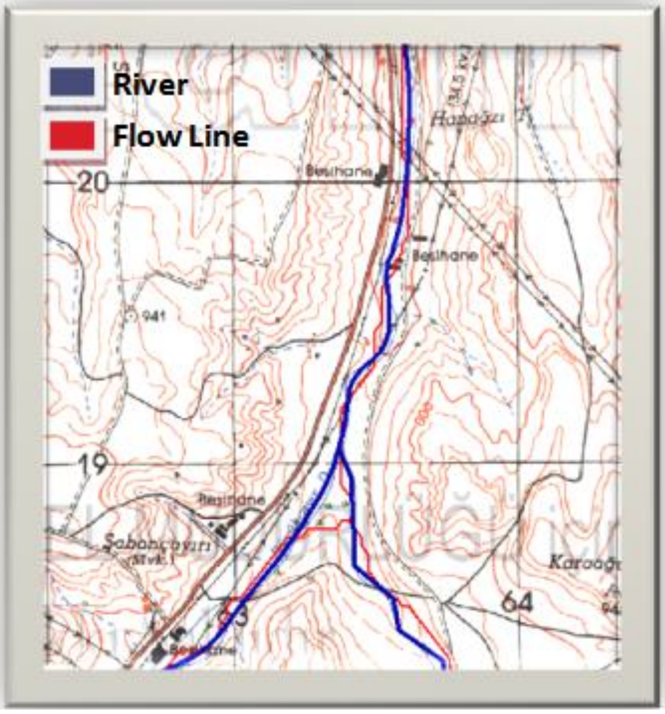

Figure 4.4. Rivers (blue) present in the area overlain by the flow lines (red) produced by the drainage analysis.

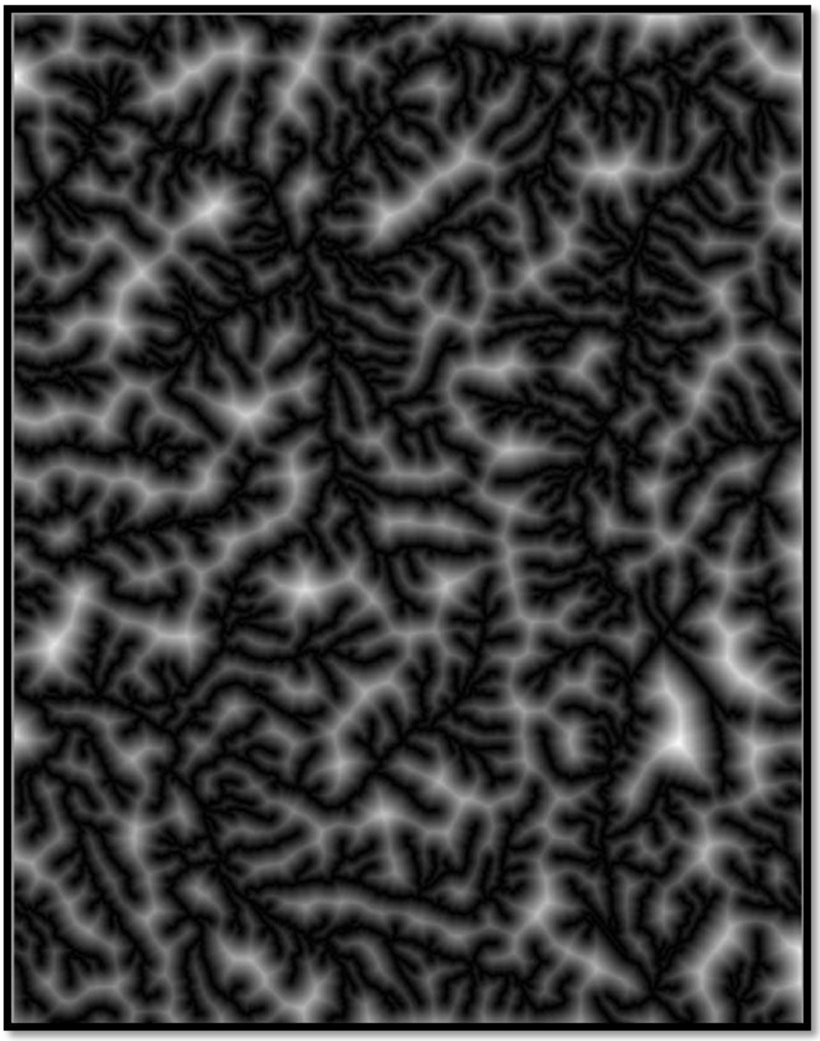

Figure 4.5. Distance raster produced from the flow lines.

Table 4.2. Suitability rankings based on the distance to flow line (Sharifi et al., 2009).

Distance to flow line (m)	**Rank**
0 -100	0
100 – 400	0.25
400 – 1500	0.5
1500 – 5000	0.75
5000	1

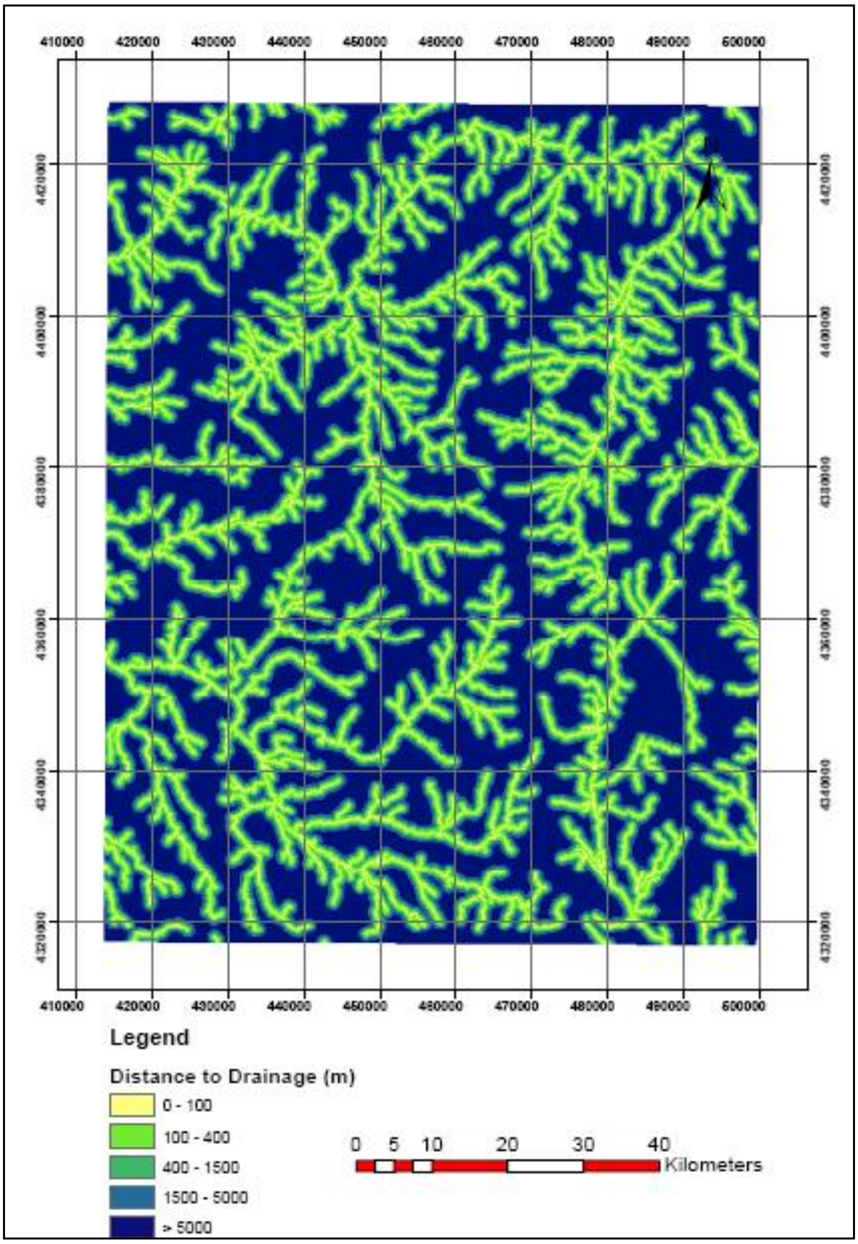

Figure 4.6. Map showing the suitability rankings with regards to the distance to flow lines.

4.1.2.2. Slope

The slope of the land surface is an important factor as far as the construction costs are concerned, such that steep slopes results in high excavation costs. A slope value is calculated for each pixel from the DEM by using the TNT Mips software.

It is a common approach to make the data discrete by putting constraints (Baban et al., 2001). For example, Nas et al. (2009) define slope values above 15% as not suitable and below 15% as suitable. Converting the continuous slope data to discrete data causes loss of information. Guiqina et al. (2009) followed a different approach and transformed the slope values ranging from 0-50% into a scale from 1 to 5. 1 (the lowest suitability number) is assigned to slope values of 40-50% and 5 (the highest suitability number) is assigned to slope values of 0-10%. A similar approach is followed where slope values between 0-10% are assigned a suitability value of “1”, being the highest suitability value and slope values between 40-50% are assigned a suitability value “0”, being the lowest suitability value (Figure 4.7). The suitability map generated with values scaled between 0 and 1 can be seen in Figure 4.8.

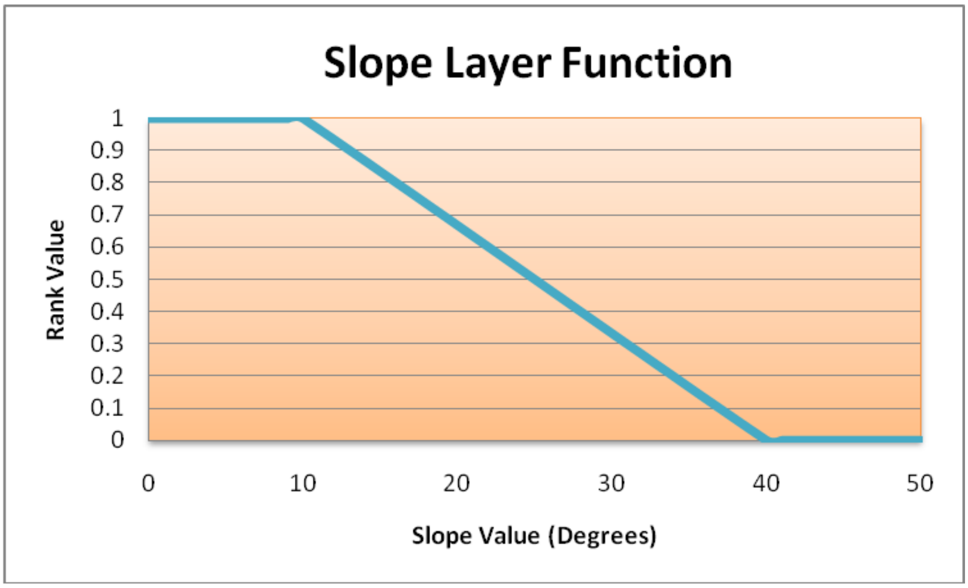

Figure 4.7. Slope layer rank variation function.

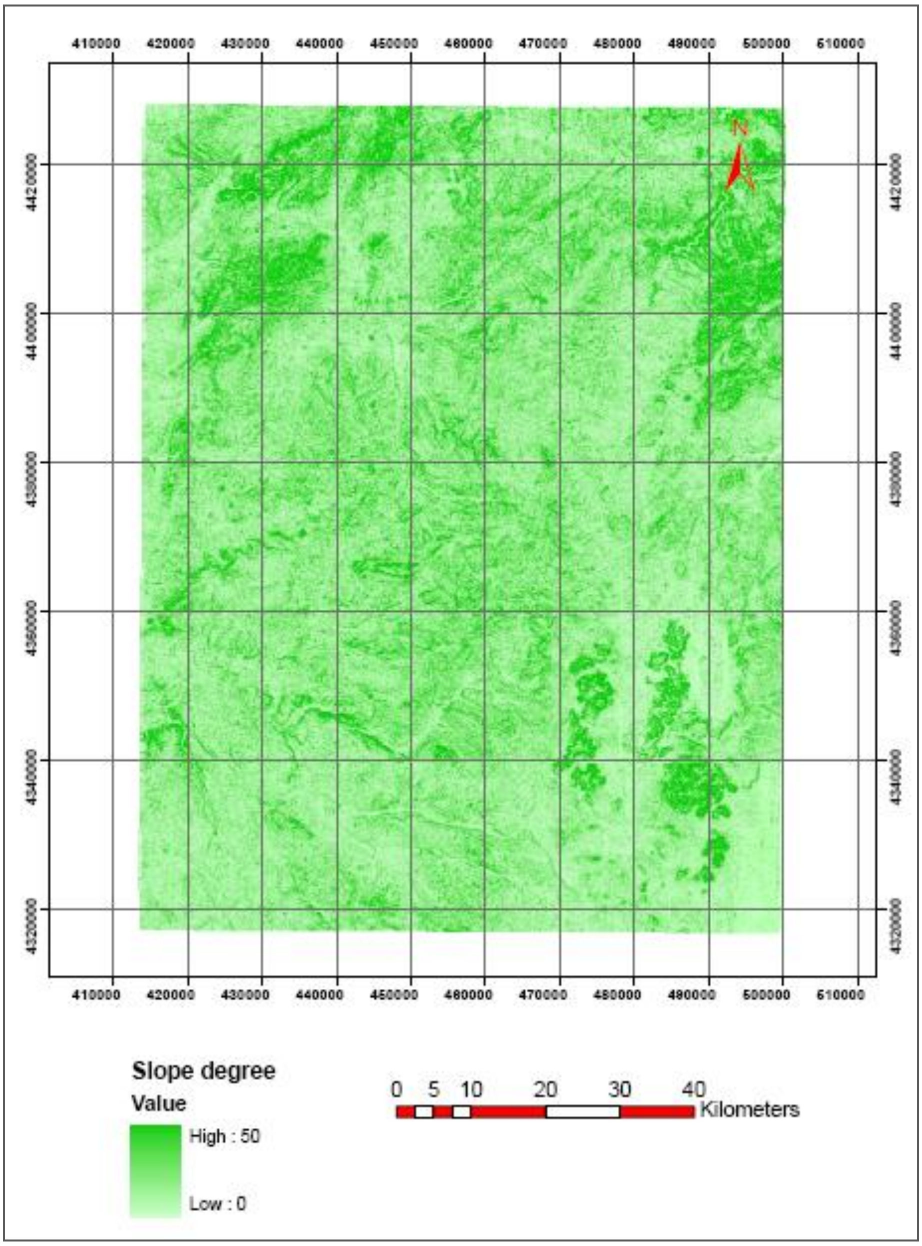

Figure 4.8. Slope map of the area

4.1.3. Erosion

The erosion susceptibility map is gathered from the General Directorate of Rural Services (2009). This deterministic map represents the degree of erosion in three levels (Table 4.3). A standardized suitability rank for landfill construction is assigned to each region (Figure 4.9).

Table 4.3. Suitability ranking based on the degree of erosion. (General Directorate of Rural Services, 2009).

Degree of Erosion	**Rank**
High Erosion	0.5
Moderate Erosion	0.75
Low or No Erosion	1

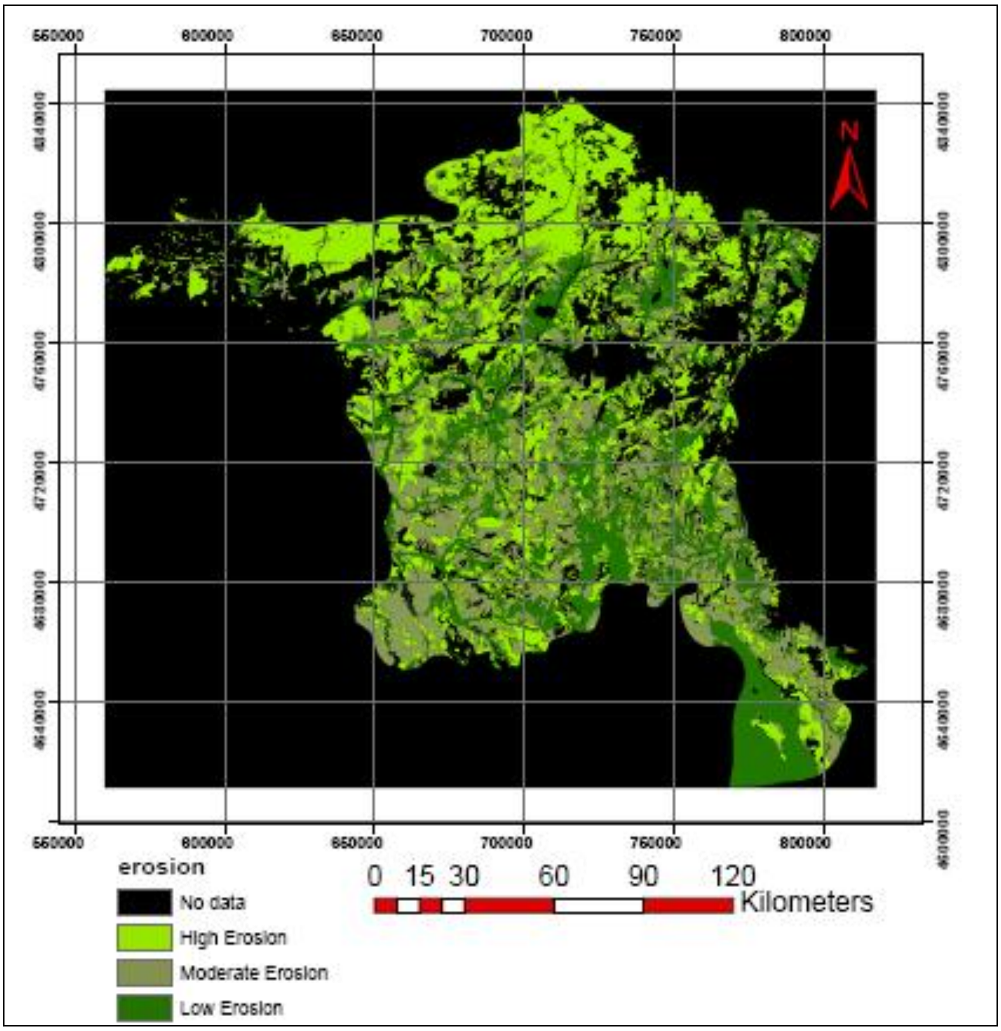

Figure 4.9. Erosion susceptibility map (General Directorate of Rural Services, 2009)**.**

4.1.4. Lineaments

The fault map of the area prepared by Koçyiğit (2003) and quoted by Kaplan (2004) was digitized and a distance raster of the fault map was produced. The distance raster was divided into zones of distance to faults and suitability rankings were assigned to each zone (Sharifi, et al., 2009) (Table 4.4 and Figure 4.10).

Table 4.4. Suitability rankings based on the distance to fault (Sharifi et al., 2009).

Distance to Fault (m)	**Rank**
0 – 100	0
100 – 400	0.25
400 – 1500	0.5
1500 -5000	0.75
> 5000	1

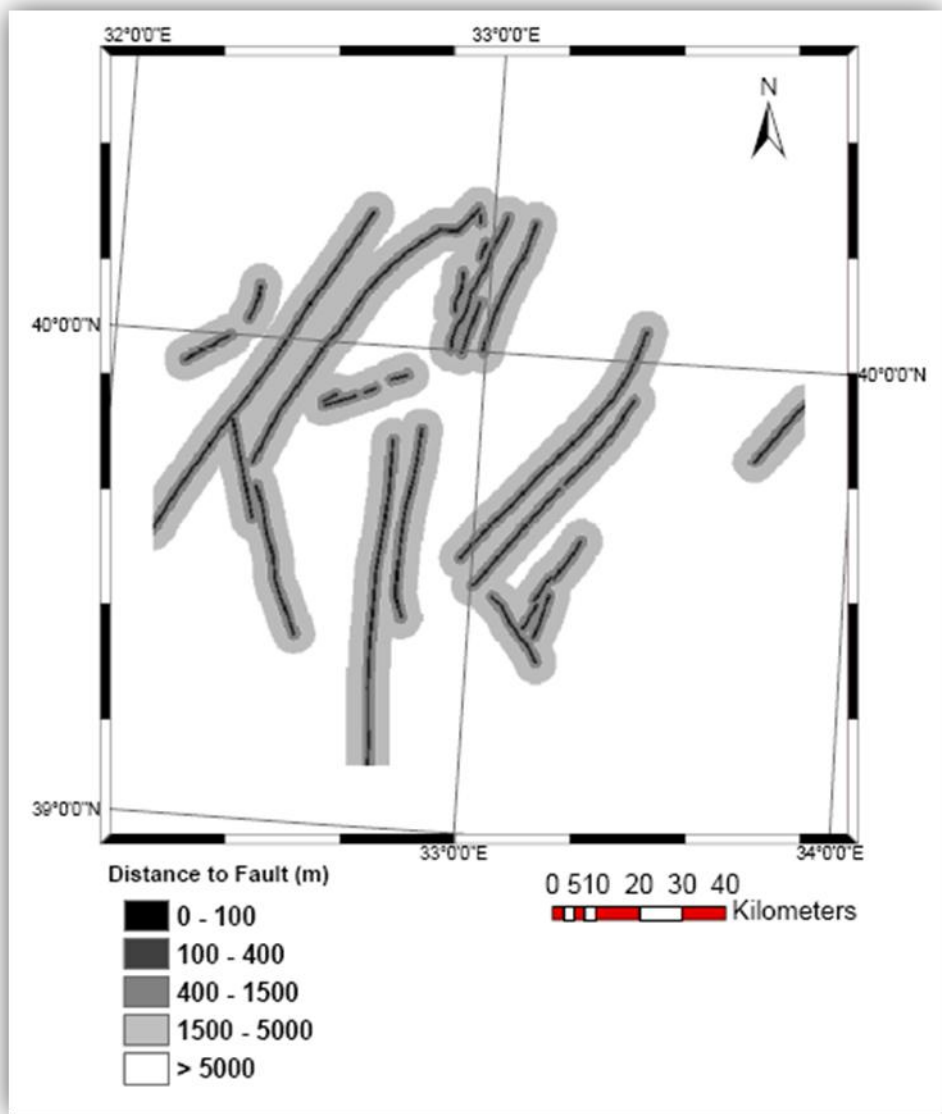

Figure 4.10. Faults present in the area digitized from Kaplan (2004).

4.1.5 Geology

The 1/100,000 geology map acquired from General Directorate of Mineral Research and Exploration was used for obtaining information on the geology of the area. The geological formations were digitized and a vector map was created.

The only formation in the region with a possibility to possess a shallow groundwater level is alluvium so the lowest suitability ranking of “0”, was assigned to alluvium and the highest suitability ranking, “1” was assigned to “Ankara Clay” and andesite in an attempt to account for the water bearing characteristics of the geological formations in Ankara. The other geological formations were assigned values between 0 and 1 with regards to their suitability for a landfill site (Şener, 2005). The suitability map created for Sincan and Gölbaşı is presented by Figures 4.11 and Figure 4.12, respectively.

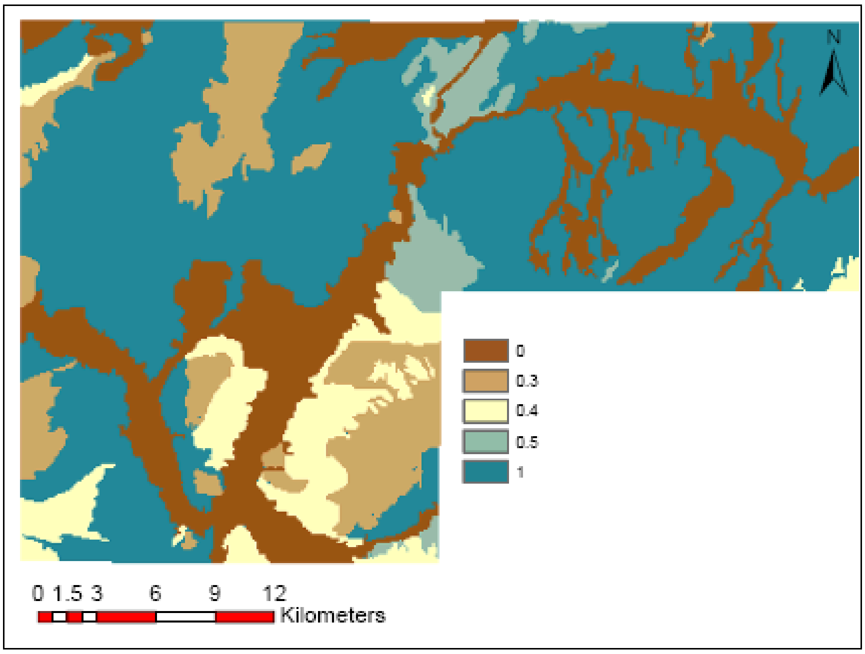

Figure 4. 11. Geological suitability map of Sincan.

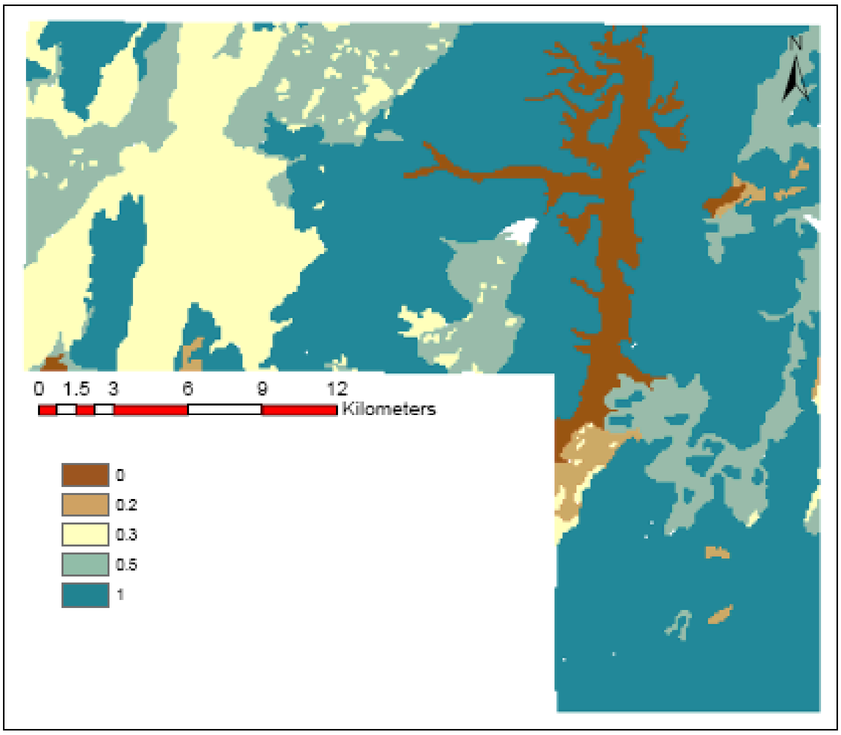

Figure 4.12. Geological suitability map of Gölbaşı

The ranking value assigned to each geological formation is summarized in Table 4.5.

Table 4.5. **Rankng values assigned to geological formations.**

Geological Formation	Ranking
Tg, Ke, Tkiz, Th, Tb, Kh, Jh, Ja	1
Tmk, Tt, Tmb, Tma	0.5
Teta, Teab, Tea, kb, Pkb, Jmb, Jg	0.3
Mof, Keo, Kd	0.2
Qh, Qa	0

4.1.6. Roads

Information for the highways and rural roads were extracted from the topographic map with 1/25,000 scale produced by General Directorate of Mapping (2002) for the Sincan and Gölbaşı sites. The distance raster was created both from extracted highways and rural roads. A 500 m buffer zone was created around the highways, and the suitability ranking was increased linearly away from the highway. On the other hand, since landfill sites distant from the roads make the sites less attractive due to additional costs imposed due to the need for constructing new roads, the suitability ranking decreases going away from the rural roads. A 100 m buffer zone was created around the rural roads in order for the landfill vehicles not to interfere with the traffic (Guiqina et al., 2009). The highway and local road suitability maps for Sincan are shown by Figures 4.13 and Figure 4.14, respectively; and the highway and local road suitability maps for Gölbaşı are shown by Figures 4.15 and Figure 4.16, respectively.

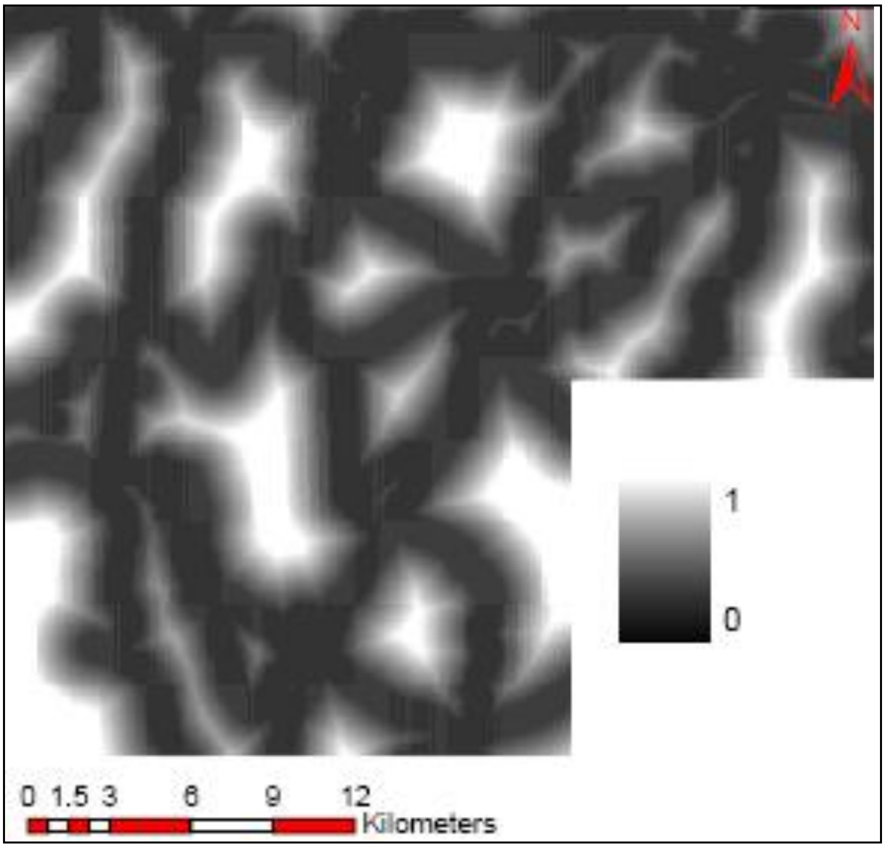

Figure 4. 13. Highway suitability map for Sincan.

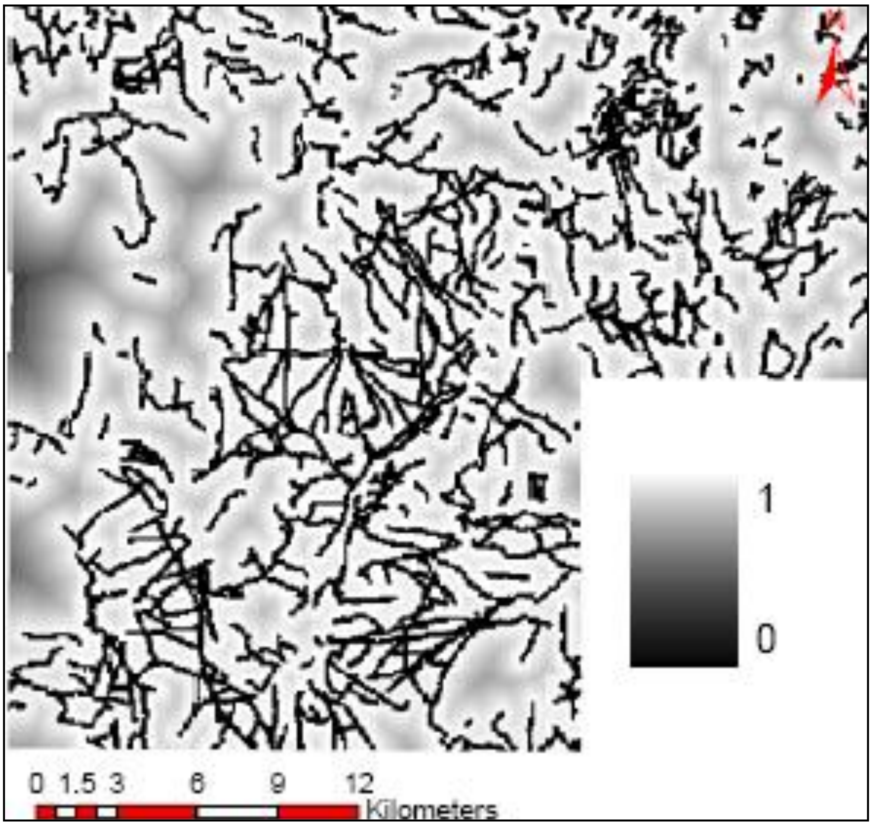

Figure 4.14. Local road suitability map for Sincan.

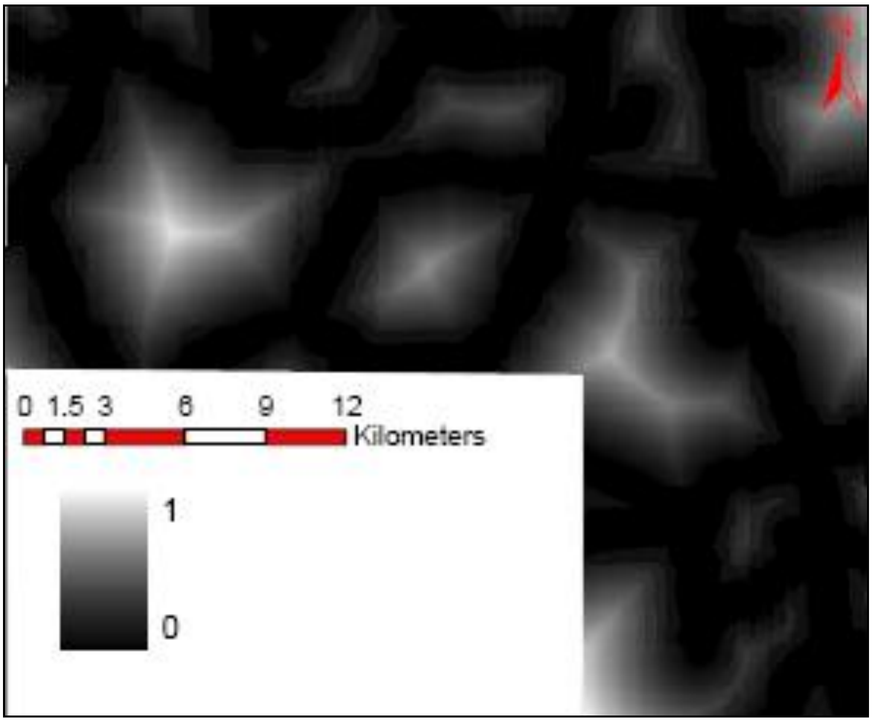

Figure 4.15. Highway suitability map for Gölbaşı.

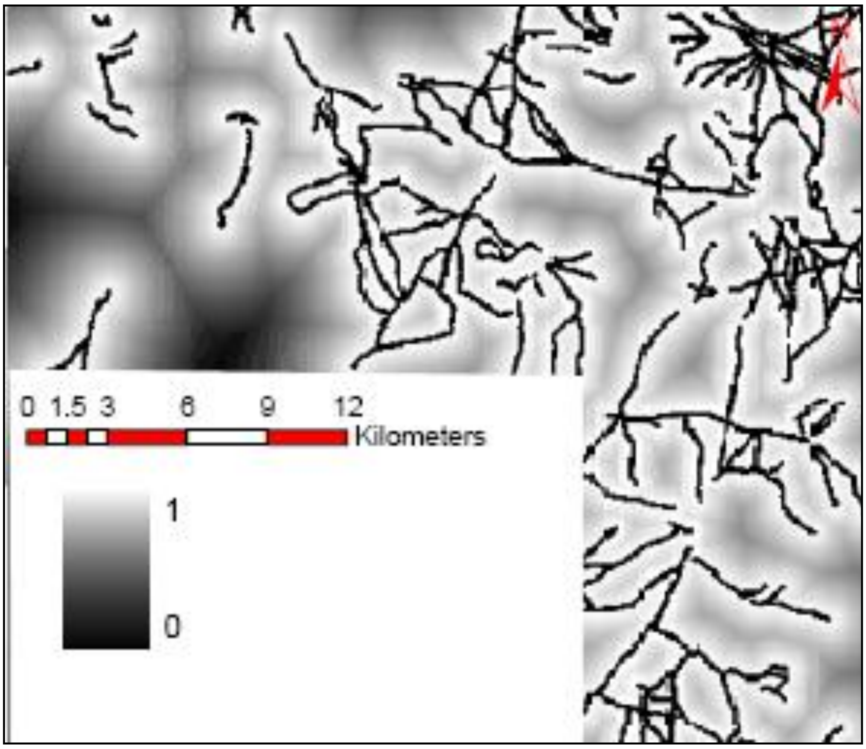

Figure 4.16. Rural road suitability map for Gölbaşı.

4.1.7. Normalized Difference Vegetation Index (NDVI)

In order to extract the vegetated areas, the Normalized Difference Vegetation Index (NDVI) was used. NDVI is a simple relationship that is represented by Eq. (4.1) which uses two satellite bands: Near Infrared (NIR) and Red. Healthy vegetation reflects well in NIR and the visible red channel is used for atmospheric correction (Figure 4.17).

$$NDVI = \frac{NIR - RED}{NIR + RED} \tag{4.1}$$

LANDSAT TM imagery was used for NDVI analysis. The vegetated areas were determined in order to determine the suitability ranking.

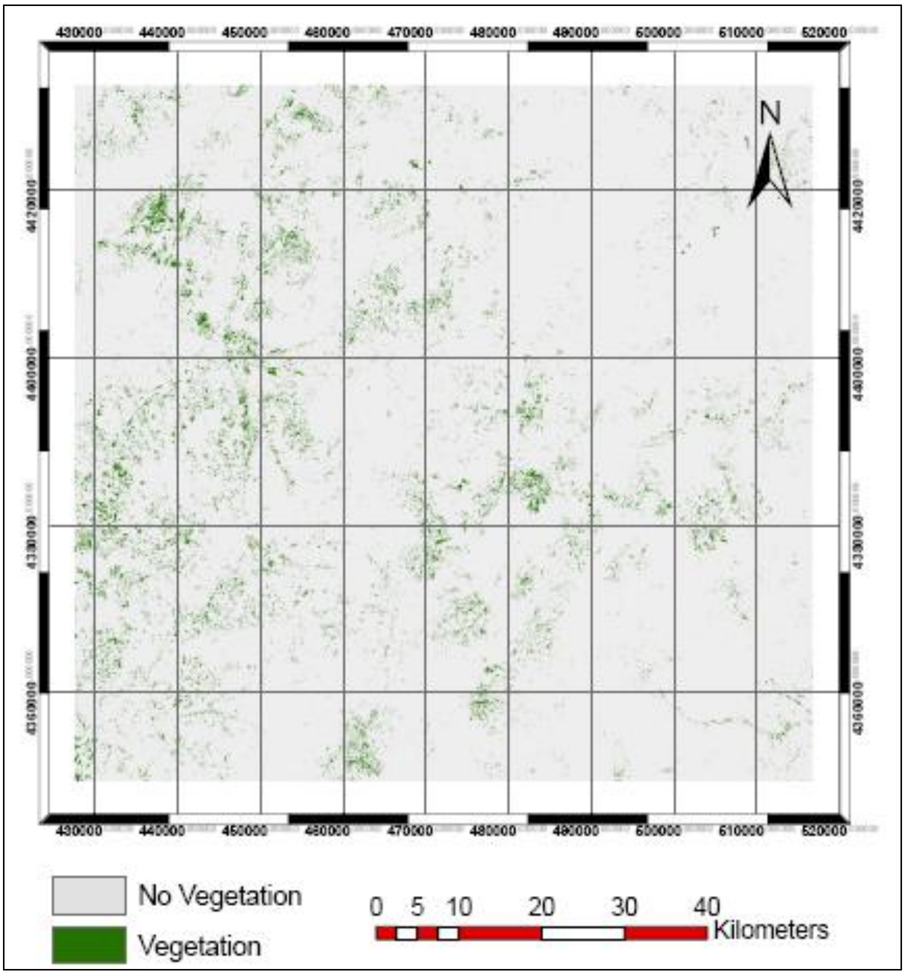

Figure 4.17. NDVI map showing the vegetated areas

4.1.8. Land use

The land use map of Ankara was gathered from the Turkish Soil and Municipal Directorate. The moors, forests, irrigated fields, gardens, pasture areas were considered not to be suitable (rank = 0) whereas the dry fields and the abandoned lands area were ranked to be suitable (rank = 1) (Figure 4.18).

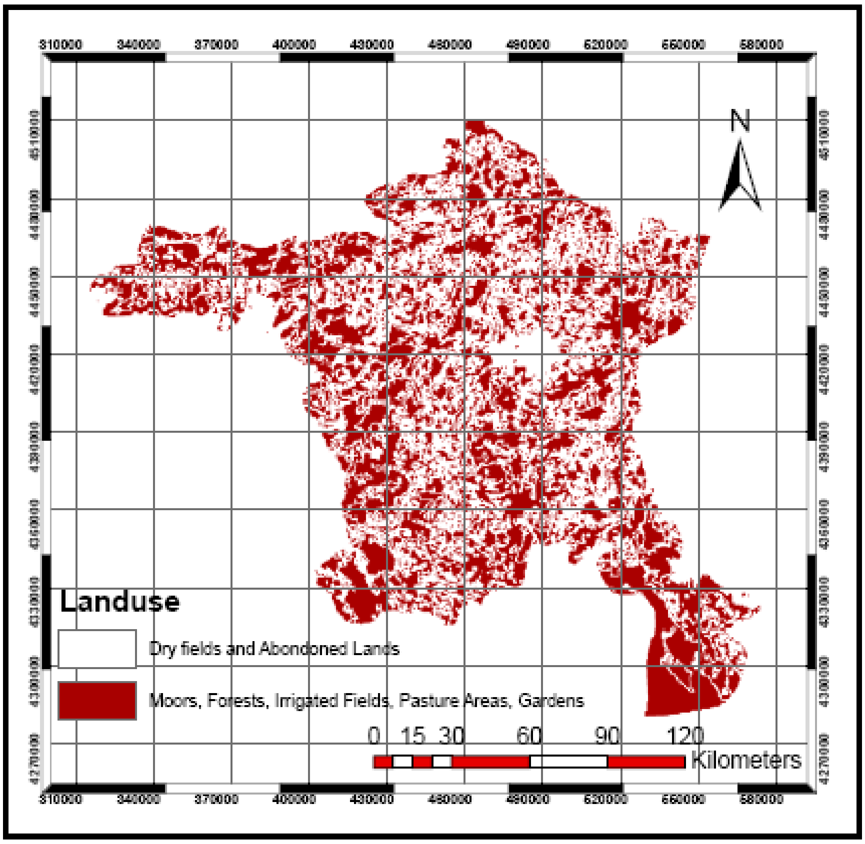

Figure 4.18. Land use map of the area (General Directorate of Rural Services, 2009).

4.1.9. Settlement

In areas where industrial and/or residential settlement was determined, a buffer zone of 500 m was applied. The ranks assigned to different distances to settlements as suggested by Sharifi et al. (2009) can be seen in Table 4.6 and the resulting map can be seen in Figure 4.19.

Table 4.6. Suitability rankings based on the distance to settlements (Sharifi et al., 2009).

Distance to Settlement (m)	**Rank**
0 – 500	0
500 – 1000	0.25
1000 – 1500	0.5
1500 – 2000	0.75
> 2000	1

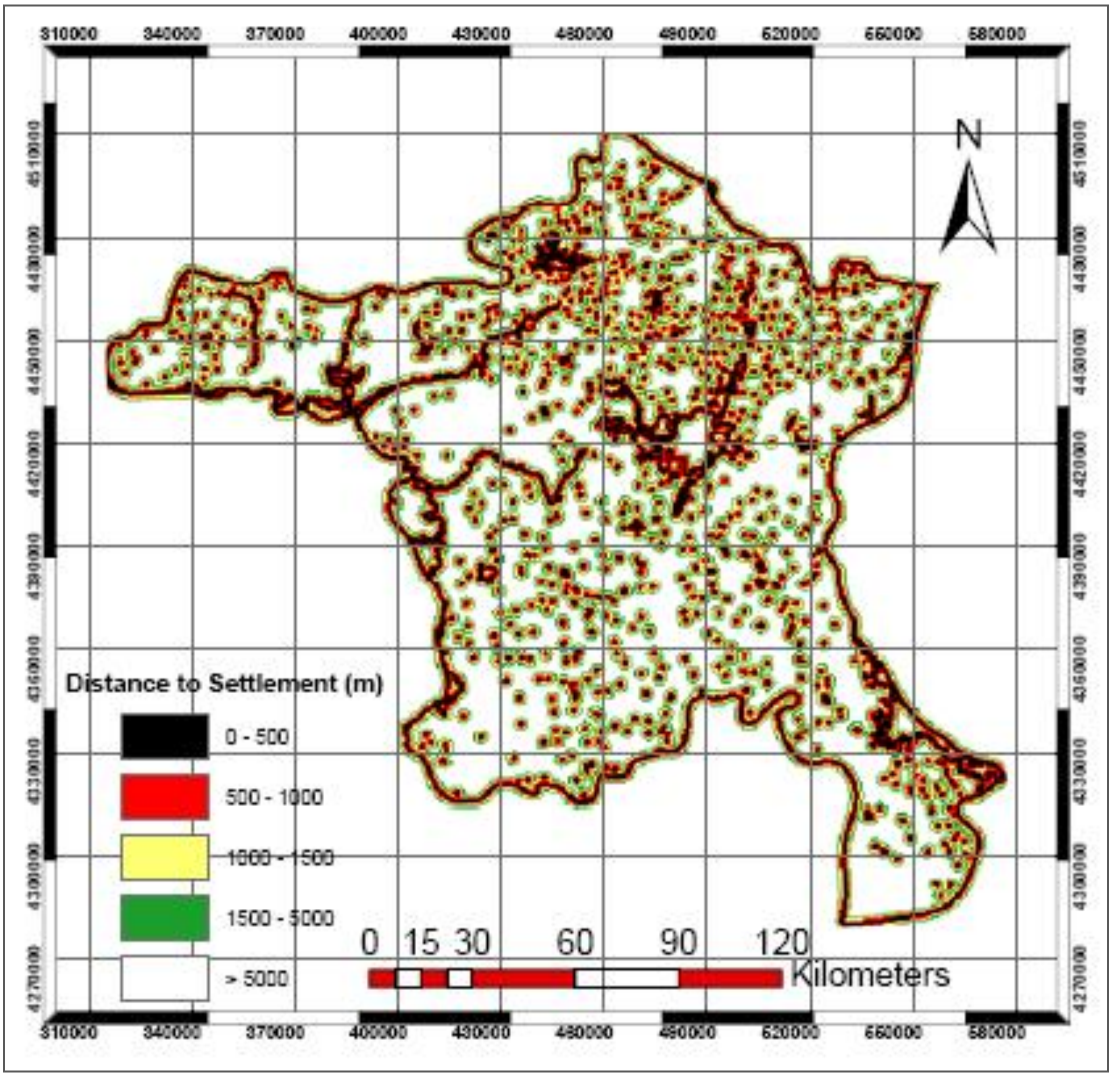

Figure 4.19. Distance to settlement map of the area (General Directorate of Rural Services, 2009).

4.2. Landfill Site Selection by MCDA in Sincan and Gölbaşı

The landfill site selection was conducted for the northwest and southwest parts of Ankara. A study area further northwest of that of Şener (2005) which included the Sincan–Etimesgut–Polatlı–Ayaş municipalities was selected for the landfill site selection investigation through taking the long-term growing trends of Ankara into consideration. By recognizing the necessity, site selection was also performed for the Gölbaşı municipality as well, Prior to continuing with the analysis that is presented in the following pages, a co-linearity analysis performed by using the ArcGIS software indicated that none of the layers used in the analysis appeared to be co-linear. The criteria used in the analysis were defined in the previous section. However, since the criteria used for landfill site selection do have the equal importance, the weight values need to be assigned in order to account for the relative importance of layers.

In order to assign weight values, the pairwise comparison method was employed (Chapter 3). First, the layers were constructed into a hierarchical structure (Figure 4.20) and each criterion was assigned a value between 1 and 8 with regards to its relative importance. Determination of the relative importance of each criterion with each other is solely user dependent. While determining the weights for each criterion, which define its importance, the location of the study area and the type of structure for which the site selection is performed needs to be taken into consideration. In the study of Baban and Parry (2000), site selection is performed for locating wind farms. In this study a higher weight value is assigned to slope criteria than to the distance to settlements considering that the structure (wind farms) is not hazardous.

Din et al (5000), performed landfill site selection using 7 layers where the highest ranking is given to surface water followed by residential area. Since the study area is in Malaysia, with a very humid climate and high groundwater level, the main importance is given to surface water. Şener et al. (2010) performed landfill site selection in Isparta Basin, Turkey. The highest weight values were given to groundwater depth , aquifer type, lithology and distance to lineaments, since the Isparta Basin has high groundwater level and is located in a seismicly active zone. In the study by Guiqin et al. (2009), landfill site selection was performed using a total of 9 layers where the weight values from highest to lowest followed the the following order: residential areas, surface water, groundwater, airport areas, land use, slope, price of land, roads, proximity to waste production center. Also, in the study of Şener (2004) for landfill site selection, the urban centers and villages were selected as the criteria with the highest weight value followed by surface water, flood, swamp and geology. Slope and road layers were given relatively lower suitability values.

In this study the the settlement is determined to have the highest weight value considering previous studies. Followed by DEM which includes surface water and slope. The road layer has the third highest weight since as mentioned in Chapter I, transportation of waste to the current landfill sites has been a problem due to high transportation costs thus it is aimed to select a site where the transportation costs can be minimized through optimization. The geology layer is placed right after roads, followed by suitability for agriculture and erosion susceptibility, seismic impact and NDVI.

Table 4.7 presents the assembled pairwise comparison matrix. The criteria represented on the left (X) is compared with respect to the criteria represented on the top (Y) of the matrix. In the case where X is more important than Y, a value greater than 1 is entered, and if X is less important than Y then the reciprocal of that value is entered into the matrix. The scalar quantity of the value defines the relative degree of importance. Subsequently, in order to determine the weights of each criterion, a normalized pairwise comparison matrix was assembled (Table 4.8).

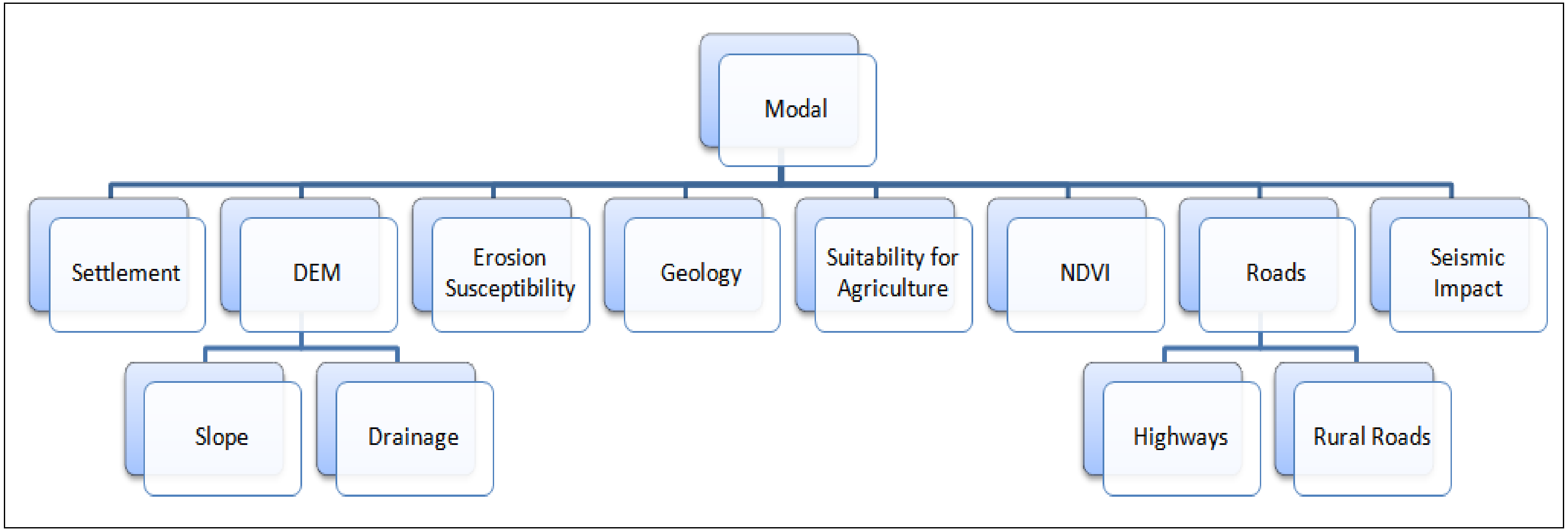

Figure 4.20. Structure of the layers used in the landfill site selection process.

Table 4.7. Pairwise Comparison of the Evaluation Criteria

	Settlement	DEM	Roads	Geology	Suitability for Agriculture	Erosion	Fault	NDVI
Settlement	1	2	3	4	5	6	7	8
DEM	1/2	1	2	3	4	5	6	7
Roads	1/3	1/2	1	2	3	4	5	6
Geology	1/4	1/3	1/2	1	2	3	4	5
Suit. for Agriculture	1/5	1/4	1/3	1/2	1	2	3	4
Erosion	1/6	1/5	1/4	1/3	1/2	1	2	3
Fault	1/7	1/6	1/5	1/4	1/3	1/2	1	2
NDVI	1/8	1/7	1/6	1/5	1/4	1/3	1/2	1
SUM	2.72	4.59	7.45	11.28	16.08	21.83	28.50	36.00

Table 4. 8. Normalized Pairwise Matrix

	Settlement	DEM	Roads	Geology	Suitability for Agriculture	Erosion	Fault	NDVI	Average
Settlement	**0.37**	**0.44**	**0.40**	**0.35**	**0.31**	**0.27**	**0.25**	**0.22**	**0.33**
DEM	**0.18**	**0.22**	**0.27**	**0.27**	**0.25**	**0.23**	**0.21**	**0.19**	**0.23**
Roads	**0.12**	**0.11**	**0.13**	**0.18**	**0.19**	**0.18**	**0.18**	**0.17**	**0.16**
Geology	**0.09**	**0.07**	**0.07**	**0.09**	**0.12**	**0.14**	**0.14**	**0.14**	**0.11**
Suit. for Agriculture	**0.07**	**0.05**	**0.04**	**0.04**	**0.06**	**0.09**	**0.11**	**0.11**	**0.07**
Erosion	**0.06**	**0.04**	**0.03**	**0.03**	**0.03**	**0.05**	**0.07**	**0.08**	**0.05**
NDVI	**0.05**	**0.04**	**0.03**	**0.02**	**0.02**	**0.02**	**0.04**	**0.06**	**0.03**
Fault	**0.05**	**0.03**	**0.02**	**0.02**	**0.02**	**0.02**	**0.02**	**0.03**	**0.02**

In the lower level of the hierarchical structure, the slope and drainage criteria and the highway and local road criteria were compared and the assigned weight values can be seen in Tables 4.9 and 4.10.

Table 4.9. Slope and Drainage Weight Values.

Layer	Weight	
DEM	0.23	
SLOPE	0.80	0.18
DRAINAGE	0.20	0.05

Table 4.10. Highway and Local Road Weight Values.

Layer	Weight	
ROADS	0.16	
HIGHWAY	0.60	0.09
LOCAL ROAD	0.40	0.06

Table 4.11 presents the weight values of each criterion used in the analysis.

Table 4.11. Weights of Each Criterion

LAYER	WEIGHT
Settlement	0.33
Slope	0.1819
Drainage	0.0455
Highway	0.0941
Local Road	0.0627
Geology	0.1077
Suitability for Agriculture	0.0734
Erosion	0.0498
NDVI	0.0340
Fault	0.0242
Sum	1

In order to check the reliability of the comparisons, a consistency ratio (λ) was estimated (Table 4.12). The λ value for each criterion was calculated and consequently the consistency ratio was determined to be approximately 0.04 (smaller than 0.1) which indicated that the comparisons were consistent.

Table 4.12. Consistency Ratio Calculation Matrix.

	Settlement	DEM	Roads	Geology	Suitability for Agriculture	Erosion	NDVI	Fault	Sum	λ*
Settlement	0.33	0.45	0.47	0.43	0.37	0.30	0.24	0.19	2.78	8.51
DEM	0.16	0.23	0.31	0.32	0.29	0.25	0.20	0.17	1.94	8.55
Roads	0.11	0.11	0.16	0.22	0.22	0.20	0.17	0.14	1.33	8.47
Geology	0.08	0.08	0.08	0.11	0.15	0.15	0.14	0.12	0.90	8.33
Suitability for Agriculture	0.07	0.06	0.05	0.05	0.07	0.10	0.10	0.10	0.60	8.17
Erosion	0.05	0.05	0.04	0.04	0.04	0.05	0.07	0.07	0.40	8.07
NDVI	0.05	0.04	0.03	0.03	0.02	0.02	0.03	0.05	0.27	8.07
Fault	0.04	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.20	8.16
Consistency Ratio = 0.04										

*Degree of inconsistency

4.2.1. TOPSIS Analysis

The methodology for TOPSIS analysis is described in Chapter 3. The required operations for the application of the TOPSIS methodology were performed through utilizing the TNT Mips and ArcGIS softwares. A model, including ideal and negative ideal layers and the required operations were produced with the output of this model being a landfill suitability map. The landfill suitability map was created both for the Sincan and Gölbaşı sites (Figures 4.21 through 4.23).

The area with dense settlement is extracted from the suitability map assuming possible environmental risks and high lot prices. The Çadırtepe landfill site appeared to be suitable as can be seen in Figure 4.21. However, as stated in Chapter 1 due to the fact that the constructed bottom clay liner most probably lost its integrity, the use of this landfill prior to any remedial action would possess serious environmental risks. Two areas were selected as candidate sites. The first candidate site selected coincided with a proposed organized industrial development area as reported in the 2023 development plan of Ankara, thus this site has been eliminated. The second candidate site selected was located inside the Sincan municipality. The satellite image of the area can be seen in Figure 4.22.

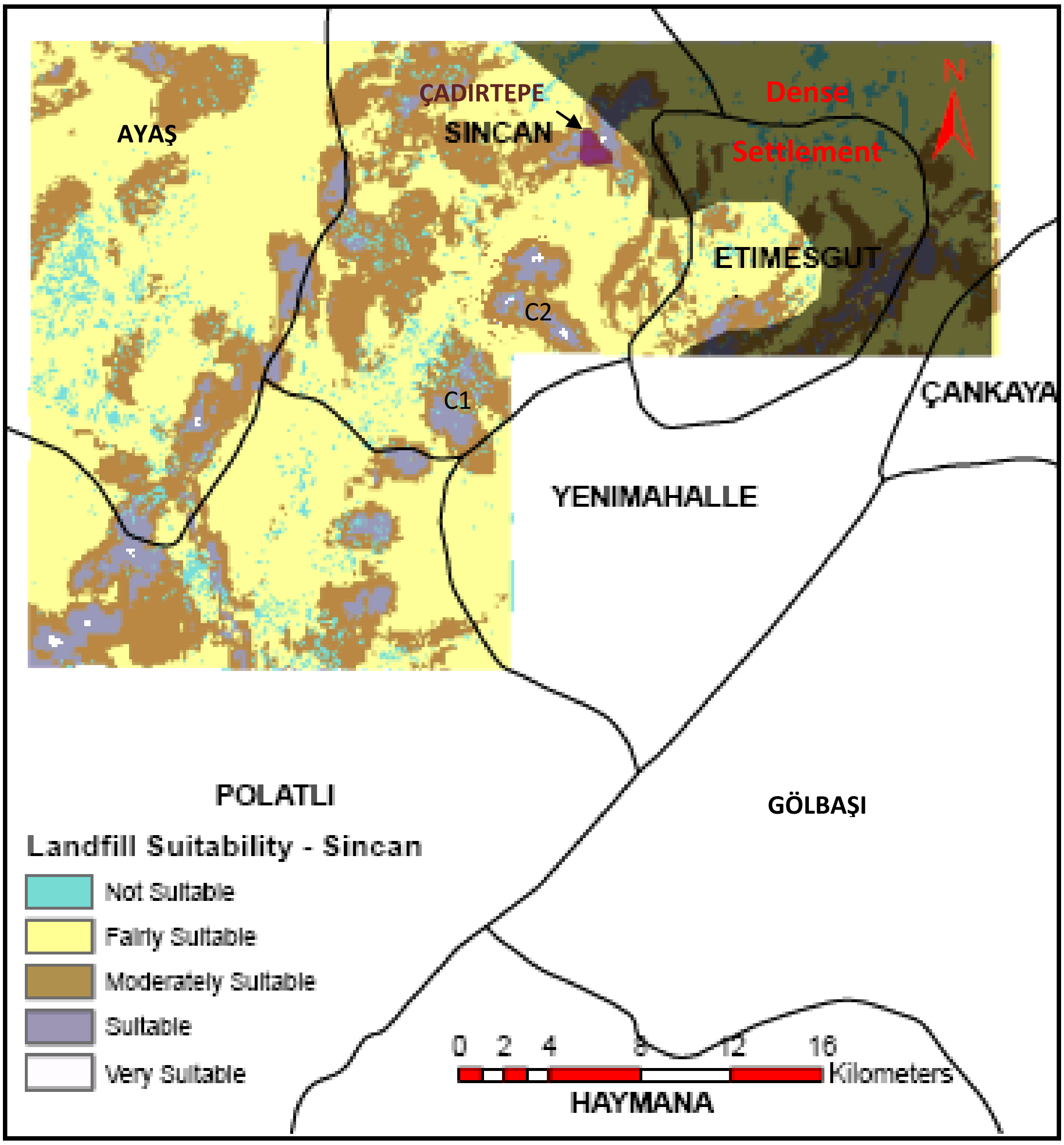

Figure 4.21. Final suitability map of Sincan (C1, C2 are candidate landfill sites).

Figure 4.22. Satellite image of the candidate and selected landfill sites in Sincan.

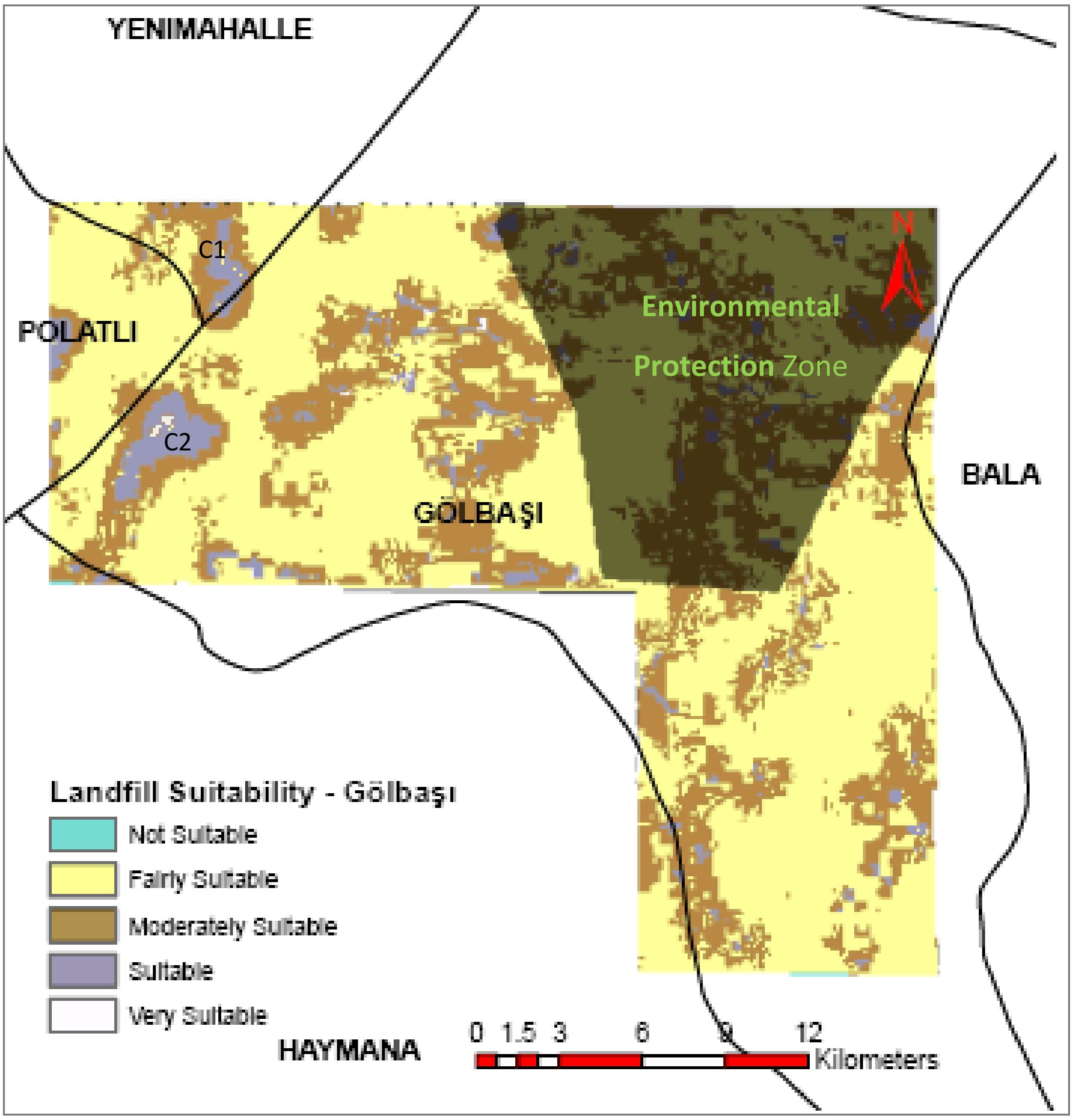

Figure 4.23. Final suitability map of Gölbaşı (C1, C2 are candidate landfill sites).

For Gölbaşı two candidate sites have been selected as well. The first candidate site was located inside the Yenimahalle municipality which has high lot prices. The second candidate site as can be seen on Figure 4.23 covers a large area suitable for landfill siting and accordingly was selected as the most suitable site for hosting a landfill. The satellite image of the area can be seen in Figure 4.24. The candidate and selected sites for Gölbaşı and Sincan can be seen on Figure 4.25.

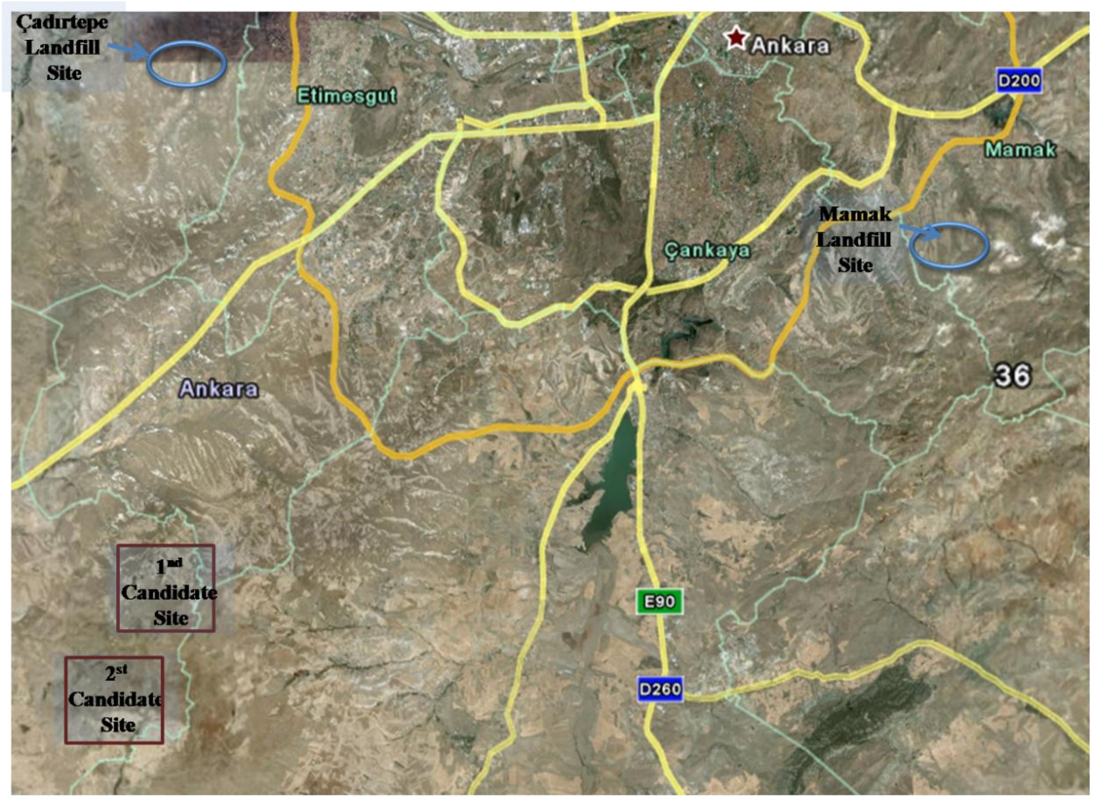

Figure 4.24. Satellite image of the candidate and selected landfill sites in Gölbaşı.

Figure 4.25. Sattelite image showing approximate landfill site locations

4.3. Seismic Impact

The selected sites are plotted with the epicenters digitized from Kocyigit (1999). As can be seen from Figure 4.26, the selected sites are located reasonably far from the epicenters present in the area justifying the suitability of the selected landfill sites in terms of possible seismic impact.

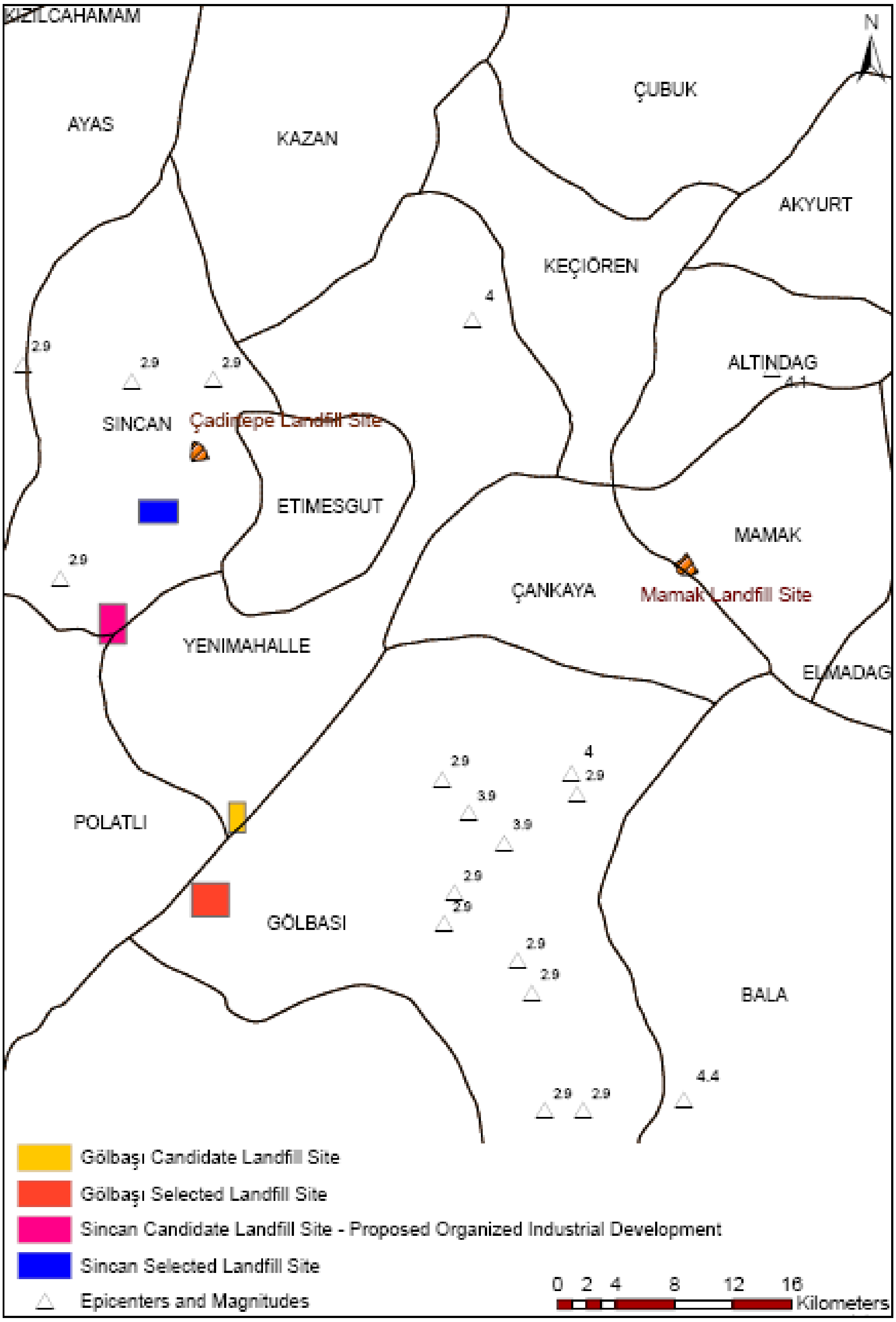

Figure 4.26. Earthquake epicenters present in the study area (Koçyiğit, 2003 and Kalafat et al.,2007)

4.4. Sensitivity Analysis and Discussion

Sensitivity analysis may be performed in several ways such as altering the weight values of the individual layers, changing the buffer zones of layers where applicable, and excluding a layer one at a time and repeating the analysis to see its effect on the resultant map. Chen et al. (2009) performed a sensitivity analysis by varying different parameter weights and utilizing a GIS based sensitivity analysis tool based on the C+ language. A sensitivity analysis was performed in this study in order to determine the individual effects of each layer to the resultant suitability map. The analysis was repeated with the exclusion of one layer at a time.

One of the layers was excluded in each analysis and a total of 10 suitability maps were created. It should be noted that the analysis was performed only on the selected landfill site area in Sincan which is cropped out from the suitability map, in order to determine the effect of each criteria on the resultant suitability map. Each image was reclassified into five classes from 1 to 5 where 1 was considered to be the least suitable and 5 was considered to be the most suitable. The number of cells corresponding to each suitability class was determined. The number of cells corresponding to class 5 (most suitable) for each image where one of the layers was excluded, are shown Figure 4.28. The red bars show the number of cells representative of class 5 on the resultant map which includes all the layers. The difference between the blue and the red bars shows the effect of the exclusion of a layer. The most variation can be seen for the geology layer. This indicates the importance of the geology layer for the analysis. When the geology is excluded from the analysis the area appears more suitable. This shows that prior to the selection of the landfill site, a detailed geological and geotechnical investigation is required and warranted. Moreover, it should be noted that the analysis is performed using information on the geological formations that outcrop in the area and it lacks geotechnical information. Due to the distinct quality of the Ankara region that possesses a thick impermeable clay layer of up to 30 m in thickness at places, the geology and geotechnics is still reasonably reliable. The presence of this thick layer was also verified, by borehole data for Sincan and Gölbaşı gathered from the Sincan and Gölbaşı municipalites. A total of 26 borehole data for Sincan and 10 borehole data for Gölbaşı was gathered. The spatial distribution of the borehole locations is not sufficient to make a spatial inference on the thickness of the clay layer. Just rough values for the thickness of the clay layer are determined. The average depth to clay is 3m and 3.5m for Gölbaşı and Sincan respectively. Most of the boreholes were not deep enough to reach to the bottom of the clay layer where it was assumed that the borehole was terminated at the bottom of the clay layer. Even with this fairly conservative assumption, the average thickness of the clay layer was determined to be 14m and 10m for Gölbaşı and Sincan, respectively. Figure 4.27 gives borehole locations.

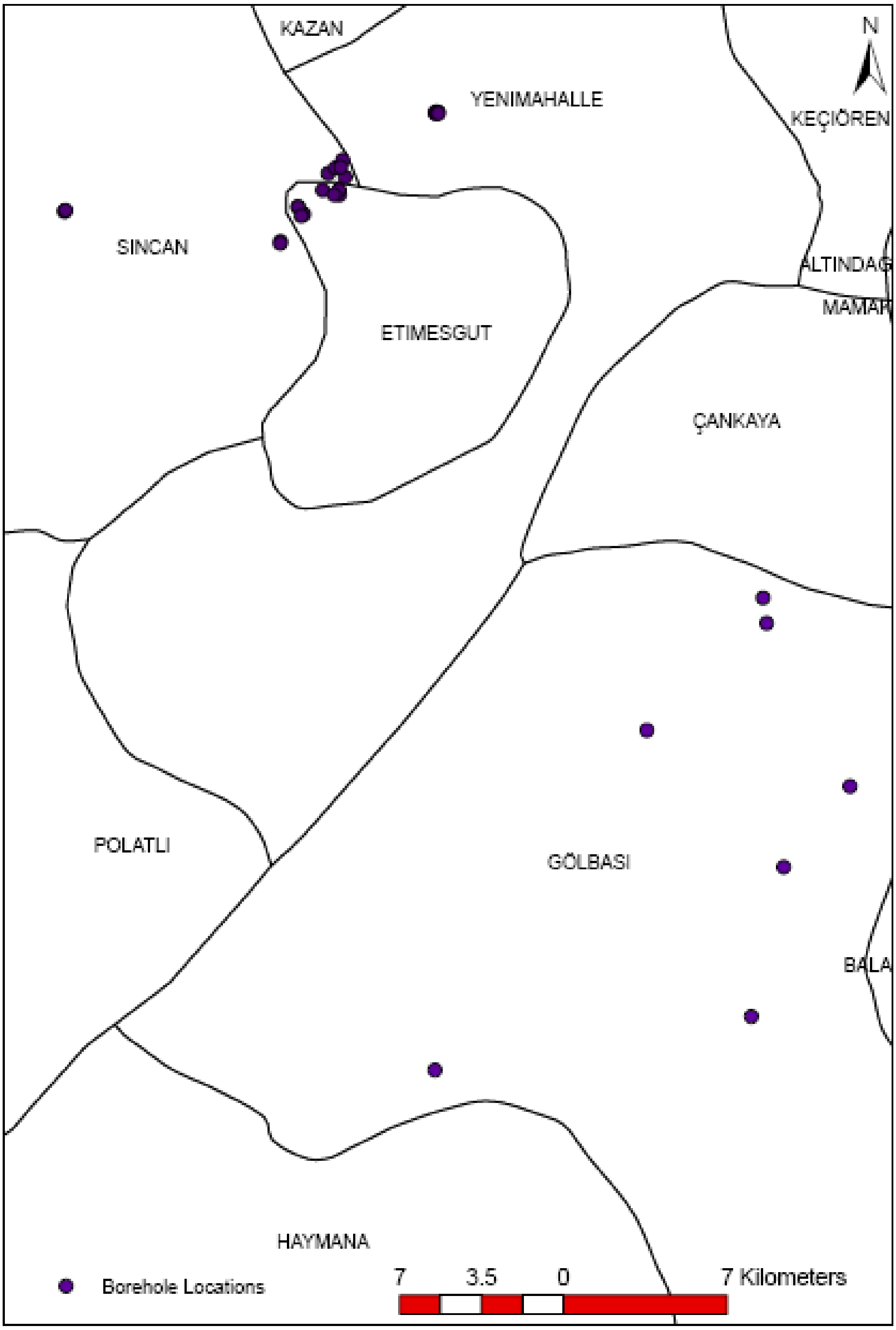

Figure 4.27. Borehole Locations.

For the other layers in Figure 4.28, the number of cell values are either very close to the resultant map including all the layers or less which does not indicate a problem. For example for the map where the highways are excluded, the number of cells corresponding to class 5 are less than the number of cells for the resultant map including all the layers which means that when the highway layer is included the site appears even more suitable.

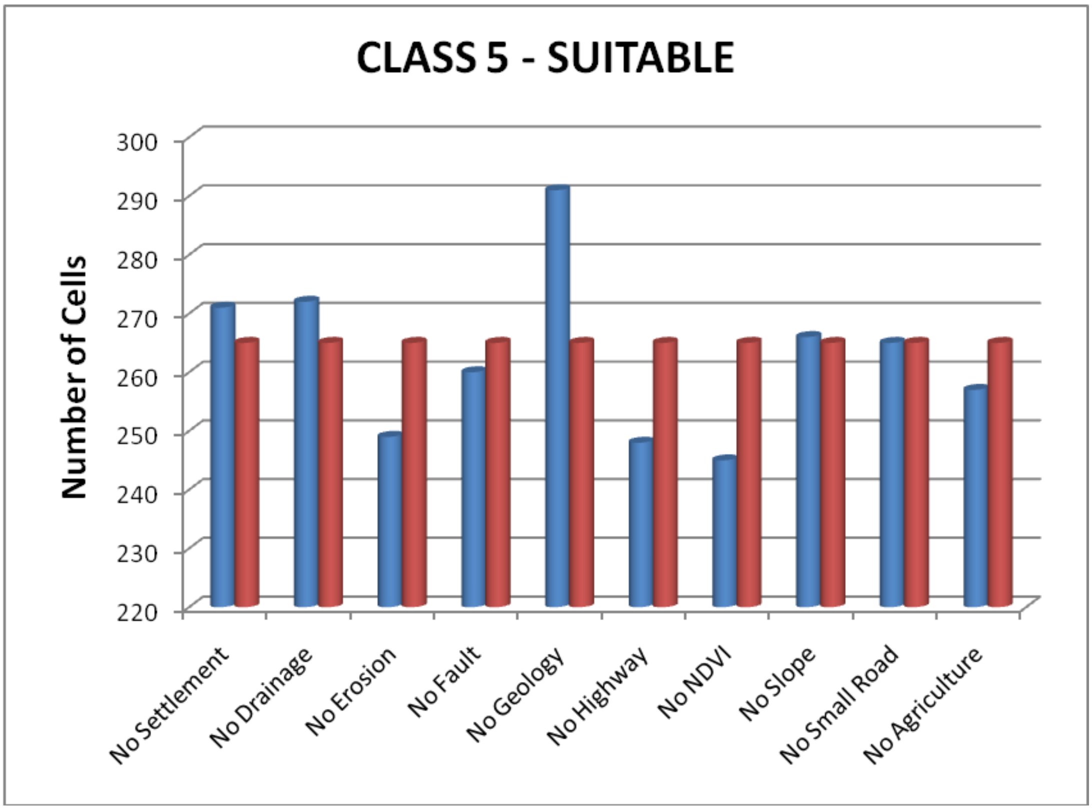

Figure 4.28. The number of cells corresponding to class 5 (most suitable) for each image where one of the layers is excluded.

The number of cells corresponding to class 1 (least suitable) for each image where one of the layers is excluded, are shown on Figure 4.29. When the number of cells that correspond to class 1 for the map where a layer is excluded is less than the number of cells that correspond to class 1 for the map that includes all of the layers, it indicates a problem. This situation is observed mainly for the drainage and the NDVI layers. In conducting the drainage analysis a very conservative approach is followed, meaning the main dry and perennial rivers are assumed to be wet in order to account for rainy years. So this difference can be overseen. On the other hand in order to account for the variation in the number of cells corresponding to class 1 appear between the maps excluding and including the NDVI layer which shows the vegetated areas, further investigation should be performed before constructing the landfill site in order not to use an area for the landfill site that is densely vegetated which could be an indicator of low groundwater depth.

This analysis both for the geology and the NDVI layers justify the need for detailed geological, geotechnical investigation in the landfill site for geological and geotechnical characterization and for obtaining detailed information on the groundwater depth in the area.

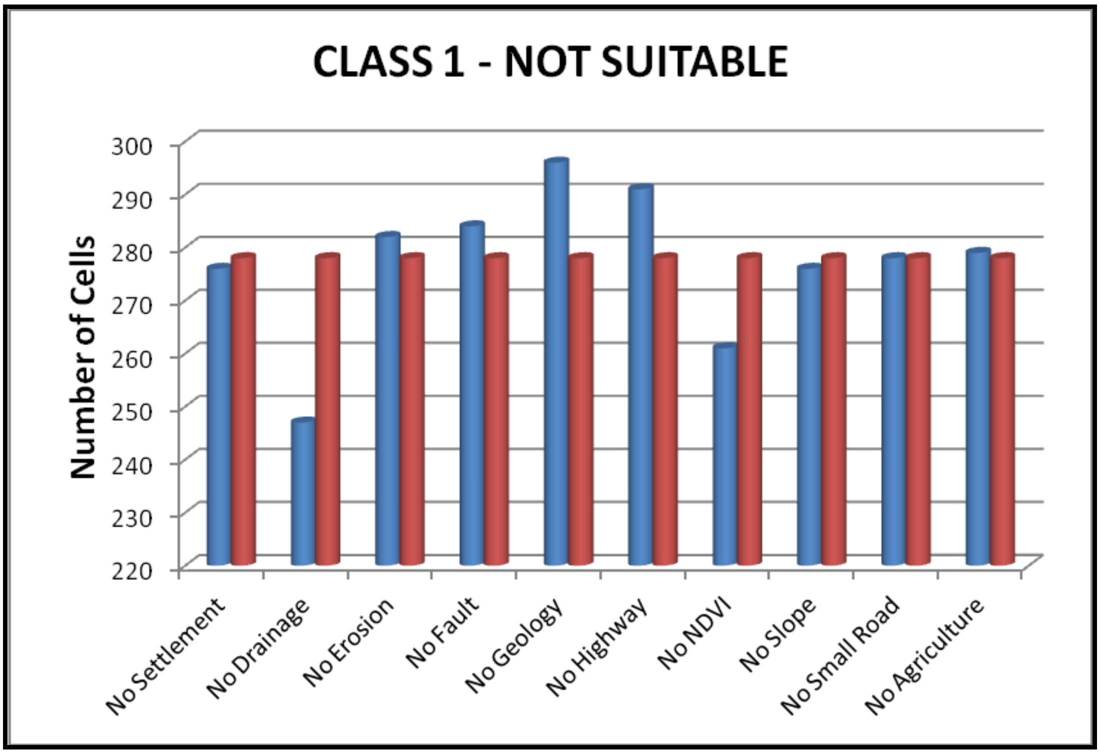

Figure 4.29. The number of cells corresponding to class 1 (least suitable) for each image where one of the layers is excluded.

CHAPTER FIVE

LANDFILL LINER DESIGN

5.1. Introduction

The basic design of a sanitary landfill consists of waste cells and soil layers (daily cover). The waste water that percolates through the waste creates leachate. Landfills are designed in way that this leakage is not completely prevented but controlled and anticipated. At a landfill site, the percolation of water into the waste, and the release of leachate to the subsurface should be minimized and gas and leachate should be collected and removed. For this purpose bottom liners and cut-off walls are used. In Figure 5.1 a clay layer and geomembrane serve as a composite barrier to the movement of leachate and landfill gas thus protect the ground water from landfill contaminations. A leachate collection layer (sand/gravel or geonet) is used to minimize the intermixing of the soil and gravel layers. The protective soil layer is utilized to protect the drainage and barrier layers form getting punctured. (Tchobanoglous et al., 1993) The geotextiles are used to prevent the movement of soil and refuse particles into the leachate collection layers and trap the particles in order to prevent clogging while allowing the movement of water.

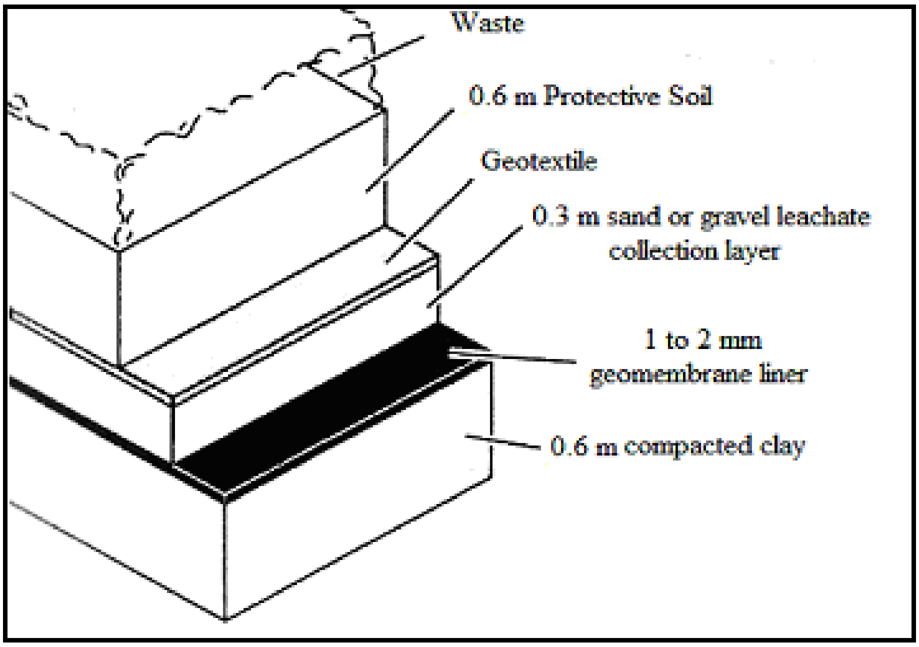

Figure 5.1. Bottom liner design (modified from Tchobanoglous et al., 1993).

The daily waste is covered by intermediate cover layers in order to limit the surface infiltration. Yard waste mulch, yard waste compost, municipal solid waste (MSW) compost, geosynthetic clay liner (GCL), typical native soil, clayey silty sand, and clay can be used as the intermediate cover material (Tchobanoglous et al., 1993).

The landfill should also be composed of a final cover layer in order to minimize the infiltration of water from rainfall and snowfall, limit the uncontrolled release of gases and serve as a reclamation site. A cover layer design can be seen in Figure 5.2. The typical components of a landfill cover and their use are illustrated on Table 5.1.

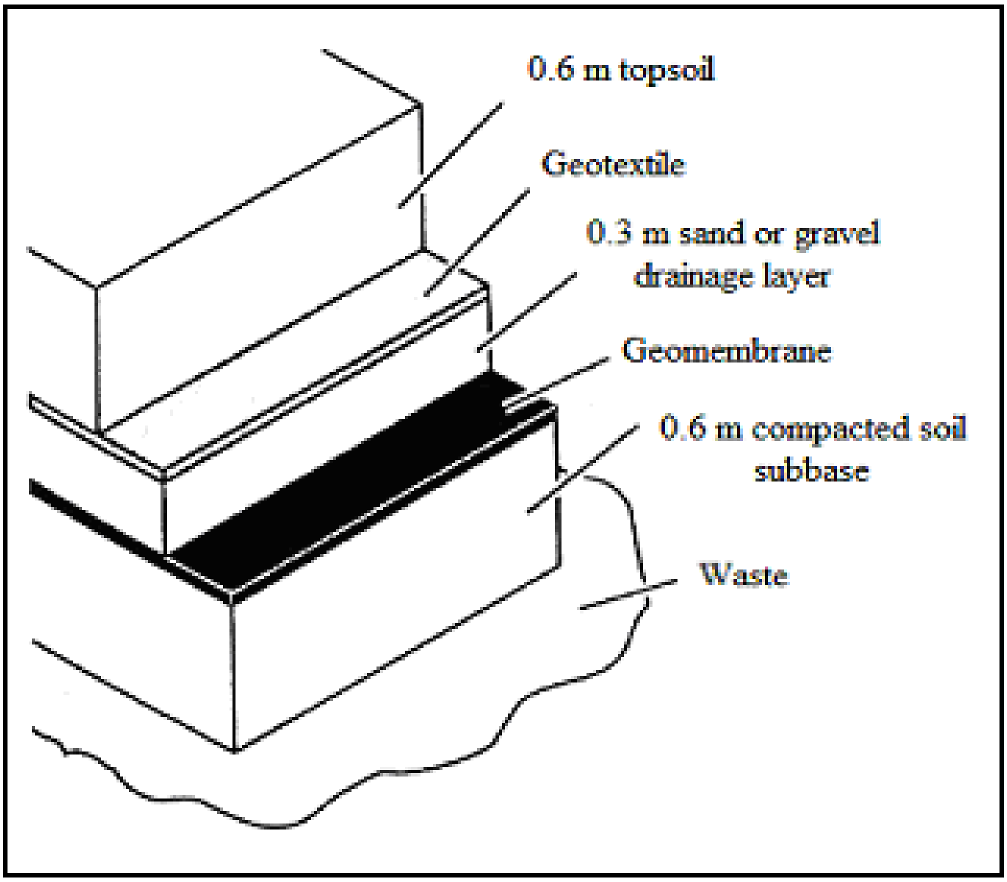

Figure 5.2. Landfill cover design (from Tchobanoglous et al., 1993).

Table 5.1. The typical components of a landfill cover and their use (Tchobanoglous et al., 1993).

Component	Typical Materials	Function
Surface Layer	Cover soil, available locally or imported	To contour the surface of the landfill and to support the plants
Protective Layer	Sand and gravel or soft refuse	To protect the drainage and barrier layers
Drainage Layer	Sand, gravel or geonet and geotextile separator	To transport the rainwater and snowwater that infiltrates through the cover material away from the barrier layer
Barrier Layer	Geomembrane	To restrict the movement of liquids into the landfill and to release landfill gas
Subbase	Compacted and graded native soil	To contour the surface of the landfill and to serve as a base for the barrier layer

5.2. Standards and Requirements

The design of the landfill sites should comply with the regulatory requirements enacted by the government. The standards and requirements implemented by the US Environmental Protection Agency (US EPA) and the Turkish Republic, Ministry of Environment are summarized respectively.

5.2.1. US Environmental Protection Agency-Criteria for Municipal Solid Waste Landfills

The U.S. Environmental Protection Agency requires the use of a composite lining system for the containment of municipal solid waste. A composite liner implies a system consisting of two components: a geomembrane or flexible membrane liner

(FML) overlying a compacted clay liner (CCL). According to the US EPA regulations the upper component of the composite lining system must consist of a flexible membrane liner (FML) possessing a thickness of at least 30 mil (0.75 mm). The lower component must consist of at least a 0.6 m thick layer of compacted soil with a coefficient of permeability of no more than 1×10^{-9} m/s. FML components consisting of high density polyethylene (HDPE) are required to be at least 60 mil (1.5 mm) thick. The FML component must be installed to assure direct and uniform contact with the compacted soil component.

The final cover is required to have a coefficient of permeability less than or equal to the coefficient of permeability of any bottom liner system or natural subsoils present, or a coefficient of permeability no greater than 1×10^{-9} m/s. An infiltration layer that contains a minimum 0.46 m thick earthen material and an erosion layer that contains a minimum 0.4 m of earthen material can sustain native plant growth.

A leachate collection system is required to be constructed that functions and continuously monitors leachate to ensure that the head of leachate maintained over the liner does not exceed 0.3 m (U.S. Environmental Protection Agency, 2010).

5.2.2. Turkish Republic, Ministry of Environment - Criteria for Municipal Solid Waste Landfills

A composite liner is required by the Turkish Republic, Ministry of Environment as well. At the base of the landfill, the upper component must consist of a flexible membrane liner (FML) and the lower component of at least a 0.6 m thick layer of compacted soil with a coefficient of permeability of no more than 1×10^{-10} m/s. For slightly discontinuous rock foundations this value is 1×10^{-9} m/s. The FML components consisting of high density polyethylene (HDPE) are required to be at least 2 mm thick. The density of the FML component should be between 941-965 kg/m^3. Above the impermeable layer a 0.3 m thick drainage layer is required in order to collect leachate water (Republic of Turkey, Ministry of Environment and Forestry, 2010).

5.3. Data Description

The estimation of the percolation of rainwater or snowmelt through the layers of the designed landfill was performed by utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder 1994a, b). The native low permeability soils of Ankara known as "Ankara Clay" were used as a compacted clay liner (CCL) material. In order to provide input to the HELP model, the geotechnical properties (i.e., Atterberg limits, compaction parameters such as maximum dry density and optimum moisture content, coefficient of permeability, etc.) of the clay needed to be determined. A total of four Ankara Clay soil samples were collected where two samples were collected from Gölbaşı (samples Gölbaşı 1 and Gölbaşı 2) and two from Sincan (samples Sincan 1 and Sincan 2). Figure 5.3 shows the sampling locations. In addition to the geotechnical properties, temperature, precipitation and evapotranspiration data pertaining to Ankara was gathered to provide input to the HELP model.

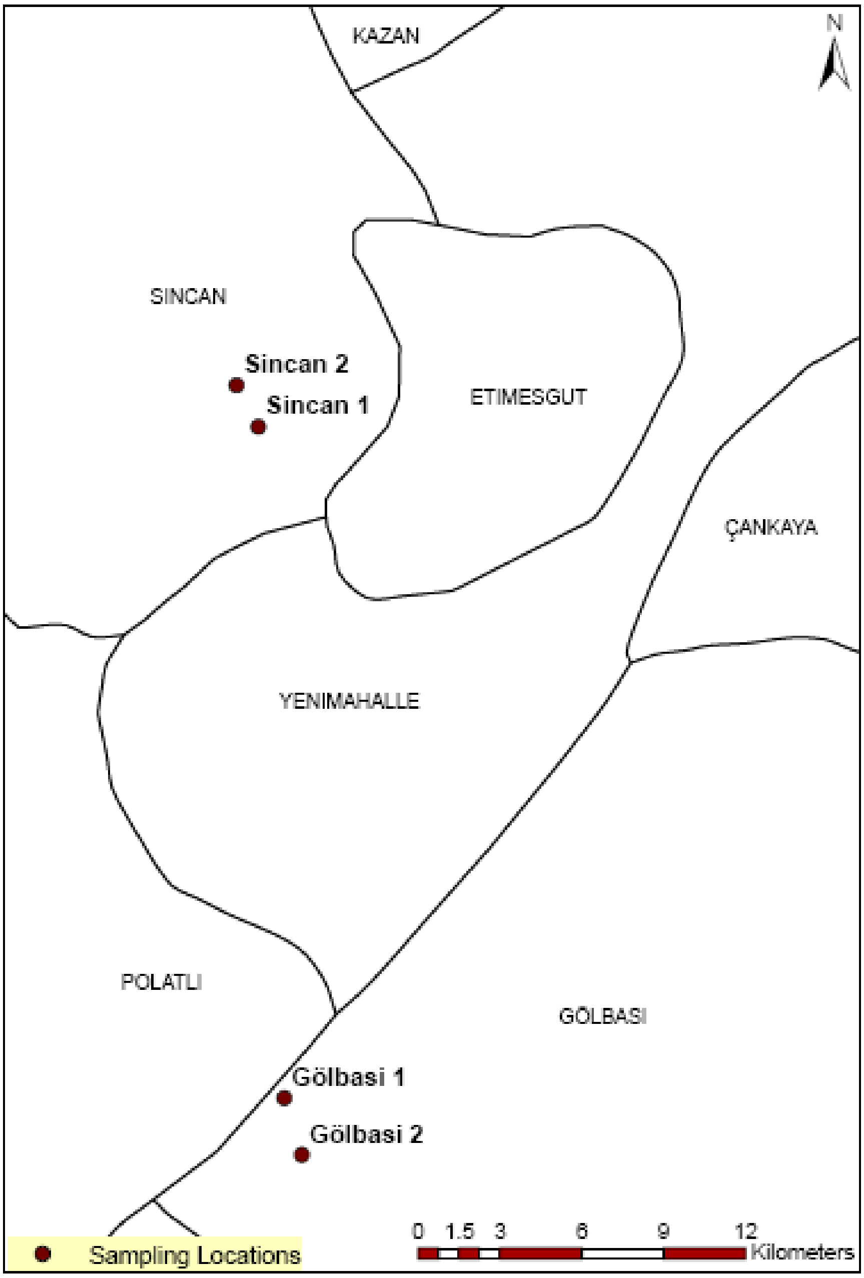

Figure 5.3. Sampling Locations

5.3.1. Specific Gravity, Particle Size Distribution and Plasticity Index

Soil mechanics laboratory tests, in order to obtain the specific gravity, particle size distribution and Atterberg limits have been conducted. The specific gravity values of the soils specimens are presented in Table 5.2. (ASTM D854-02). The particle size distribution of soil specimens using sieve analysis was performed according to standard practice (ASTM D422-63, 2002). The results of the test can be seen in Tables 5.3 through 5.6.

Table 5.2. Specific Gravity values of the soil specimens.

Sample Number	Specific Gravity G_s (g/cm^3)
Sincan 1	2.461
Sincan 2	2.48
Gölbaşı 1	2.432
Gölbaşı 2	2.476

Table 5.3. Sieve analysis results for soil sample Sincan 1.

Sieve Size		Mass of soil retained on each sieve (g)	Percent of mass retained on each sieve %
Inch	mm		
3	75	0	100
2	50	0	100
1 ½	37.5	0	100
1	25	62	100
¾	19	39	99
3/8	9.5	116	99
No. 4	4.75	244	98
No. 10	2.00	0.50	97
No. 40	0.42	3.50	95
No. 200	0.075	18.20	86

Table 5.4. Sieve analysis results for soil sample Sincan 2.

Sieve Size Inch	Sieve Size mm	Mass of soil retained on each sieve (g)	Percent of mass retained on each sieve %
3	75	0	100
2	50	0	100
1 ½	37.5	0	100
1	25	37	100
¾	19	31	100
3/8	9.5	170	99
No. 4	4.75	295	98
No. 10	2.00	11.20	93
No. 40	0.42	16.50	87
No. 200	0.075	36.60	72

Table 5.5. Sieve analysis results for soil sample Gölbaşı 1.

Sieve Size Inch	Sieve Size mm	Mass of soil retained on each sieve (g)	Percent of mass retained on each sieve %
3	75	0	100
2	50	0	100
1 ½	37.5	0	100
1	25	46	100
¾	19	68	99
3/8	9.5	256	98
No. 4	4.75	201	97
No. 10	2.00	11.30	91
No. 40	0.42	18.60	81
No. 200	0.075	24.00	68

Table 5.6. Sieve analysis results for soil sample Gölbaşı 2

Sieve Size Inch	Sieve Size mm	Mass of soil retained on each sieve (g)	Percent of mass retained on each sieve %
3	75	0	100
2	50	0	100
1 ½	37.5	0	100
1	25	43	100
¾	19	48	100
3/8	9.5	155	99
No. 4	4.75	204	98
No. 10	2.00	4.00	96
No. 40	0.42	10.40	90
No. 200	0.075	15.80	82

The soils may be in four states being solid, semi-solid, plastic and liquid with regards to their water content. Plastic limit (PL) and liquid limit (LL) are arbitrary divisions between these states. PL and LL are determined according to ASTM standards for liquid limit, plasticity limit, and plasticity index of soils (ASTM D4318). PI is then calculated using the following relation:

$$PI = LL - PL \tag{5.1}$$

The results of the Atterberg limit tests are tabulated in Table 5.7.

Table 5.7. Plastic limit, liquid limit and plasticity index values

Sample Number	LL	PL	PI	Soil Type
Sincan 1	47.3	20	27.3	CL
Sincan 2	58.9	26.2	32.8	CH
Gölbaşı 1	49.3	23.0	26.3	CL
Gölbaşı 2	46.6	19.2	27.4	CL

The plasticity index (PI) values vary between 27.3 and 32.8. The minimum PI required for a clay liner is specified by Gordon et al. (1990) to be greater than 15 and by Daniel et al. (1990) to be greater than 10. The soil specimens collected from Gölbaşı and Sincan satisfy both of these requirements. It is also required by Gordon et al. (1990) that the LL should be greater than 30 which is also satisfied by all four soil specimens collected.

5.3.2. Optimum Water Content

Soil samples with varying water contents were compacted by using the Standard Proctor compaction apparatus according to laboratory compaction characteristics of soil using standard effort (ASTM D698). The bulk density and water content of the compacted soil samples were determined in order to compute the corresponding dry unit weights. The soil samples were compacted six times at varying water contents thus five unit weight values were obtained. The dry unit weight increased with increasing water content until it reached a peak value beyond which the water content increased with decreasing dry unit weight. The peak of the compaction gave the optimum water content (w_{opt}) and the corresponding maximum dry unit weight ($\gamma_{d\ max}$). The dry unit weight versus water content graphs are presented in the Appendix A. The results of the Standard Proctor compaction tests are summarized in Table 5.8

Table 5.8. Summary of maximum dry unit weight ($\gamma_{d\ max}$) and optimum water content (w_{opt}) values.

SAMPLE NUMBER	$\gamma_{d\ max}$ (kN/m^3)	w_{opt} (%)
Sincan 1	13.39	38.5
Sincan 2	17.73	22.9
Gölbaşı 1	13.34	34.7
Gölbaşı 2	14.61	23.1

5.3.3. Permeability

5.3.3.1. Falling head permeability tests

Falling head permeability testing was conducted according to ASTM for measurement of hydraulic conductivity of porous material using a rigid-wall, compaction-mold permeameter (ASTM D5084) to calculate the coefficient of permeability values of the compacted soil samples Sincan 1 and Gölbaşı 1. The 10.2 cm (4 in.) diameter compacted soil specimens were placed in rigid-wall compaction permeameters for hydraulic conductivity determination. The compacted soil specimens were first placed in a water filled tank for a period of 2 weeks in an attempt to fully saturate the clay specimens prior to permeability testing. The tests were each run for a period of 3 days using distilled water Table 5.9. gives the dimensions of the testing apparatus.

Table 5.9. Rigid-wall compaction permeameter equipment dimensions.

Sample Diameter (mm)	101.8
Sample Length (mm)	117
Pipette Diameter (mm)	9.4
Sample Area (mm^2)	8135
Pipette Area (mm^2)	69.4

The coefficient of permeability values reported by Table 5.10 were determined.

Table 5.10. Coefficient of permeability values determined from falling head compaction permeameter testing.

Sample Number	Coefficient of Permeability (m/s)
Sincan	9.94×10^{-11}
Gölbaşı	2.06×10^{-10}

5.3.3.2. One-Dimensional Consolidation

One-dimensional consolidation testing was conducted according to ASTM for one-dimentional properties of soils using incremental loading (ASTM D2435-04) on the Sincan 1 and Gölbaşı 1 soil specimens. Consolidation testing was performed over a number of load increments being 0-0.25, 0.25-0.50, 0.50-1, 1-2, 2-4, and 4-8 kgf/cm^2 increments with 24 hour durations were doubled in the successive increments using distilled water First the t_{50} values were determined by using Casagrande's method or the log time method. The plots can be seen in the Appendix B. The determined t_{50} values are shown by the blue arrows for the Sincan 1 soil specimen. The plot of void ratio (e) versus log pressure (p) graphs for the Sincan 1 and Gölbaşı 1 soil samples which have not been used in any analysis as related to this thesis can be found in Appendix B and the determined coefficient of volume compressibility (m_v), coefficient of consolidation (c_v) and coefficient of permeability (k) values are presented by Tables 5.11 and 5.12, respectively.

Table 5.11. Coefficient of volume compressibility (m_v), coefficient of consolidation (c_v), coefficient of permeability (k) values determined from consolidation testing of soil sample Sincan 1.

P (kgf/cm^2)	**m_v (cm^2/kgf)**	**c_v (cm^2/min)**	**k (m/s)**
0.00-0.25	0.0152	0.0131	3.3 x 10^{-11}
0.25-0.50	0.0189	0.0259	8.2 x 10^{-11}
0.50-1.00	0.0167	0.0226	6.3 x 10^{-11}
1.00-2.00	0.0150	0.0208	5.2 x 10^{-11}
2.00-4.00	0.0223	0.0434	9.6 x 10^{-11}
4.00-8.00	0.0117	0.0412	8.1 x 10^{-11}
Mean			6.78 x 10^{-11}

Table 5.12. Coefficient of volume compressibility (m_v), coefficient of consolidation (c_v), permeability (k) values determined from consolidation testing of soil sample Gölbaşı 1.

P **(kg/cm^2)**	**m_v** **(cm^2/kg)**	**c_v** **(cm^2/dak)**	**k** **(m/s)**
0.00-0.25	0.0320	0.1961	5.7×10^{-10}
0.25-0.50	0.0244	0.0324	1.3×10^{-10}
0.50-1.00	0.0261	0.0238	1.0×10^{-10}
1.00-2.00	0.0140	0.0741	1.7×10^{-10}
2.00-4.00	0.0136	0.0174	6.9×10^{-11}
4.00-8.00	0.0166	0.0163	2.7×10^{-11}
Mean			1.8×10^{-10}

It should be noted that the coefficient of permeability values for the Sincan clay samples were an order of magnitude lower than that of the Gölbaşı clay samples which may have been caused by the higher lime content of the Gölbaşı clayey soils. This lime content might have caused preferential pathways for water leading to an increase in the coefficient of permeability.

5.3.4. Compaction- Permeability Relations and Field Permebility

The compaction behaviors of the soil specimens are illustrated by the results of the Standard Proctor Compactions Test (Appendix A). The particles develop a water film around them which increases in thickness as the water content increases. This thin water film makes the movement of particles easier and allows them to reorient to a denser configuration. However, at a optimum water content (w_{opt}) and maximum dry unit weight ($\gamma_{d\ max}$) further densification of the soil is not possible and water starts to replace soil particles in the mold thus the dry density starts to decrease. Meanwhile the permeability (k) decreases with the increasing water content and reaches a minimum at the optimum water content. When the soil is compacted on the dry side of the optimum the permeability is approximately one order of magnitude higher than when it is compacted wet of optimum.(Compaction). This decrease is due to the precence of more dispersed soil structure when compacted wet of optimum. Generally the liner compaction specifications are based on Standard Proctor compaction data. However, at water contents drier than that of the optimum moisture (water) content, care should be given when specifying field compaction since hardened soil clods are difficult to compact, soil becomes brittle, giving rise to the possibility of formation of compaction-induced fractures. Also compaction wet of optimum may pose the risk of shrinkage since such soils shrink on drying. On the other hand horizontal shrinkage causes cracking rather than shrinkage, in order to prevent cracking, the clay liner should not be allowed to dry (Holtz and Kovacs, 1981).

The reliability of the clay liners has been questioned over the years. To this respect the variation between the field permeability values and the laboratory permeability values have been investigated by several researchers over the years. Daniel (1984) reported field k values 100,000 times greater then laboratory values. Also, Giardi and Paci (1991) reported field k values 1000 times greater than laboratory values. A two orders of magnitude difference between field and laboratory permeability values is reported by Gogula et al. (2003). The four main factors causing this inconsistency is explained by Rowe at al. (1995) which are light compaction, cracking, damage during k-test system installation, and the inability of the filed tests to represent the stress levels due to later imposed load (waste and cover materials). Uttermost care should be given during the compaction of clay liner as it appears that for well designed and constructed clay liners the laboratory and field permeability values coincide. The compactor needs to be capable of varying its frequency and have the range to obtain the maximum dry unit weight. The first and the most common roller developed for field compaction is the sheepsfoot roller which is best suited for cohesive (Holtz and Kovacs, 1981).

5.3.5. Meteorological Data

The meteorological data required for the HELP model are: monthly precipitation and temperature data, evaporative zone depth, maximum leaf area index, dates starting and ending the growing season, average annual wind speed and average quarterly relative humidity. The evaporative zone depth is the maximum depth at which evapotranspiration is effective thus the water can be removed. Clayey soils exert great capillary suction thus the evaporative zone depths are larger. The evaporative depth suggested for clayey soils is between 0.3-1.5 meters (Schroeder, et al., 1994a). The mean value of 0.9 m was used for the analysis. The leaf area index (LAI) is defined as the dimensionless ratio of the leaf area of actively transpirating vegetation to the nominal surface area of the land on which the vegetation is growing. LAI values vary between 1 (poor) to 5 (excellent) stand of grass. A value of 1.5 was taken assuming poor to fair stand of grass.

The temperature and precipitation data between years 1975-2008 was gathered from the General Directorate of State Meteorological Works as presented by Table 1.2 in Chapter 1. These values were assumed to be representative of the next 30 years.

5.4. Modeling

5.4.1. Hydrologic Evaluation of Landfill Performance (HELP) Model

5.4.1.1. Introduction

The estimation of the percolation of rainwater or snowmelt through the layers of the designed landfill was performed through utilizing the Hydrologic Evaluation of Landfill Performance (HELP) model (Schroeder et al., 1994a, b). Four different landfill profiles were modeled. The thickness, porosity and coefficient of permeability values of the layers in the landfill profile are shown in Table 5.13. The standards suggested by EPA were considered in selecting the thickness values. The waste layer thickness was taken as 20 m which is the mean waste thickness for the Mamak landfill site (Dilek, 2006). For the HELP analysis the mean coefficient of permeability value of Sincan soil sample was used since Sincan would be the first choice for the construction of a landfill site due to the city expanding towards it.

Table 5.13. Thickness, porosity, and coefficient of permeability values used in the analysis.

Layer	Thickness (m)	Porosity*	Coefficient of Permeability (m/s)
Topsoil	1	0.475	2.00E-07*
Sand	0.3	0.457	1.00E-03*
HDPE Geomembrane Liner	0.002	~ 0	24.00E-15*
Compacted Clay Liner (CCL)	0.6	0.427	8.40E-11**
Waste	20	0.671	1.00E-05*
Lateral drainage net	0.005	0.85	1.00E-01*

*From Schroeder et al. (1994a).
**The mean value of coefficient of permeability was obtained through compaction permeameter and consolidation testing.

Four landfill profiles from least to most conservative were created with the HELP model. The HELP model was employed in order to determine the leachate head and leakage amounts when a 30 year life span for the landfill is assumed. Four different profiles from least conservative to most conservative were created. The first profile, from top to bottom consisted of a topsoil layer, a waste layer, and a geomembrane/compacted clay composite liner. A compacted clay liner was added to the cap below the topsoil for the second profile (Figure 5.4). The second profile, from top to bottom consisted of a topsoil layer, a compacted clay liner, a waste layer and a geomembrane/compacted clay composite liner (Figure 5.5). A lateral drainage layer in order to collect leachate was added below the waste layer for the third profile. The third profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner (Figure 5.6). The fourth profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane/compacted clay composite top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner (Figure 5.7). The fourth profile selected was the one with the least environmental impact.

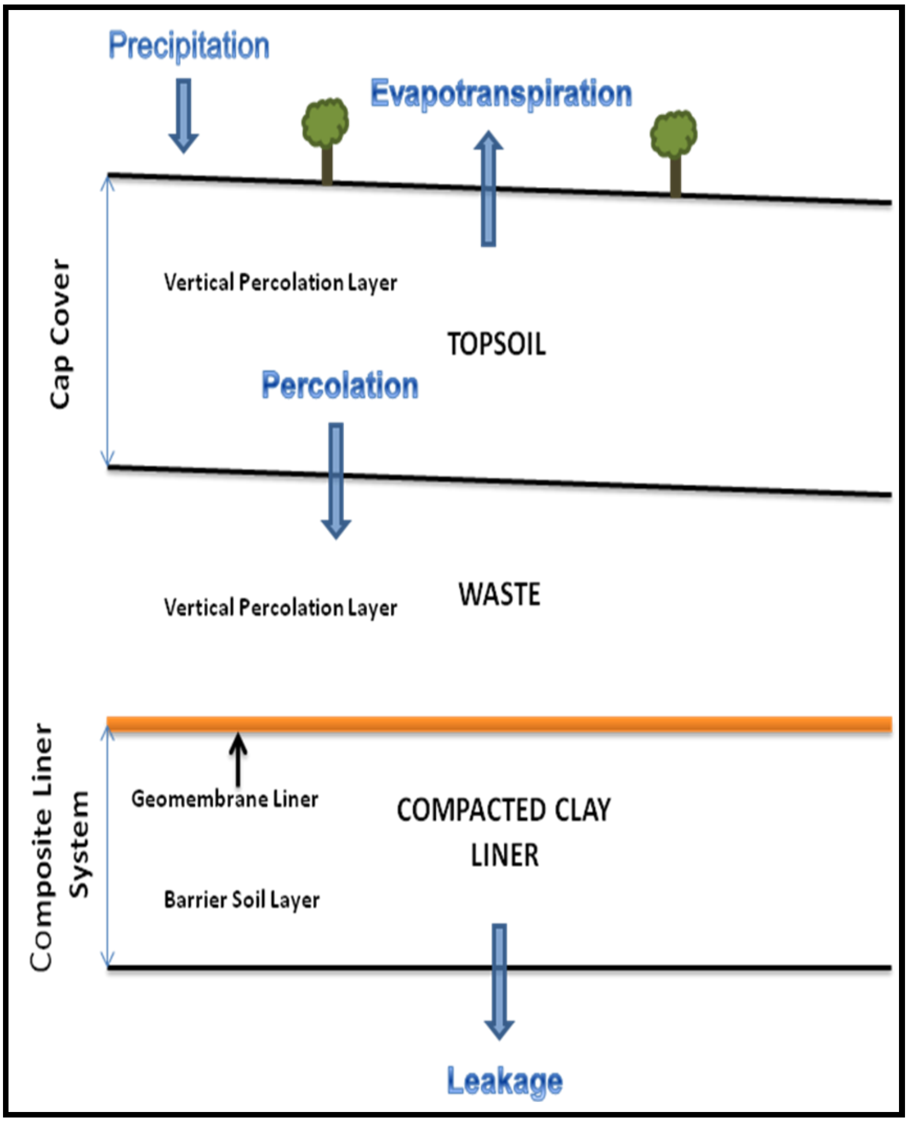

Figure 5.4. Profile 1 modelled by HELP (from Met, 1999).

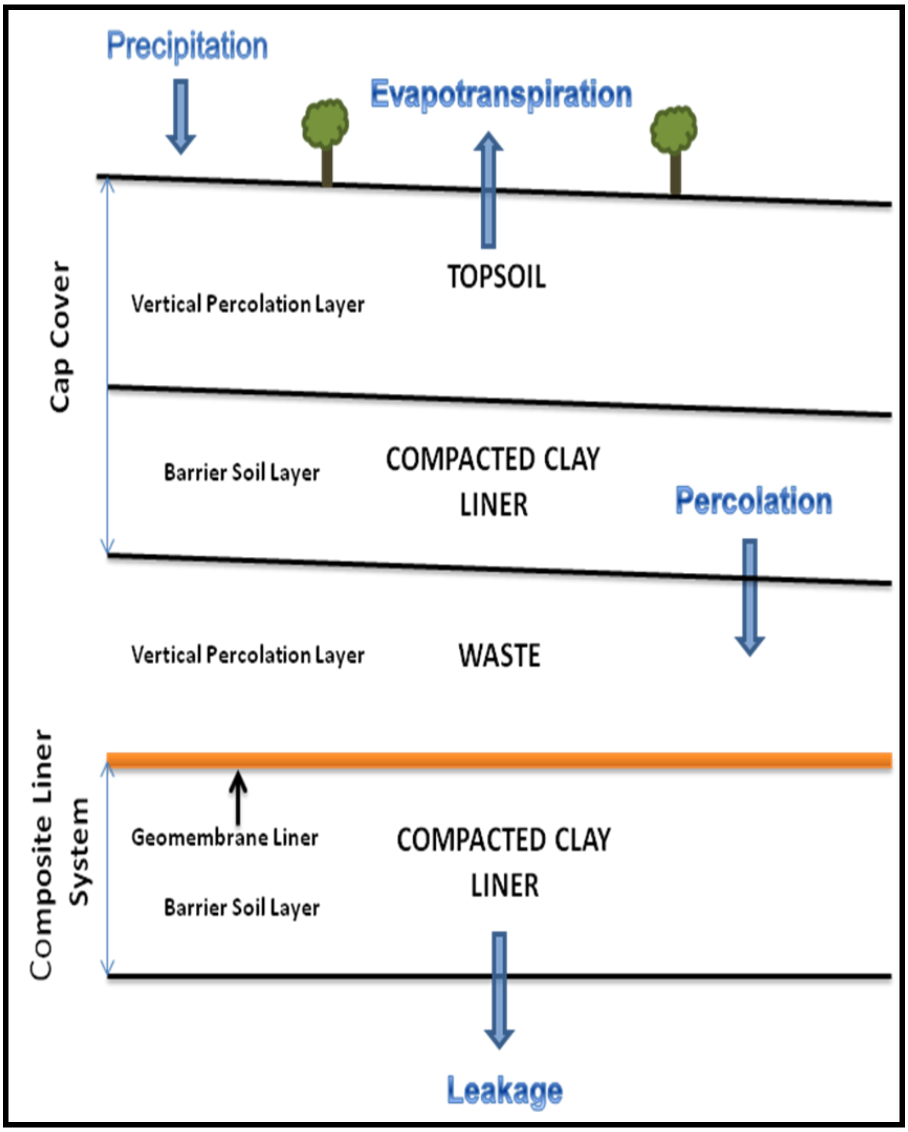

Figure 5.5. Profile 2 modeled by HELP (from Met, 1999)

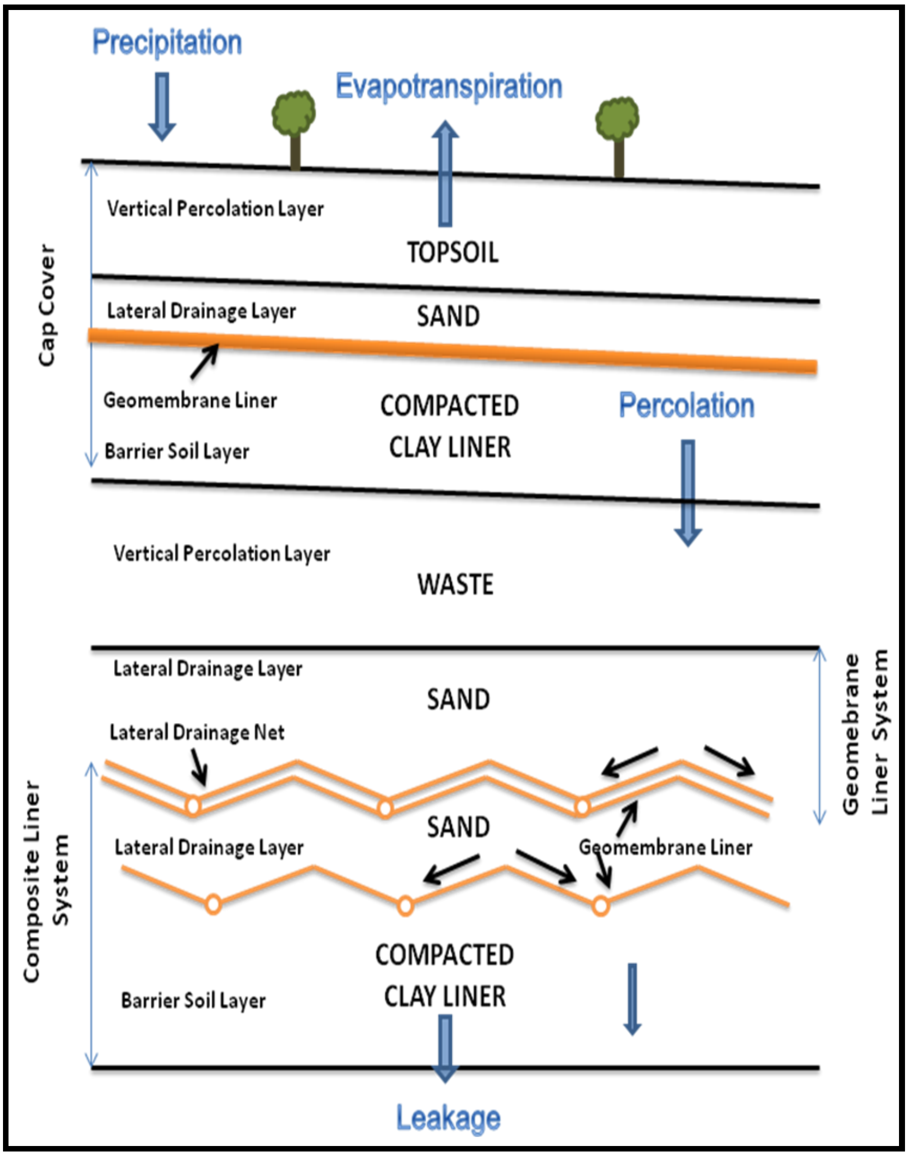

Figure 5.6. Profile 3 modeled by HELP (from Schroeder et al., 1994a).

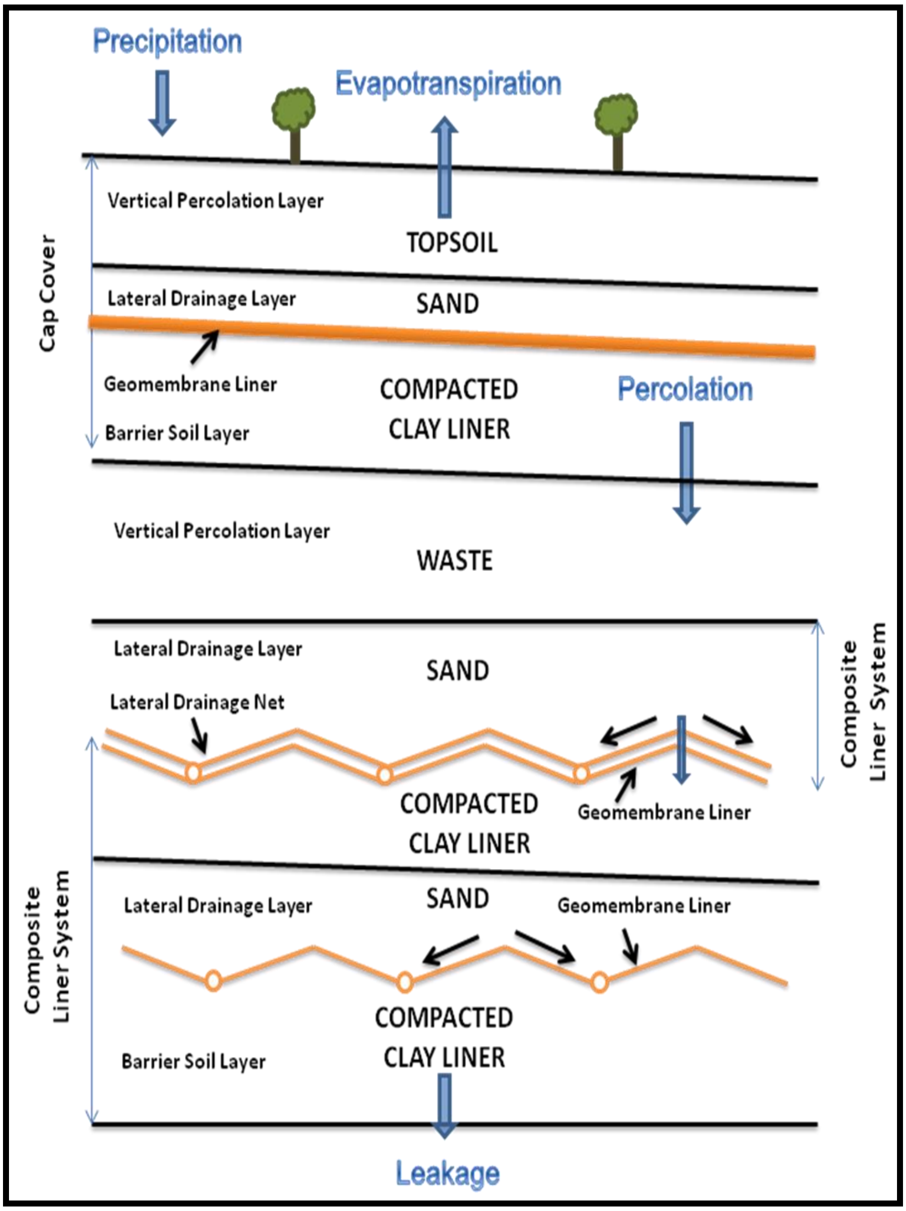

Figure 5.7. Profile 4 modeled by HELP.

5.4.1.2. Results

The HELP model was performed for all the four profiles. The cumulative unitized expected leakage rate versus time and cumulative mean leachate head versus time for a 30 year period are plotted in Figures 5.8 and 5.9, respectively. As can be seen from Figure 5.20 the cumulative unitized expected leakage for Profile 1 is about in the order of 10^{-3} m^3/year/10,000 m^2 at the end of 30 years. For Profile 2, the cumulative unitized expected leakage rate decreases approximately one order of magnitude to 10^{-4} m^3/year/10,000 m^2 with the insertion of the compacted clay liner (CCL) in the cap system. The unitized expected leakage decreases drastically to approximately 5 x 10^{-6} m^3/year/10,000 m^2 with the insertion of the lateral drainage layer and the geomembrane liner leading to a double lined system. Profile 4 being the most conservative profile composed of a double composite lining system yields the lowest cumulative unitized leakage rate that is in the neighborhood of 10^{-7} m^3/year/10,000 m^2 at the end of 30 years. This profile is used for the disposal of hazardous waste in the US.

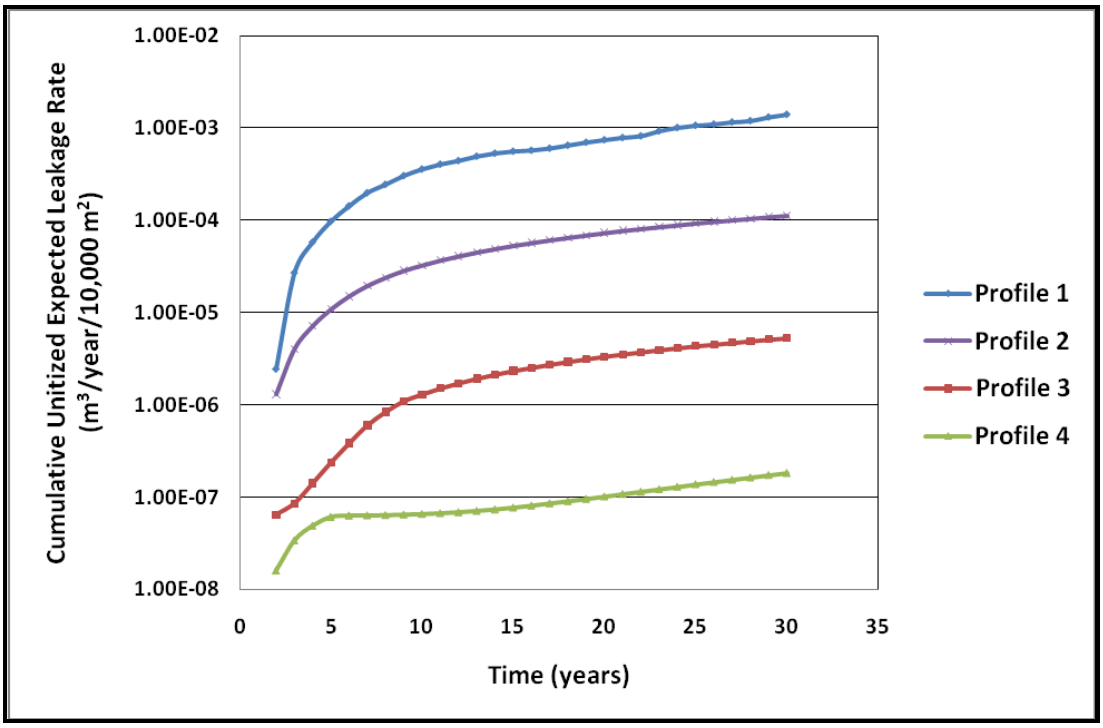

Figure 5.8. Cumulative unitized expected leakage rate versus time

The cumulative mean leachate head versus time graphs for 30 years in Figure 5.9 also shows a decreasing trend in the mean leachate head values going from Profile 1 to Profile 4. The mean leachate head for Profile 1 and 2 at the end of 30 years is approximately 8 m and 0.5 m, respectively. Conversely the mean leachate heads for Profile 3 at the end of 30 years is approximately 0.01.m. An apparent decrease in the mean leachate head was observed for Profile 4 with a mean leachate head value between 10^{-3} to 10^{-4} m. In Figures 5.8 and 5.9 a similar trend for all four profiles in which a steep increase till approximately 10 years followed by a moderate increase throughout the next 20 years is observed.

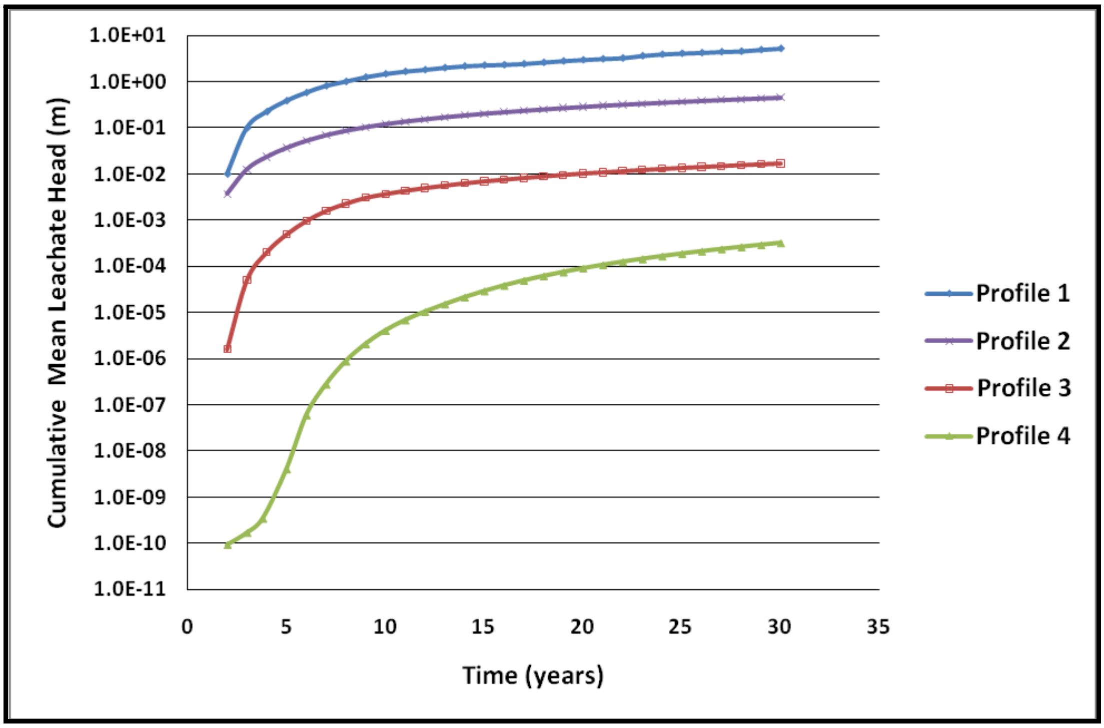

Figure 5.9. Cumulative Mean leachate head versus time.

5.4.2. POLLUTE Model

5.4.2.1. Introduction

As mentioned in the Chapter 2 the so called "Ankara Clay" formation with variable thickness exceeds 200 m at places and the only groundwater bearing formation is the alluvium (i.e., the aquifer is located at a depth of approximtely 200 m below the ground surface). However, in order to simulate a worst case scenario, the landfill liner was modeled by inserting an aquifer just below the clay liner for Profile 1 and Profile 4 utilizing POLLUTE v7 software (Rowe, et al., 2004). The porosity, hydraulic conductivity, layer thickness and leachate head values used in the HELP analysis were utilized in the POLLUTE analysis. A diffusion coefficient of 5.42 x 10^{-6} was used for the compacted clay liner as recommended by Çamur and Yazıcıgil (2005). The POLLUTEv7 software has the capability to calculate the concentration of municipal waste that leaks to the bottom of the landfill liner. 1000 mg/L of municipal waste leachate is allowed to percolate through the landfill liner for Profiles 1 and 4, with an assumed 30 year life span for the landfill. The upper boundary for the model being the waste layer bottom is defined as a finite mass and the lower boundary being the bottom of the landfill (bottom of the lower composite liner) is defined as a fixed outflow.

5.4.2.2. Results

The concentration of municipal waste leachate versus time for Profile 1 is presented by Figure 5.10. As can be observed from Figure 5.10, as the wastewater percolates through the liner while the concentration at the bottom of the waste layer decreases, the concentration at the bottom of the landfill liner increases reaching up to approximately 300 mg/L for Profile 1 at the end of 30 years. On the other hand as can be observed seen from the concentration of municipal waste leachate versus time for Profile 4 (Figure 5.11), the municipal waste leachate concentration after 30 years is approximately 25 mg/L.

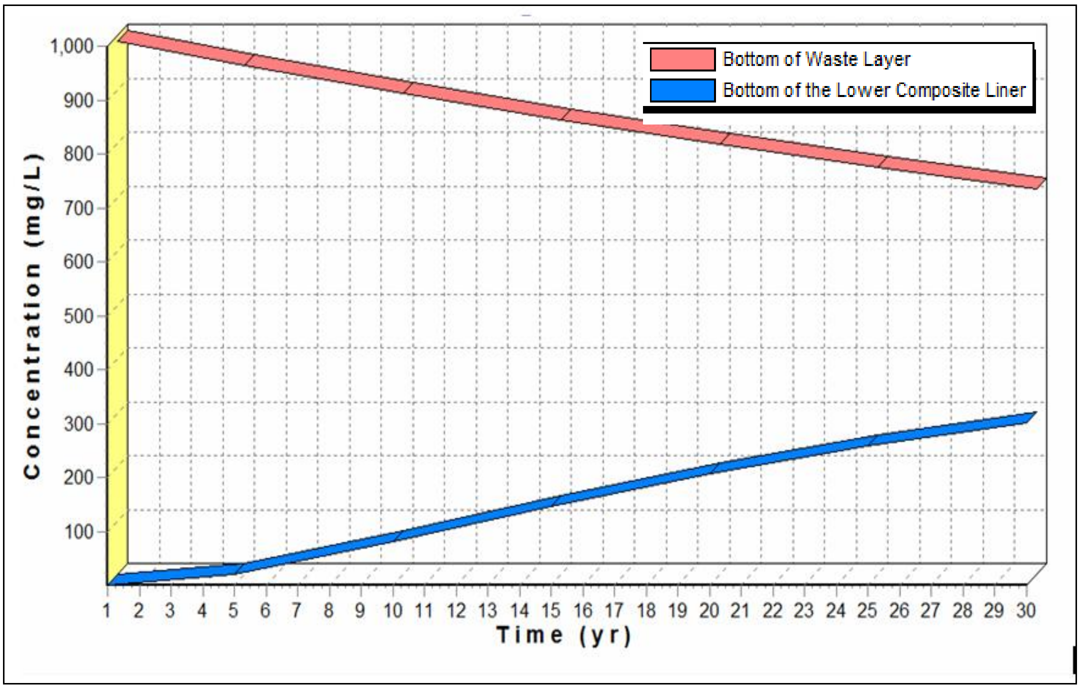

Figure 5.10. The concentration of municipal waste leachate versus time for Profile 1.

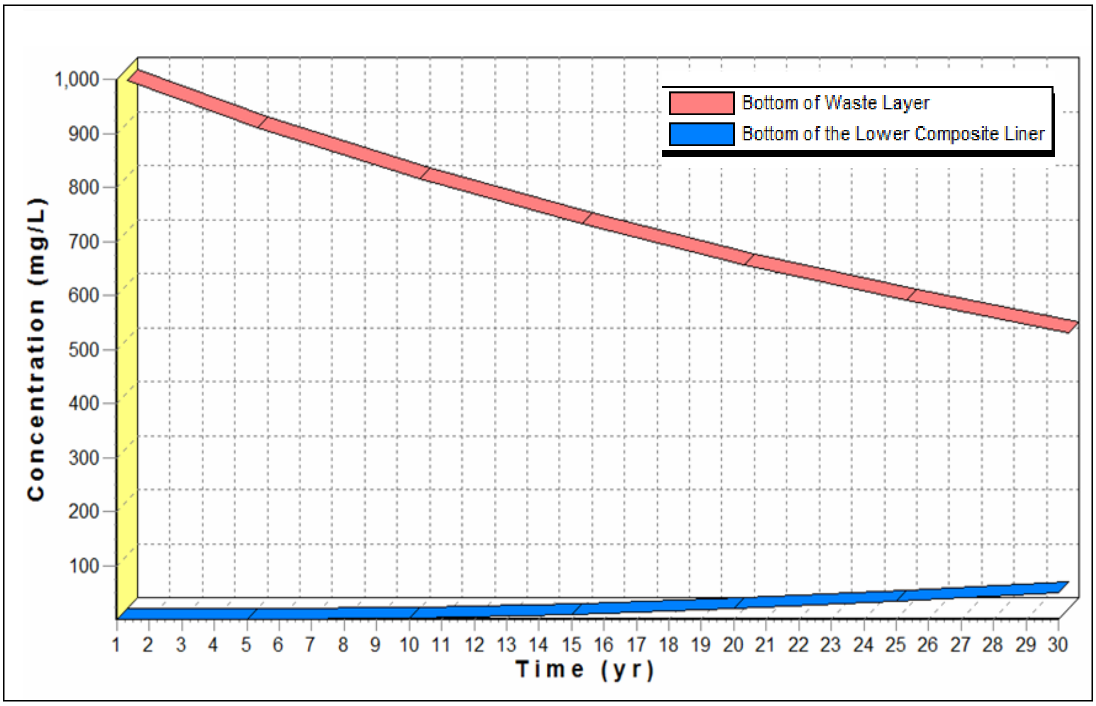

Figure 5.11. The concentration of municipal waste leachate versus time for Profile 4.

The average concentration of sodium, chloride, sulphate, chromium and cadimium present in a landfill waste leachate (Lee et al., 1986), the concentration of these components in the leachate that leaks to the bottom of the liner for Profile 1 and Profile 4 (the variations in transportation mechanisms of different components is disregarded), and the maximum allowable concentrations of these components in the landfill waste leachate that exits the bottom of the lower composite liner (regulated by the World Health Organization (2008) are tabulated in Table 5.14. As can be seen from Table 5.14 while Profile 4 complies with the regulations, the sodium, chloride, chromium and cadium concentrations for Profile 1 exceed the allowable limits. This analysis demonstrates the reliability of utilizing Landfill Profile 4 for safe deposition of solid waste even when a worst case scenario is assumed through inserting an aquifer just below the bottommost composite liner where in reality the aquifer is located at a depth of approximtely 200 m below the ground surface.

Table 5. 14. Concentrations of selected components of municipal waste leachate.

Component	Average Concentrations for Municipal Landfill Leachate (mg/L)	World Health Organization (WHO) Standards (mg/L)	Profile 1	Profile 4
Sodium	700	200	238	17.5
Chloride	980	250	333.2	24.5
Sulphate	380	500	129.2	9.5
Chromium	0.90	0.05	0.306	0.023
Cadmium	0.05	0.003	0.017	0.0013

CHAPTER SIX

SUMMARY AND CONCLUSIONS

This study comprises the selection a landfill site for Ankara, one in the Sincan municipality and one in the Gölbaşı municipality. Site selection was performed utilizing GIS and MCDA. Among various methods of MCDA, the TOPSIS method was applied in scope of this thesis. Factors or criteria considered in selecting an appropriate landfill site which will have the least environmental effect and the most suitable geology, geotechnical material properties, distance to roads, distance to settlements, slope, drainage, suitability for agriculture, land use, vegetation and seismic impact were considered. These criteria were weighed according to their relative importance utilizing the pairwise comparison method. Suitability maps were produced for Sincan and for Gölbaşı. Candidate sites possessing the highest suitability rankings were selected. In order to make a selection amongst these candidate sites, the criteria which have not been used during the GIS analysis was considered. These criteria comprised the 2023 development plan of Ankara, relative distance to the city center, and lot prices. Finally, one site for each municipality was selected.

It is common and economically rewarding practice to use native clay, if applicable, for the landfill compacted clay liner. “Ankara Clay” is known to be an excellent quality compacted clay liner (CCL) material (e.g., Met et al., 2005). The geotechnical properties of the clay samples were determined through sieve analysis, compaction, falling head testing and consolidation. The coefficient of permeability values were determined by compaction permeameter falling head and consolidation testing. The permeability values determined for the samples obtained from Sincan from falling head and consolidation tests were 6.78×10^{-11} m/s and 9.94×10^{-11} m/s respectively, and for Gölbaşı were 1.80×10^{-10} m/s and 2.06×10^{-10} m/s, respectively. By using these permeability values four landfill profiles from least to most conservative were modeled by the HELP model. The first profile, from top to bottom consisted of a topsoil layer, a waste layer, and a geomembrane/compacted clay composite liner. A compacted clay liner was added to the cap below the topsoil for the second profile. The second profile, from top to bottom consisted of a topsoil layer, a compacted clay liner, a waste layer and a geomembrane/compacted clay composite liner. A lateral drainage layer in order to collect leachate was added below the waste layer for the third profile. The third profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner. The fourth profile, from top to bottom consisted of a topsoil layer, a lateral drainage layer, a compacted clay liner, a waste layer, a lateral drainage layer, a lateral drainage net, a geomembrane/compacted clay composite top liner, a lateral drainage layer and a geomembrane/compacted clay composite bottom liner. The HELP model allowed determining the leachate head and leakage rate for a 30 year period. The result of this model proved the need for a double liner system and a leachate collection system as it was in Profile 4 where the model was drastically improved. The mean leachate head and the leakage rate was reduced approximately one order of magnitude with the addition of a double liner system. Also with inclusion of a lateral drainage system and geomebrane liner system the leachate head decreased again approximately one order of magnitude over 1 Ha and the leachate head declined approximately two orders of magnitude. The Profile 4 being the most conservative profile, involving a double composite liner system and drainage layers as expected resulted in the lowest mean leachate head and leakage rate values being 10^{-7} m^3/year/10,000 m^2 and 10^{-4} m, respectively. Modeling with POLLUTE also showed that Profile 4 can be used safely even at places with high groundwater level.

The native clay present at the sites selected proved to be appropriate for landfill liner design. However, further investigations for determining the design specifications and lot ownerships should be undertaken prior to construction. In order to determine the design specifications further detailed information on the geological and geotechnical characteristics of the geological units at the selected landfill sites need to be determined through detailed site investigation to mainly obtain a better understanding of the geotechnical characteristics and the groundwater level.

REFERENCES

Akyürek, B., Bilginer, E., Akbaş, B., Hepşen, N., Sunu, O., and Soysal, Y., 1982, "Ankara-Elmadağ-Kalecik Dolayının Jeolojisi", MTA Report No: 7298.

Akyürek, B., Bilginer, E., Akbaş, B., Hepşen, N., Sunu, O., and Soysal, Y., 1984, "Ankara-Elmadağ - Kalecik Dolayının Temel Jeoloji Özellikleri", Jeoloji Mühendisliği, V. 10, pp.31-46.

Akyürek, B., Bilginer, E., Çatal, E., Dağer, Z., Soysal, Y., and Sunu, O. 1980, "Elvidan-Şabanözü Çankırı ve Hasayaz-Çankırı Kalecik-Ankara dolayının jeolojisi" MTA Report No: 6741.

Ankara Metropolitan Municipality, 1992, "Ankara Katı Atık Yönetimi Uygulama Projesi", Ankara.

Ankara Metropolitan Municipality - Directorate of Development of City Planning, 2006, "2023 Ankara Municipality Regulatory Development Plan".

Aras, I. A., 1991, "Clay Mineralogy and Sedimentological Features of the Late Pliocene Sediments in Ankara Area", Middle East Technical University, MSc. Thesis.

ASTM D422–63, 2002, "Standard Test Methods for Particle-Size Analysis of Soils", Annual Book of ASTM Standards, Section 4, Vol.04, No.1, Soil and Rock; Building Stones, ASTM, Philadelphia.

ASTM D698–00, "Standard test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-Ibf/ft^3(600kN-m/m^3))", Annual Book of ASTM Standards, Section 4, Vol.04, No.1,Soil and Rock; Building Stones, ASTM, Philadelphia.

ASTM D854–02, "Standard Test Methods for Specific Gravity of Soils", Annual Book of ASTM Standards, Section 4, Vol.04, No.1, Soil and Rock; Building Stones, ASTM, Philadelphia.

ASTM D2435-04, "Standard Test Methods for One-Dimentional Consolidation Properties of Soils Using Incremental Loading", Annul Book of ASTM Standards, Section 4, Vol.04, No.1, Soil and Rock: Building Stones, ASTM Philadelphia.

ASTM D4318–00, "Standard Test Methods For Liquid Limit, Plasticity Limit, and Plasticity Index of Soils", Annual Book of ASTM Standards, Section 4, Vol.04, No.1, Soil and Rock; Building Stones, ASTM, Philadelphia.

ASTM D5856–95, 2002, "Standard Test Methods For Measurement of Hydraulic Conductivity of Porous Material Using A Rigid-Wall, Compaction-Mold

Permeameter” Annual Book of ASTM Standards, Section 4, Vol.04, No.1, Soil and Rock; Building Stones, ASTM, Philadelphia.

Baban, S., Parry, T., 2001, “Developing and Applying A GIS-Assisted Approach To Locating Wind Farms In The UK”, Renewable Energy, Vol.24, pp.59-71.

Birand, A., 1963, “Study Characteristics of Ankara Clays Showing Swelling Properties”, Middle East Technical University, MSc Thesis (unpublished).

Bracci, G., Giardi, M., Paci, B., 1991, “The Problem of Clay Liners Testing in Landfills”, Proceedings Third International Landfill Symposium, Cagliari, Italy, pp.679-689.

Briggs, T., Kunsch, P. L., and Bertrand, M., 1990, “Nuclear Waste Management: An Application of The Multicriteria PROMETHEE Methods”, European Journal of Operational Research, Vol.44, No.1, pp.1-10.

Chaput, E., 1931, Esquisse de I'evolotion tectonique de la Turquie, Publ., I'lnst. de Geol de I'Univ. de Stamboul, Vol.6.

Chamber of Enironmental Engineers, 2009, “Environmental State Report Ankara: Yerleşim Yerlerinde Katı Atık Sorunu, Hava Kirliliği, Yer Üstü ve Altı Sularında Kirlilik, Ankara Içme Suyu Sorunu, Kentsel Dönüşümü”, TMMOB Chamber of Enironmental Engineers Ankara Chapter, 26 pp.

Chen, Y., Yu, J., Shahbaz, K., and Xevi, E., 2009, “A GIS-Based Sensitivity Analysis of Multi-Criteria Weights”, 18th World IMACS / MODSIM Congress, Cairns, Australia.

Chou, S., Chang, Y., and Shen, C., 2008, “A Fuzzy Simple Additive Weighting System under Group Decision-Making for Facility Location Selection with Objective/Subjective Attributes”, European Journal of Operational Research, Vol.189, pp.132-145

Chu T., 2002, “Facility Location Selection using Fuzzy TOPSIS under Group Decisions Source International Journal of Uncertainty”, Fuzziness and Knowledge-Based Systems”, Vol.10, No.6, pp. 678-701.

Çamur, Z. and Yazıcıgil, H., 2005, “Laboratory Determination of Multicomponent Effective Diffusion Coefficients for Heavy Metals in a Compacted Clay”, Turkish Journal of Earth Sciences, Vol.14, pp.91-103.

Çalgın, R., Ercan, T., Pehlivanoğlu, H., and Şengün, M. 1973, “Ankara Çevresi Jeolojisi”, MTA Raporu No: 6487.

Çokça, E., 2000, “An Overview of the 35 Years of Research on the Volume Change Behavior of Ankara Soils”, Bizim Büro Basım Evi, Ankara, 35 pp.

Daniel, D., and Benson, C., 1990, “Water Content Density Criteria for Compacted Soil Liners”, Journal of Geotechnical Engineering ASCE, Vol. 116, pp. 1811-1830.

Daniel, D. E., 1984, “Predicting Hydraulic Conductivity of Clay Liners”, Journal of the Geotechnical Engineering, ASCE, Vol.110, No.2, pp. 285-300.

Dilek, E., 2006, “Tuzluçayır - Mamak Düzensiz Depolama Alanı için Peysaj Onarımının Önemi ve Gereği”, Tarım Bilimleri Dergisi, Vol.4.

Ekmekçioğlu,M., Kaya, T., and Kahraman, C., 2010, “Fuzzy Multi-Criteria Disposal Method and Site Selection for Municipal Solid Waste”, Waste Management.

Erol, O., 1993, “Geomorpholocical Evolution of the Ankara Region”, A.Suat Erk Geology Symposium Publications, pp. 25-35.

General Command of Mapping – Turkey, 2002, “Topographic Maps of Turkey”, 1:25,000, Ankara.

General Directorate of Mineral Research and Exploration, 1997, “Geological Maps of Turkey Ankara”, F-15, 1:100,000, Ankara.

General Directorate of Rural Services, 2009, National Soil Database, 1:25,000, Ankara.

Gogula, A., Hossain, M., Romanoschi, S., 2003, “Correlation Between the Laboratory and Field Permeability Values for the Superpave Pavements”, Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa.

Gordon, M., Huebner, P., and Kmet, P., 1990, “An Evaluation Of The Performance Of Four Clay Lined Landfills In Wisconsin”, Proceedings of the Seventh Annual Waste Conference, pp. 399-460.

Guiqina, W., Lib, Q., Guoxuea, L., and Lijunc, C., 2009, “Landfill Site Selection Using Spatial Information Technologies and AHP: A Case Study In Beijing, China”, Journal of Environmental Management, Vol.90, pp. 2414–2421.

Güngör, K., and Torunoğlu, E., 2000, “Ankara'da Katı Atık Çöp Sorununa İlişkin Son Durum ve Düşünceler”, Turkiye Mühendislik Haberleri , Vol. 409, pp. 19 -21.

Holtz, D. H., and Kovacs, D.K., 1981, “An Introduction to Geotechnical Engineering”, New Jersey: Prentice-Hall, USA, 733 pp.

Hwang, C., and Yoon, K., 1981, “Multiple Attribute Decision Making: Methods and Applications”, 75 pp.

Johnny, K.W., and Heng L., 2008, “Application of the Analytic Hierarchy Process (AHP) in Multi-Criteria Analysis of the Selection of Intelligent Building Systems”, Building and Environment, Vol.43, pp.108-125.

Kalafat, D., Güneş, Y., Kara, M., Deniz, P., Kekovalıö K., Kuleli, H. S., Gülen, L, Yılmazer, M. and Özel, N. M., 2007, “A Revised and Extended Earthquake Catalogue for Turkey Since 1900 ($Mw \geq 4.0$)”, Bosphorus University, Istanbul.

Kaplan, T., 2004, “Neotechtonics and seismicity of the Ankara Region: A Case Study in the Uruş Area”, METU, Ankara, MSc. Thesis.

Kasapoğlu, K. E., 1982, “Geo-Engineering Properties of the Grounds in the City of Ankara”, Vol.9, pp. 19 - 40.

Khalil, A.G., Goonetilleke, A., Kokot, S., and Carroll, S., 2004, “Use of Chemometrics Methods and Multicriteria Decision-Making for Site Selection for Sustainable On-Site Sewage Effluent Disposal”, Analytica Chimica Acta, Vol.506, pp. 41–56.

Kleindorfer, P., Kunreuter, H., and Schoemaker, P., 1984, “Decision Sciences: An Integrative Perspective”, Cambridge: Cambridge University Press.

KOÇYİĞİT, A., 1991, “Changing Stress Orientation in Progressive inTracontinental Deformation as Indicated by the Neotectonics of the Ankara Region (NW Central Anatolia)”, Türkiye Petrol Jeologları Derneği Bülteni, Vol.3, pp. 43–55.

Koçyiğit, A., 2003, “Orta Anadolunun Genel Neotektonik Özellikleri ve Depremselliği” Türkiye Petrol Jeologları Derneği Bulliten - Special Issue, pp. 1-26.

Koçyiğit, A., Winchester, J.A., Bozkurt, E. and Holland, G,2003, “Saraçköy Volcanic Suite: Implications for the Subductional Phase of Arc Evolution in the Galatean Arc Complex, Ankara-Turkey”, Geological Journal, Vol.37, pp.1-14.

Koçyiğit, A., and Lünel, A., 1987, “Geology and tectonic Settings of Alçı Region”, Journal of Applied Sciences, Vol.201, pp. 35-57.

Koçyiğit, A. and Türkmenoğlu, A., 1991, "Ankara Kili Olarak Bilinen Formasyonun Jeolojisi Ve Minerolojisi: "Ankara Kili" Problemine Jeolojik bir Yaklaşım”, V. Ulusal Kil Sempozyumu Bildiriler Kitabı, pp.87 -101.

Lee, G. F., Jones, R. A., and Ray, C., 1986, "Sanitary Landfill Leachate Recycle," Biocycle, Vol. 27, pp.36-38.

Malczewski, J., 1999, “GIS and Multicriteria Decision Analysis”, New York: John Wiley and Sons, Canada, 392 pp

Malczewski, J., 2006, “GIS-based Multicriteria Decision Analysis: A Survey of the literature”, European Journal of Operational Research, Vol. 20, No. 7, pp.703-726.

Mazaher, M., Nematollah, K., Afshin, D., Ali, A. D., and Mehdi, Z. S., 2007, MSW Landfill using Weighted Linear Combination and Analytical Hierarchy Process (AHP) Methodology in GIS Environment (case study: Karaj), Waste Management, Vol.30, pp.1879-2456.

Met, İ., 1999, “Engineering Geological Assessment Of Clayey Soils In Ankara For Being Utilized As Compacted Clay Liners”, METU, Ankara, MSc. Thesis.

Met, İ., and Akgün, H., 2005, “Composite Landfill Liner Design with Ankara Clay Turkey”, Environmental geology, Vol.47, pp.795 - 803.

Met, İ., Akgün, H., and Türkmenoğlu, A., 2005. Environmental Geological and Geotechnical Investigation Related to the Potential Use of Ankara Clay as a Compacted Landfill Liner Material, Turkey, Environmental Geology , Vol.47, No.2, pp.225-236.

Mohammad, H. V., Ali, A. A., and Abbas, A., 2009, "Hospital Site Selection Using Fuzzy AHP And Its Derivatives", Journal of Environmental Management, Vol.90, pp.3048-3056.

Nas, B., Cay, T., Iscan, F., and Berk, A., 2009, "Selection of MSW Landfill Site for Konya, Turkey Using GIS and Multi-criteria Evaluation", Environmental Monitoring and Assessment, Vol.160**,** pp. 491-500.

Norese, M.F., 2006, "ELECTRE III as a Support for Participatory Decision-Making on the Localization of Waste-Treatment Plants, Land Use Policy, Vol.23, pp.76-85.

Ordemir, I., Soydemir, C., and Birand, A., 1977, "Swelling Problems of Ankara Clay", International Conference on Soil Mechanics and Foundation Engineering, Tokyo Vol.1, pp. 243-247.

Pitz, G., and McKillip, J., 1984, "Decision Analysis for Analysis for Program Evaluations". Thousand Oaks, CA, Sage Publications.

Pohekar, S., and Ramachandran, M., 2004, "Application of Multi-criteria Decision Making to Sustainable Energy Planning - a review", Renewable and Sustainable Energy Reviews, Vol.8, No.4,, pp.365-381.

Republic of Turkey Ministry of Environment and Forestry, 2010.
http://www.mevzuat.adalet.gov.tr/html/20743.html, access date: April 2010

Rowe, R. K., Quigley, R. M. and Booker, J. R., 1995, "Clayey Barrier Systems for Waste Disposal Facilities", Chapman and Hall, England, 385 pp.

Rowe, R. K., Quigley, R. M. Brachman, R.W.I., and Booker, J. R., 2004, "Barrier Systems for Waste Disposal Facilities", Spon Press, New York, 587 pp.

Saaty, T. L., 1980, "Risk - Its Priority and Probability: The Analytic Hierarchy Process", European Journal of Operational Research, Vol.7**,** No.2, pp.159-172.

Sağlam,Z., Türkmenoğlu,A.G. and Huff,W.D.,2004, "An Investigation of the Iron Oxides and Clay Minerals of the Ankara Clay", 41st Annual meeting of the Clay minerals Society, Vol.66.

Schoemaker, P., and Waid, C., 1982, "An Experimental Comparison of Different Approaches to Determining Weights in Additive Utility Models", Management Science, Vol.28, No. 2, pp. 182-196.

Schroeder, P.R., Lloyd, C.M., Zappi, P.A., and Aziz, N.M., 1994a, "The Hydrologic Evaluation of Landfill Performance (HELP) Model: User's Guide For Version 3", Risk Reduction Engineering Laboratory, Office of Research and Development, EPA/600/R-94/168a, US Environmental Protection Agency, Cincinnati, Ohio.

Schroeder, P.R., Dozier, T.S., Zappi, P.A., McEnroe, B.M., Sjostrom, J.W. and Peyton, R.L., 1994b, “The Hydrologic Evaluation of Landfill Performance (HELP) Model: Engineering Documentation for Version 3”, Risk Reduction Engineering Laboratory, Office of Research and Development, EPA/600/R-94/168b, US Environmental Protection Agency, Cincinnati, Ohio.

Lee, G. F., Jones, R. A., and Ray, C., 1986, "Sanitary Landfill Leachate Recycle," Biocycle Vol.27, pp.36-38.

Sezer, G., 1998, “Cation Exchange Capacity and Contaminant Uptake Properties of Some Natural Clays as Potential Landfill Liners”, Middle East Technical University, MSc. Thesis

Sezer, G.A, Türkmenoğlu, A.G, and Göktürk, E.H, 2003, “Mineralogical and Sorption Characteristics of Ankara Clay as a Landfill Liner”, Applied Geochemistry, Vol.18, pp.711-717.

Sharifi, M., Hadidi, M., Vessa, E., Mosstafakhani, P., Taheri, K., and Shahoie, S., 2009, “Integrating Multi-criteria Decision Analysis for a GIS-based Hazardous Waste Landfill Sitting in Kurdistan Province, Western Iran”, Vol.29, pp.2740-2758.

State Hydraulic Works, 1975a, “Hatip Ovası Hidrojeolojik Etüt Raporu”, DSI Genel Müdürlüğü Jeoteknik ve Yeraltısuları Dairesi Başkanlığı Yayını, Ankara, Report No.40

Stillwell, W. G., D. A. Seaver, and W. Edwards, 1981, “A Comparison of Weight Approximation Techniques in Multiattribute utility decision making”, Organizational Behaviour and Human Performance, Vol. 28, No.1, pp. 62-77.

Şener, B., 2004, “Landfıll Site Selection by using Geographic Information Systems”, Middle East Technical University, MSc. Thesis.

Şener, Ş., Sener, E., and Karagüzel, R., “Solid Waste Disposal Site Selection with GIS and AHP Methodology: A Case Study in Semirkent – Uluborlu (Isparta) Basin, Turkey”, Environ. Monit. Assess. (In Press)

Tchobanoglous, G., Theisen, H., and Vigil, S., 1993, “Integrated Solid Waste Management Engineering Principles and Management Issues”, New Jersey, McGraw-Hill, Inc., 977 pp.

Turkish State Meteorological Service, 2010, veridegerlendirme http://www.dmi.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx, access date: April 2010

U.S. Environmental Protection Agency, 2010, Code of Federal Regulations, Title 40, Part 258 Subtitle D, Criteria for Municipal Solid Waste Landfills.

Voogd, H., 1983, “Multicriteria Decision-Aid”, Chichester, West Sussex, England: Wiley.

World Health Organization (WHO), “Guidelines for Drinking Water Quality”,2008, Third Editiion Incorporating First and Second Addenda, Geneva,Vol.1, 515 pp.

APPENDIX A

Standard Proctor Compaction Test Results

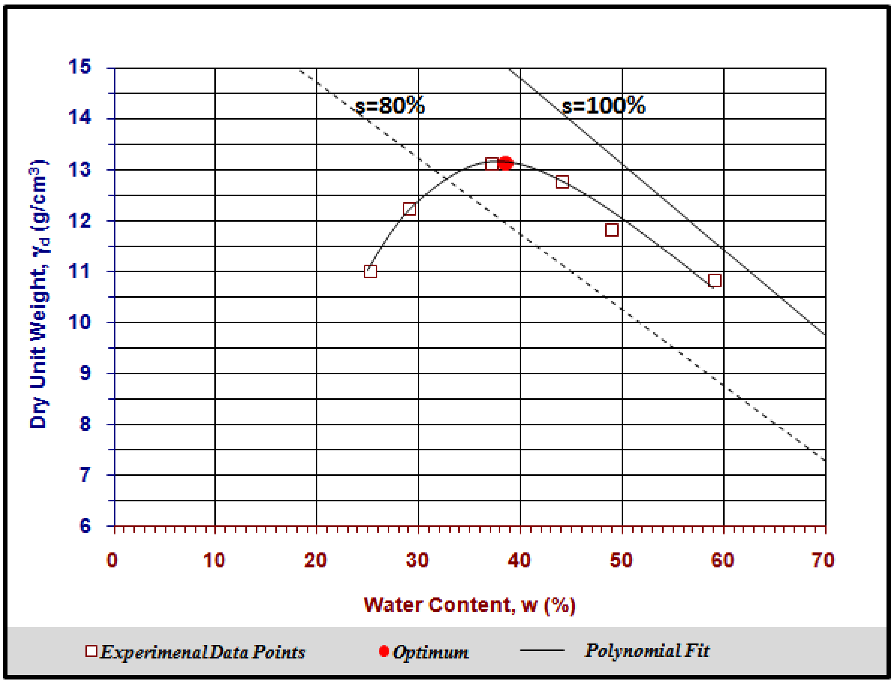

Figure A1. Dry unit weight versus water content for soil sample Sincan 1.

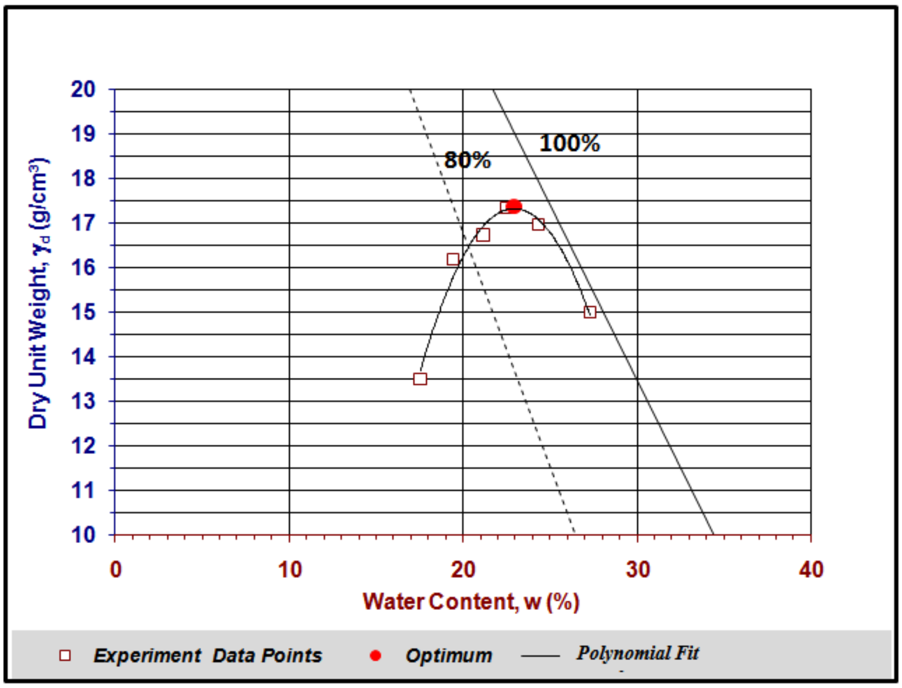

Figure A2. Dry unit weight versus water content for soil sample Sincan 2.

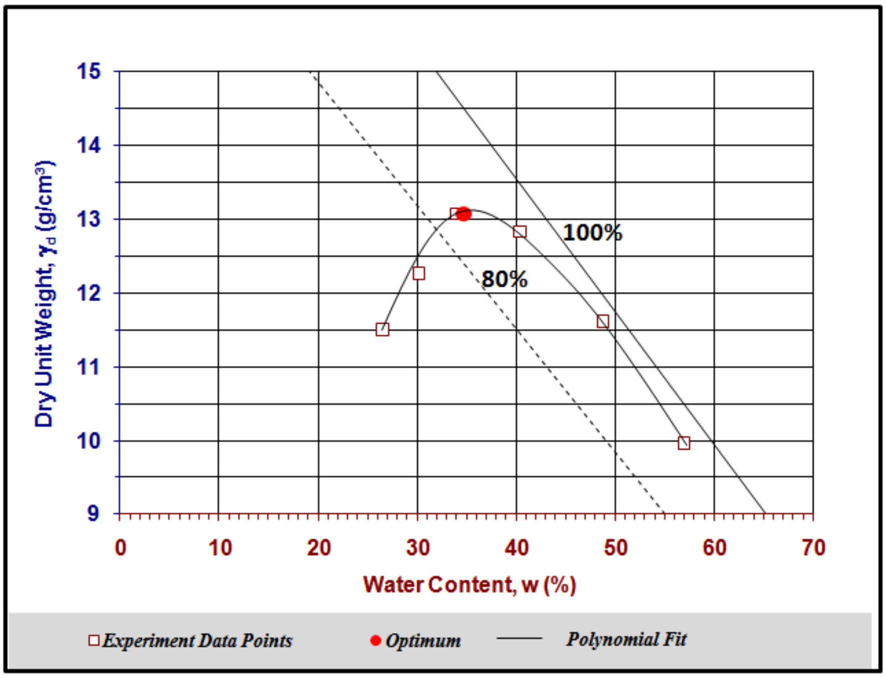

Figure A3. Dry unit weight versus water content for soil sample Gölbaşı 1.

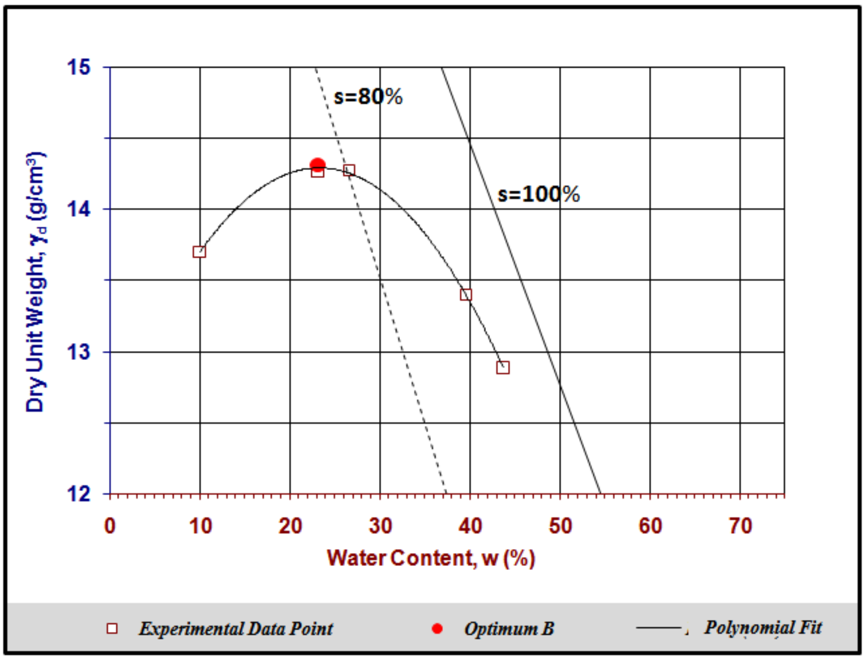

Figure A4. Dry unit weight versus water content for soil sample Gölbaşı 2.

APPENDIX B

Consolidation Test Results

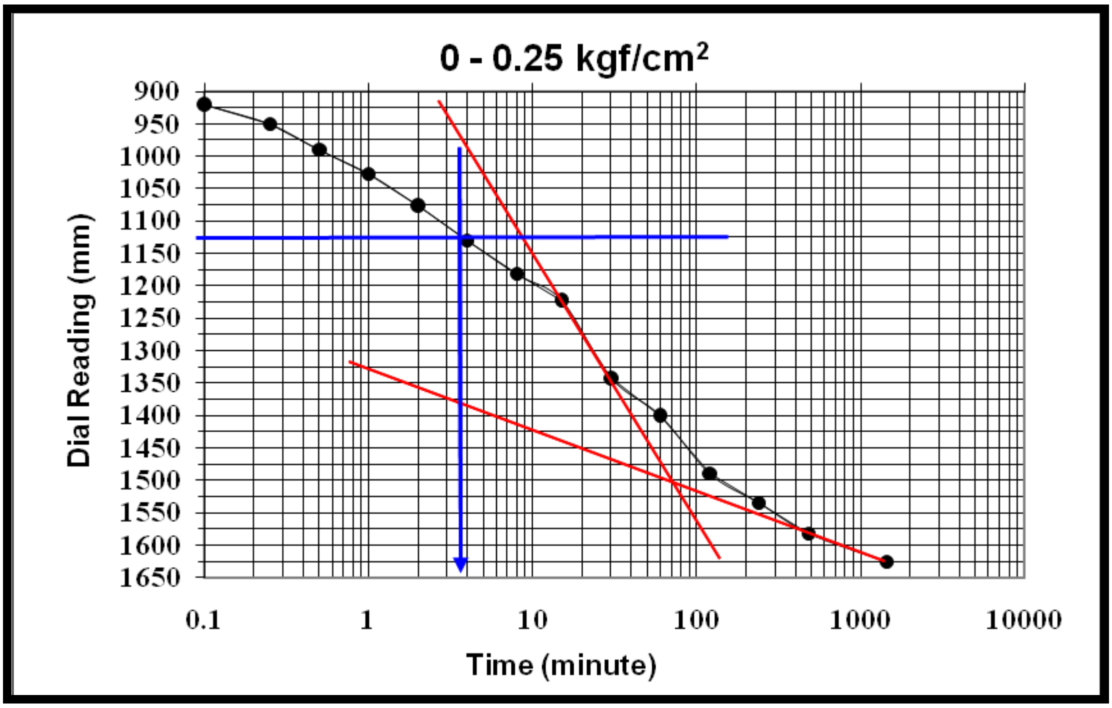

Figure B1. t_{50} value determination for 0.25 kgf/cm^2 loading.

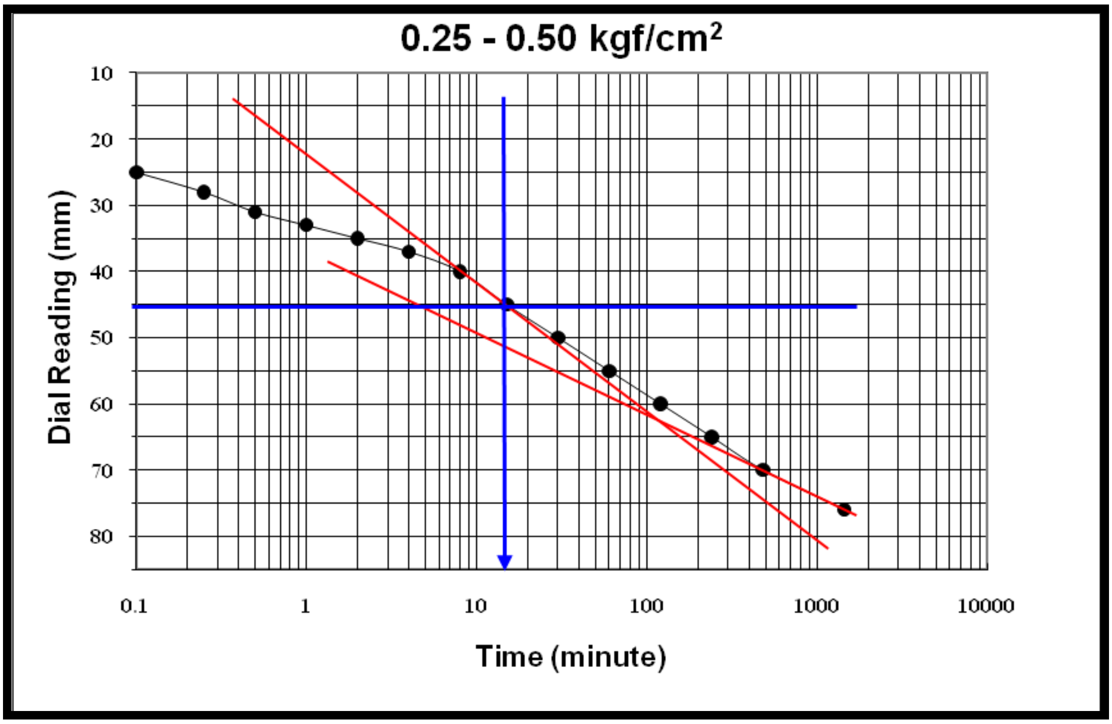

Figure B2. t_{50} value determination for 0.50 kgf/cm^2 loading.

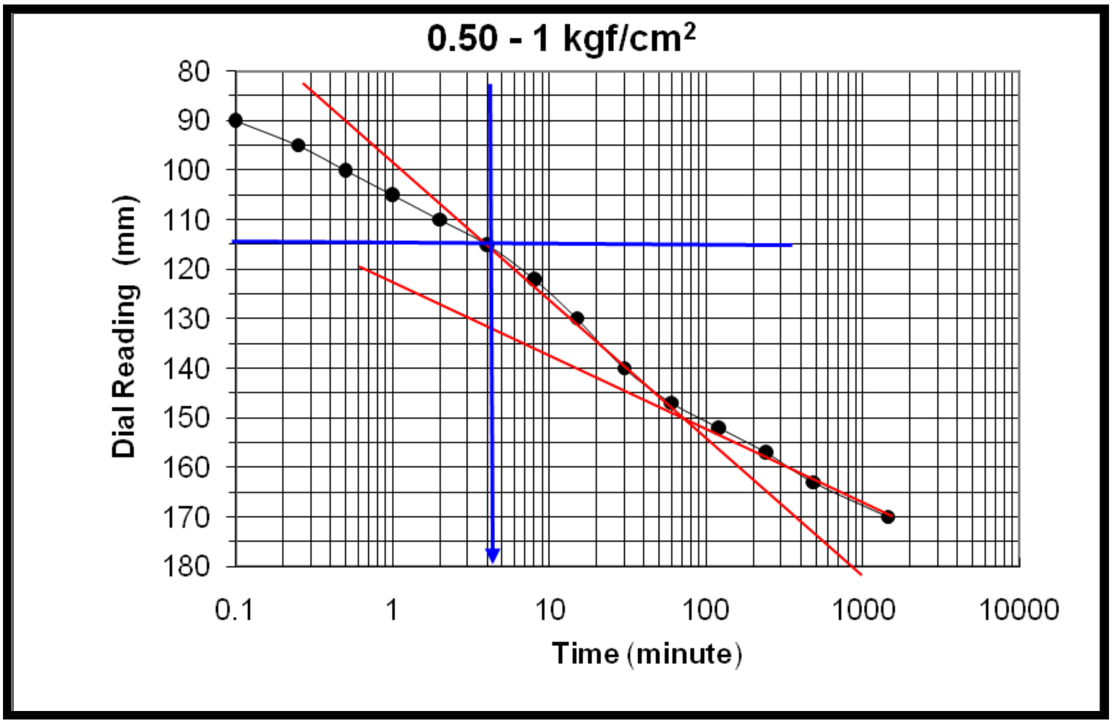

Figure B3. t_{50} value determination for 1 kgf/cm^2 loading.

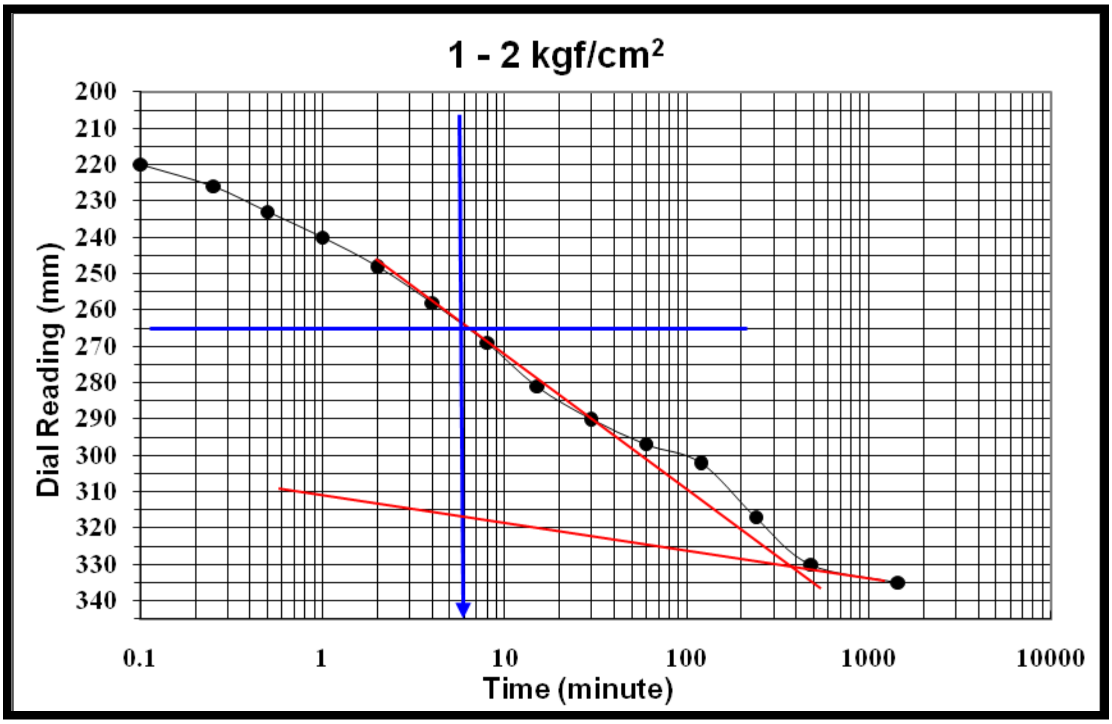

Figure B4. t_{50} value determination for 2 kgf/cm^2 loading

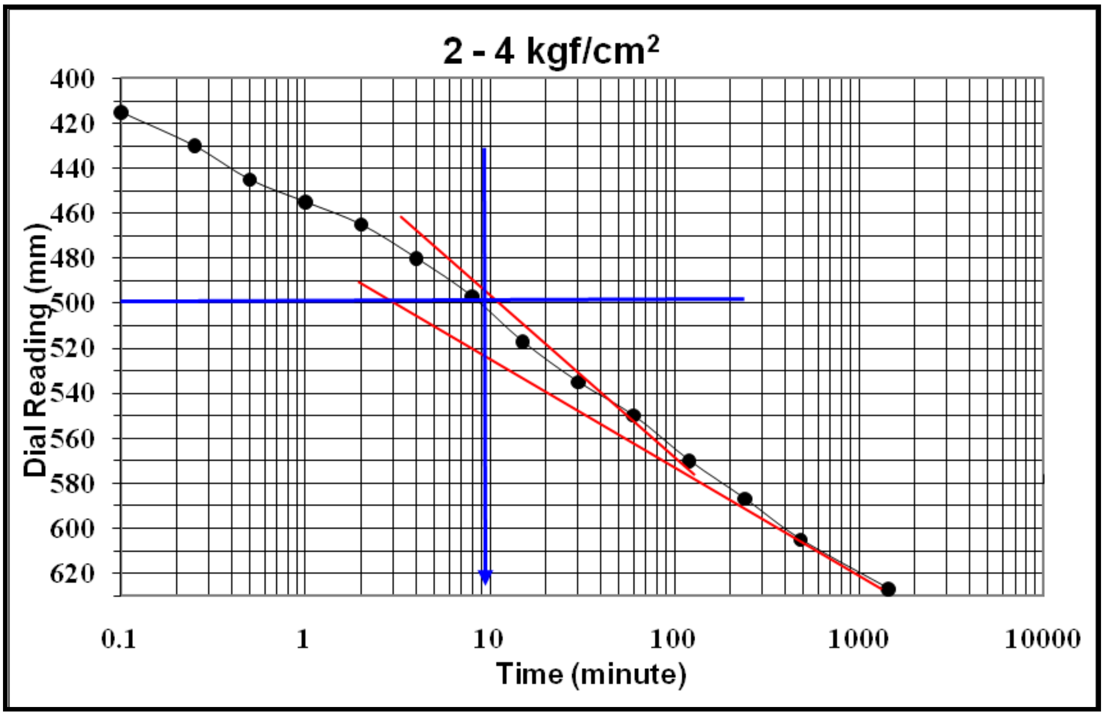

Figure B5. t_{50} value determination for 4 kgf/cm^2 loading.

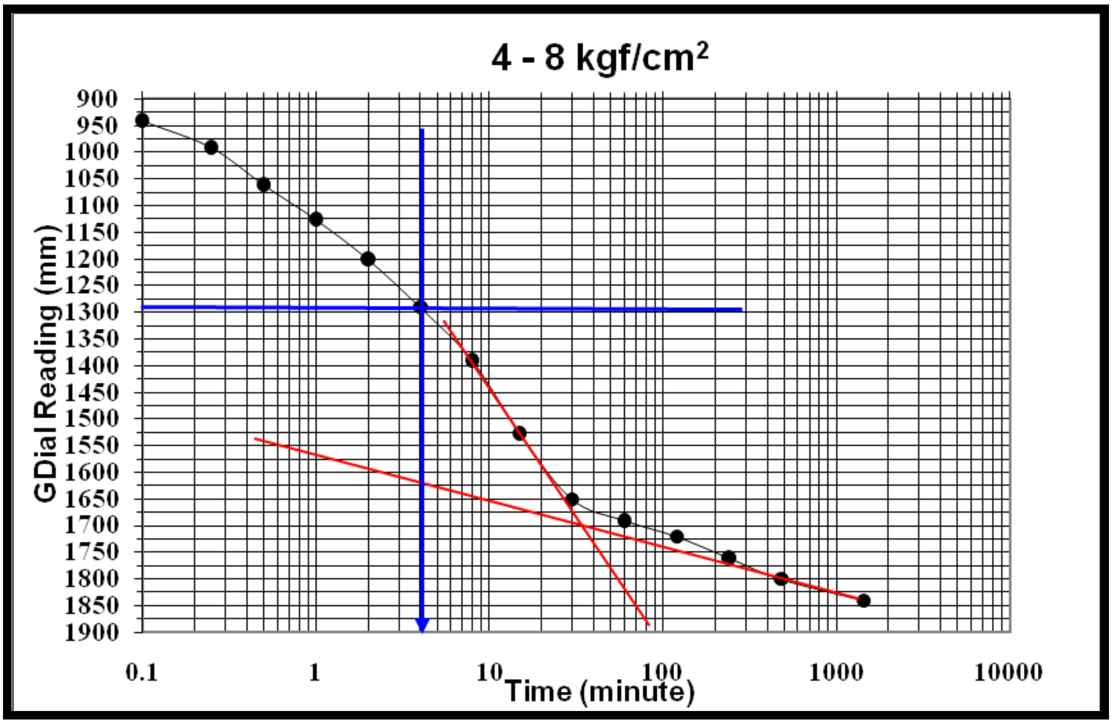

Figure B6. t_{50} value determination for 8 kgf/cm^2 loading.

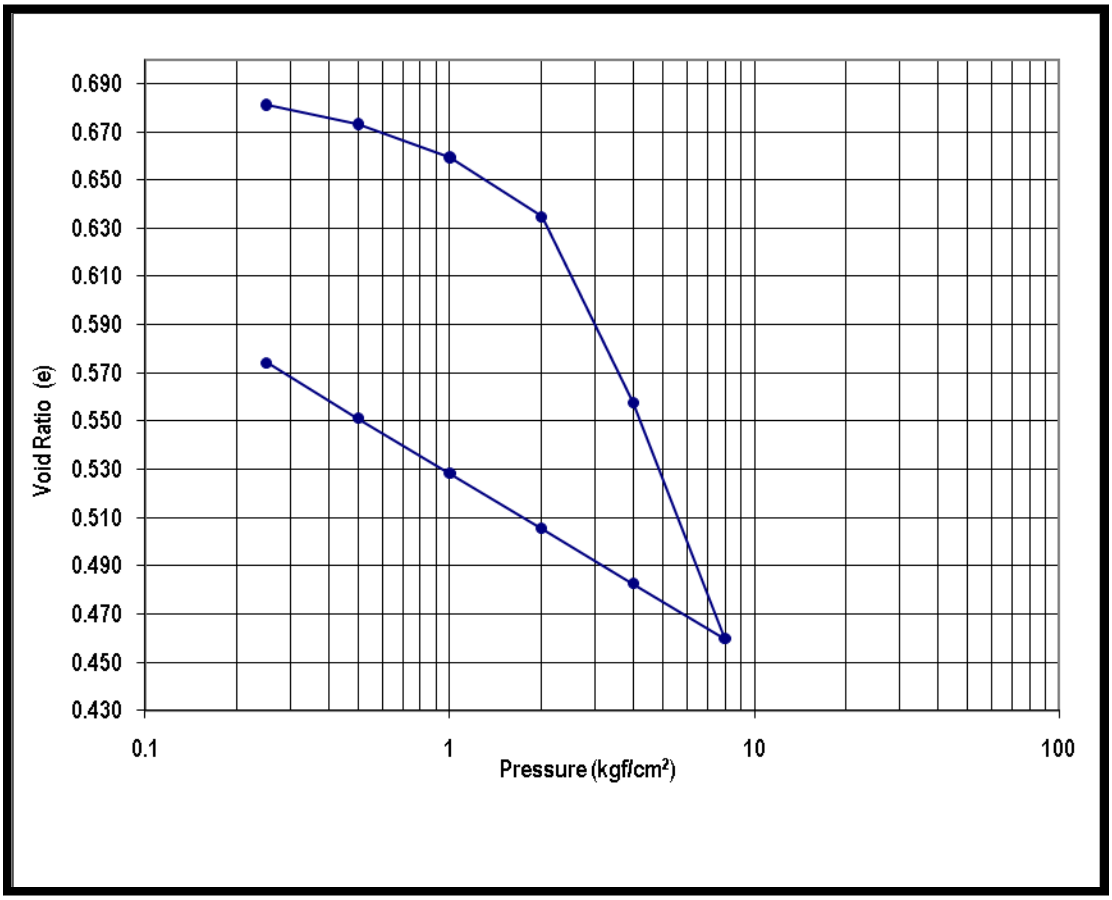

Figure B7. Void ratio versus pressure graph for soil specimen Sincan 1.

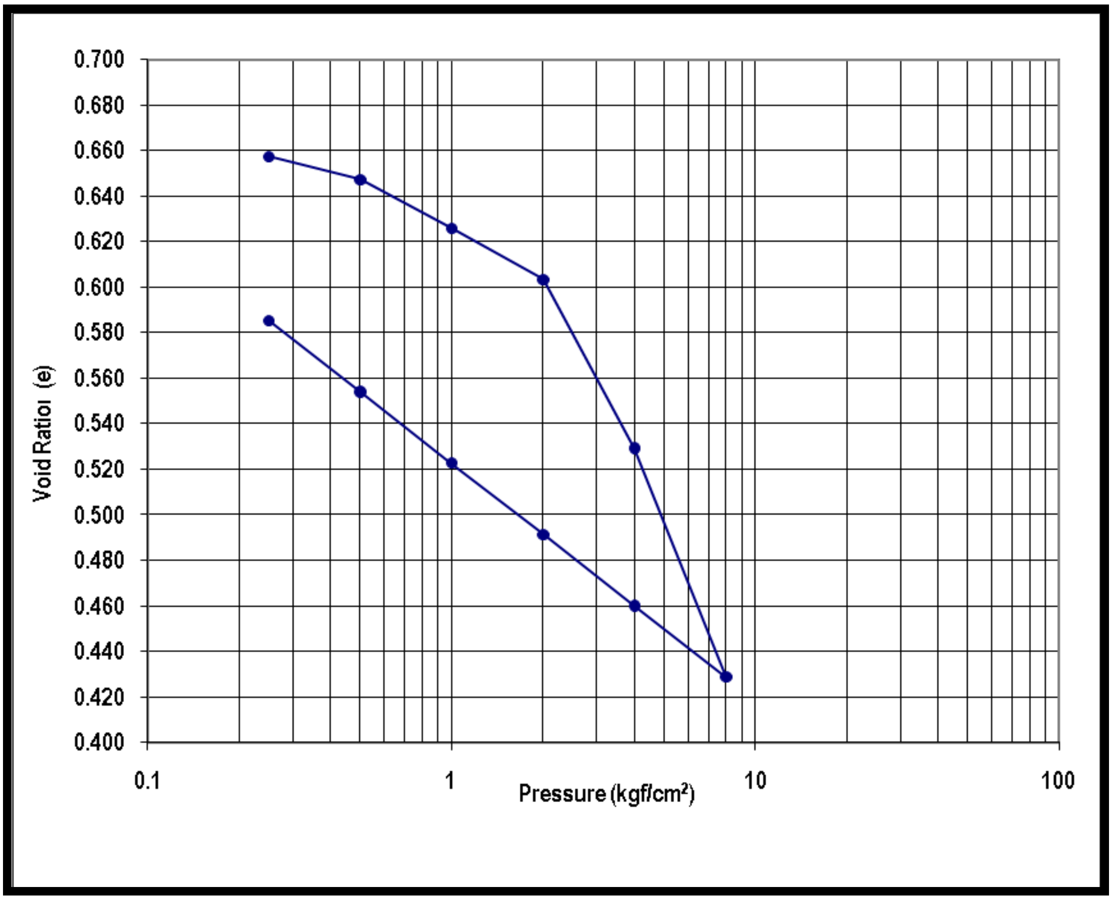

Figure B8. Void ratio versus pressure graph for soil specimen Gölbaşı 1.