LANDFILL SITE SELECTION BY USING GEOGRAPHIC INFORMATION SYSTEMS

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ABSTRACT

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One of the serious and growing potential problems in most large urban areas is the shortage of land for waste disposal. Although there are some efforts to reduce and recover the waste, disposal in landfills is still the most common method for waste destination. An inappropriate landfill site may have negative environmental, economic and ecological impacts. Therefore, it should be selected carefully by considering both regulations and constraints on other sources. In this study, candidate sites for an appropriate landfill area in the vicinity of Ankara are determined by using the integration of Geographic Information Systems and Multicriteria Decision Analysis. For this purpose, sixteen input map layers including topography, settlements (urban centers and villages), roads (Highway E90 and village roads), railways, airport, wetlands, infrastructures (pipelines and power lines), slope, geology, land use, floodplains, aquifers and surface water are prepared and two different MCDA methods (Simple Additive Weighting and Analytic Hierarchy Process) are implemented in GIS environment. Comparison of the maps produced by these two different methods shows that both methods yield conformable results. Field checks also confirm that the candidate sites agree well with the selected criteria.

Keywords: Landfill, site selection, GIS, multicriteria decision analysis, Ankara

ÖZ

COĞRAFİ BİLGİ SİSTEMLERİ KULLANILARAK KATI ATIK DEPONİ SAHALARI İÇİN YER SEÇİMİ

ŞENER, Başak

Yüksek Lisans, Jeoloji Mühendisliği Bölümü

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Ağustos 2004, 114 sayfa

Büyük kentlerde,katı atık depolama alanları için uygun arazi bulmak oldukça ciddi ve büyük bir problemdir. Yeniden kazanım ve katı atık oluşumunu azaltma çabaları olmasına rağmen, katı atık depolamak hala en çok kullanılan yöntemdir. Uygun olmayan katı atik depo alanları çevresel, ekonomik ve ekolojik açıdan olumsuz etkilere sebep olabilir. Bu yüzden bu alanlar cok dikkatli seçilmelidir. Bu çalışmada, Ankara'nın güneybatısındaki bir alan için Coğrafi Bilgi Sistemleri ve Çok Ölçütlü Karar Analizi'nin entegrasyonu kullanılarak uygun katı atık depolama alanları seçilmiştir. Bunun için, topoğrafya, yerleşim (şehir ve köy), yollar (E90 ve köy yolları), demiryolu, hava alanı, sulak alan, altyapı sistemi (doğalgaz boru hattı ve yüksek gerilimli iletim hattı), eğim, jeoloji, arazi kullanım, taşkın alanı, akifer ve yüzey suyu olmak üzere onaltı veri katmanı oluşturuldu ve bu katmanlar kullanılarak Basit Ağırlıklı Toplama ve Analitik Hierarşi İşlemi olmak üzere Çok Ölçütlü Karar Analizi methodlarından ikisi CBS ortamında uygulandı. Bu metodlarla oluşturulan sonuç haritaları karşılaştırılarak iki metodun uyumu kontrol edilmiştir. Analizler sonucu katı atık deponi sahası için kullanılan metodların uyumlu oldukları görülmüş, saha kontrollerinde ise aday sahaların belirlenen kriterlere uygun oldukları görülmüştür. aday sahaların belirlenmesinden sonra, aday sahaların doğruluğunun ve uygunluğunun belirlenmesi için arazi çalışması yapıldı.

Anahtar Kelimeler: Katı atık deponi sahası, yer seçimi, CBS, çok ölçütlü karar analizi, Ankara

To My Family

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INTRODUCTION

1.1. Purpose and Scope

Source reduction, recycling and waste transformation methods are widely used to manage solid waste, however in all of these methods there is always residual matter even after the recovery process to disposal. The necessity of getting rid of these waste yields in an economic approach which is called as landfilling.

However, municipal landfill siting is becoming increasingly difficult due to growing environmental awareness, decreased government and municipal funding and extreme political and social opposition. The increasing population densities, public health concerns, and less land available for landfill construction are also the difficulties to overcome (Kao, 1996).

Landfill siting is an extremely difficult task to accomplish because the site selection process depends on different factors and regulations. Environmental factors are very important because the landfill may affect the surrounding biophysical environment and the ecology of the area (Dikshit *et al.*, 2000; Mummolo, 1996; Siddiqui *et al.*, 1996; Erkut and Moran, 1991; Lober, 995). Economic factors must be considered in the siting of landfills as well. Economic factors of landfill siting often include the costs associated with acquisition, development, and operation of each site (Erkut and Moran, 1991). These costs must be weighted against the amount of capital investment put into the landfill, otherwise the development will not be successful. Social and political opposition to landfill siting has been indicated as the greatest obstacle for successfully locating waste disposal facilities (Lober, 1995). The NIMBY (not in my back yard) phenomenon (Kao and Lin, 1996; Lober, 1995; Erkut and Moran, 1991), is both an important consideration and restraint to landfill siting. The external cost and undesirable characteristics of landfills often cause people to perceive the hazards and risks which outweight the long-term benefits (Baxter *et al.*, 1999).

It is evident that, many factors must be incorporated into landfill siting decisions and GIS is ideal for this kind of preliminary studies due to its ability to manage large volumes of spatial data from a variety of sources. It efficiently stores, retrieves, analyzes and displays information according to user defined specifications (Siddiqui, 1996).

Multicriteria Decision Analysis (MCDA) is used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information. The principle of the method is to divide the decision problems into smaller more understandable parts, analyze each part separately and then integrate the parts in a logical manner (Malczewski, 1997)

The integration of GIS and MCDA is a powerful tool to solve the landfill site selection problem, because GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential landfill areas based on a variety of criteria.

The main objective of this study is to suggest a methodology including both GIS and MCDA and to apply this methodology for Ankara vicinity. To achieve this goal, the criteria necessary for the preliminary site selection of landfill are reviewed.

1.2. Geographical Setting of the study area

The study area is located at the southwest of Ankara in Central Anatolia (Figure 1.1). The area is covered by four 1:25.000 scale topographical map Quadrengles of I28b2, I28b3, I29a1 and I29a4. The extents of the study area can be defined as 4428038N, 446443E in the northwest edge and 4400138N, 468000E in the southeast edge in the zone of 36 North of Universal Transverse

Mercator projection. The datum is European 1950 Mean and the ellipsoid is International 1909/1924/Hayford1910. The study area is approximately 603 km^2 with dimensions of 21.7 X 27.8 km.

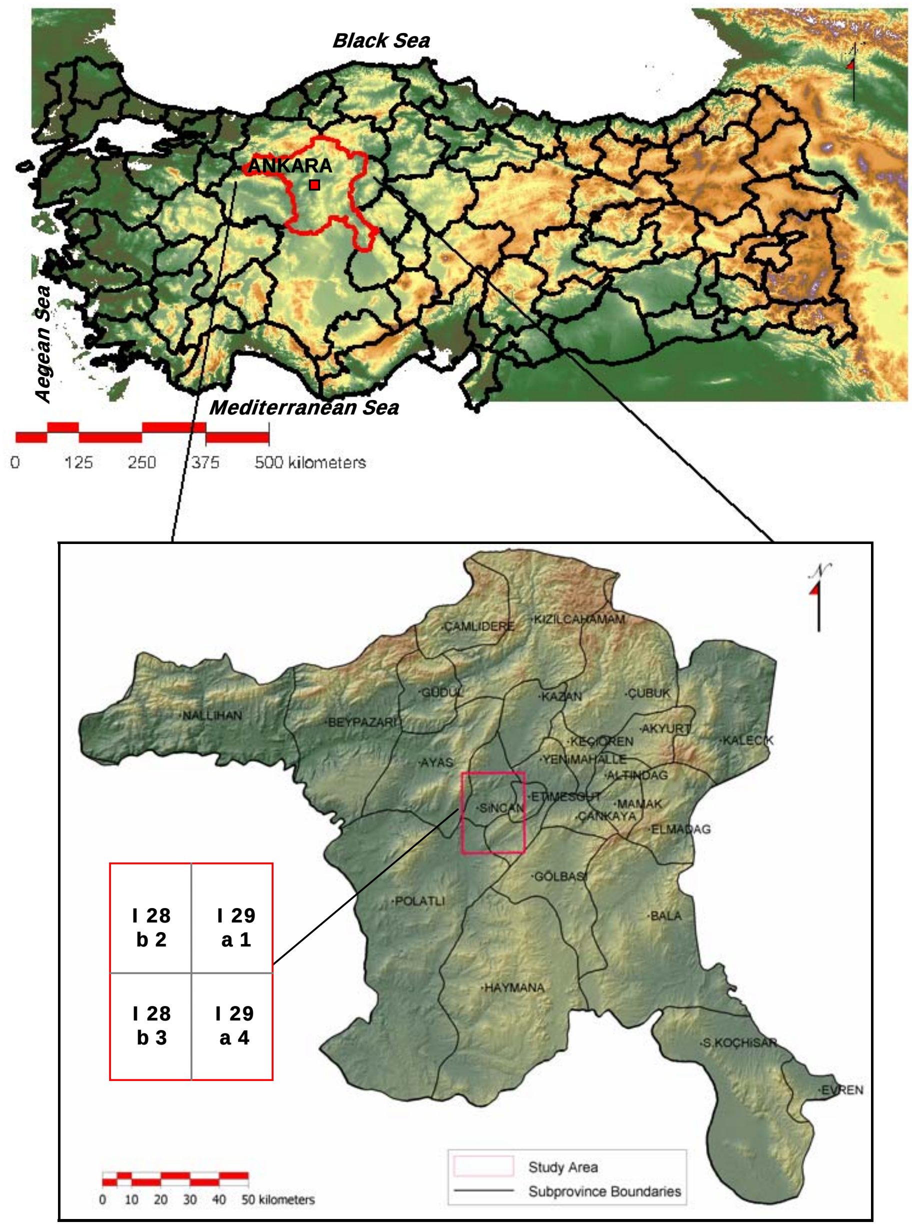


Figure 1.1. Location map of the study area

1.3. Climate

There are two weather stations in the study area which are Etimesgut and Polatlı. The latitude and longitude of Etimesgut Weather Station is 39° 57′ and 32° 41′ respectively and the altitude is 806 m. The average lowest and highest temperatures at this station are -1.1° C and 24.2 ° C in January and July, respectively. The minimum precipitation is measured in September 11.1 mm and the maximum precipitation in April 60.9mm. In Figure 1.2 and Figure 1.3, the average monthly temperatures and precipitation for 1930-1980, 1975-1992 and 1994-2003 observation periods at Etimesgut Weather Station can be seen.

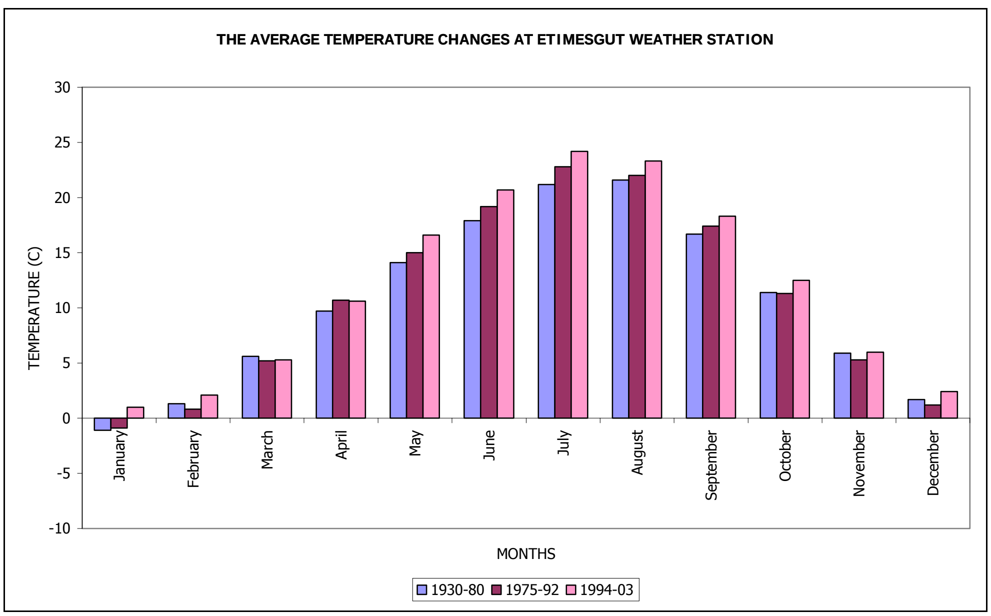


Figure 1.2. The average temperature changes recorded at Etimesgut Weather Station

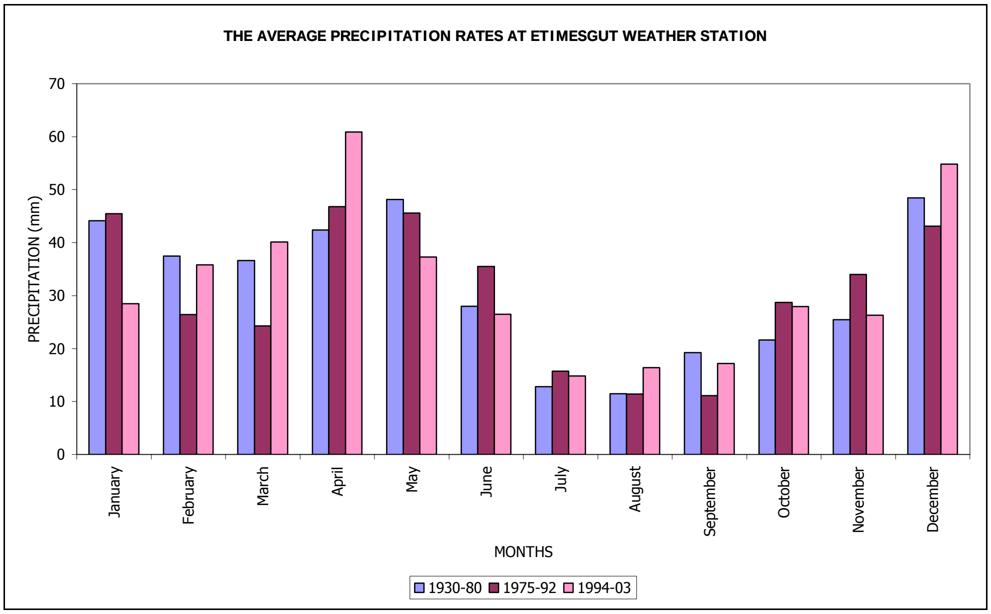


Figure 1.3. The average precipitation rates recorded at Etimesgut Weather Station

Polatlı Weather Station is located at latitude 39° 35′ and longitude 32° 09′ and its altitude is 885 m. The lowest and highest temperatures recorded at Polatlı Weather Station are -0.3° C in January and 23.3° C in July, respectively. The minimum precipitation corresponds to the months of August and September with a value of 12.1 mm and the maximum precipitation is in April and May with a value of 47.5 mm. In Figure 1.4 and Figure 1.5, the average monthly temperature and precipitation data for the period 1975-2003 at Polatlı Weather Station is given. The dominant wind direction of the area is north according to the data obtained from Etimesgut Weather Station for the period of 1994-2003 whereas it is NNE according to Polatlı Weather Station in the period of 1975-2003.

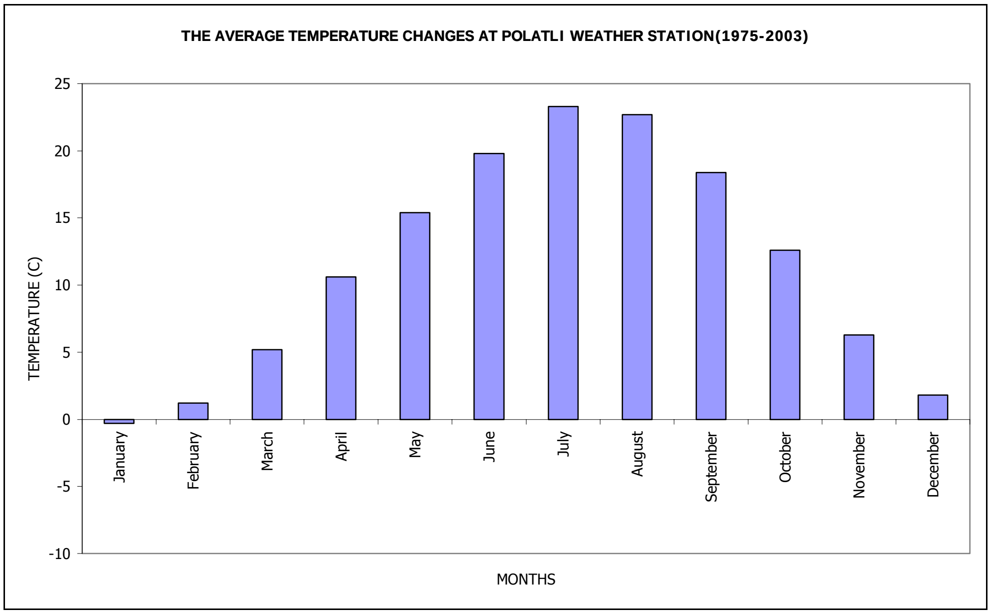


Figure 1.4. The average temperature changes recorded at Polatlı Weather Station

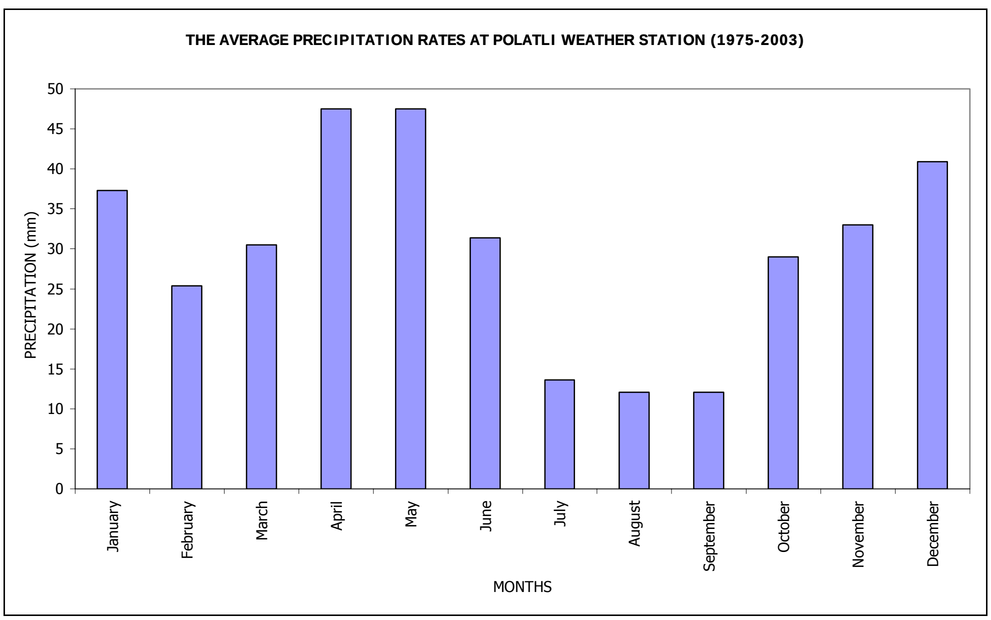


Figure 1.5. The average precipitation rates recorded at Polatlı Weather Station

CHAPTER 2

LANDFILL SITE SELECTION

2.1. Solid Waste Management

Solid waste management may be defined as the discipline associated with the control of generation, storage, collection, transfer and transport, processing and disposal of solid wastes. Integrated solid waste management includes the selection and application of suitable techniques, technologies and management programs to achieve specific waste management objectives and goals (Tchobanoglous and Kreith, 2002). Current solid waste management technologies can be summarized as:

1) Source reduction
2) Recycling
3) Waste transformation
4) Landfilling

2.1.1. Source reduction

It involves diminishing waste amount, volume and toxicity at the source of waste generation (Kreith, 1994). Source reduction is the most effective way which reduces the quantity of waste, the cost of associated with its handling, and its environmental impacts. Waste reduction may occur through the design, manufacture, and packaging of products with minimum toxic content, minimum volume of material, or a longer life and also at the household, commercial, or industrial facility through selective buying patterns and the reuse of products and material (Tchobanoglous, 1993).

2.1.2. Recycling

It involves (1) the separation and collection of waste materials; (2) the preparation of these materials for reuse, reprocessing, and remanufacture; and (3) the reuse, reprocessing, and remanufacture of these materials. Recycling is an important factor in helping to reduce the demand on resources and the amount of waste require disposal by landfilling (Tchobanoglous, 1993). Reusing waste products can be simply made by the public by returning drink containers to bottling manufacturers and the donation of used clothes, shoes, furniture, and electrical products to charities and retailers. Product recycling primarily involves melting glass and metals, pulping of paper waste so that the end product is useful as a raw material to manufacturers. Benefits of waste recovery include conserving finite resources, lowering the need for mining or harvesting virgin material, reducing inert residues from incinerators, and fewer demands on landfills (Kreith, 1994).

2.1.3. Waste transformation

It involves the physical, chemical, or biological alteration of wastes. Typically, the physical, chemical, and biological transformations that can be applied to municipal solid wastes are; (1) to improve the efficiency of solid waste management operations and system, (2) to recover reusable and recyclable materials, and (3) to recover conversion products and energy in the form of heat and combustible biogas. The transformation of waste materials usually results in the reduced use of landfill capacity (Tchobanoglous, 1993). Transformation examples include mechanical clipping, shredding, and grinding, thermal combustion, and composting organic food and yard waste (Kreith, 1994). A benefit of thermal incineration is the potential for energy generation while reducing waste volume up to 90% (Tchobanoglous, 1993).

2.1.4. Landfilling

It is the process by which the solid wastes that can not be recycled nor further used; the residual matter remaining after the recovery facility and after the recovery of conversion products and energy is placed in a landfill. Although there is a public opposition to landfills, it is necessary and there is no combination of waste management technique that does not require landfilling to make them work. Landfilling includes monitoring of the incoming waste stream, placement and the compaction of waste, and installation of landfill environmental monitoring and control facilities. The advantages and disadvantages of landfill are given in Table 2.1.

Table 2.1. The advantages and disadvantages of landfill (Tchobanoglous, 1993)

LANDFILL ADVANTAGES	LANDFILL DISADVANTAGES
Independence from other facilities	Land depreciation
Post-closure land development (ex: parks)	Wind borne paper, plastics, odor, etc.
Tipping fees from imported waste	Imported waste reducing landfill lifespan
Local employment opportunities	Public/political opposition
Potential tax from landfill	Traffic of large vehicles
Disposal strategy up to 30 years	Erosion of waste and/or cover soil
Local waste disposal	Potential risk to groundwater
Potential energy recovery from gases	Vermin/vector control

There of some terms used in landfilling of solid waste are defined below (Tchobanoglous, 1993):

Landfills are the physical facilities used for the disposal of residual solid wastes in the surface soils of the earth. In the past, the term sanitary landfill is used to describe a landfill in which the waste placed in the landfill was covered at the end of each day. Today, sanitary landfill refers to an engineered facility for the municipal solid waste designed and operated to minimize public health and environmental impacts.

The term *cell* is used to describe the volume of material placed in a landfill during one operating period, usually one day. A cell includes the solid waste deposited and the daily cover material surrounding it. During landfill operations, waste is spread thinly and compacted before it is covered by *daily cover*. It usually consists of 15.24 cm to 30.48 cm (6 to 12 in) soil or alternative material which is applied to the working faces of the landfill at the end of the each operating period. The purpose of daily cover is to control the infestation of pests, to limit windblown debris, to cover unsightly waste and to prevent infiltration of rain and snow melt into compacted waste.

A *lift* is a complete layer of cells over the active area of the landfill. Typically, landfills consist of a series of lifts. The final lift includes the cover layer. The term *bench* (or *terrace*) is commonly used where the height of the landfill will exceed to 15.24 m to 22.86 m (50 to 75 ft). Benches are used to maintain the slope stability of the landfill, for the placement of surface water drainage channels, and for the location of landfill gas recovery piping. The final cover layer is applied to the entire landfill surface after all landfilling operations are finished. It usually consists of multiple layers of soils and geomembrane materials which are designed to enhance surface drainage, intercept percolating water, and support surface vegetation.

Leachate is known as the liquid collected at the bottom of the landfill. In general, leachate is a result of the percolation of precipitation, uncontrolled runoff, irrigation water into the landfill, the water initially contained in the waste and also infiltrating groundwater. It contains a variety of chemical constituents derived from the solubilization of the materials deposited in the landfill and from the products of the chemical and biochemical reactions occurring within landfill.

Landfill gas is the mixture of gases within a landfill. It mainly consists of methane (CH_4) and carbon dioxide (CO_2). These are the principal products of the anaerobic decomposition of the biodegradable organic fraction of the municipal solid waste in the landfill. Other components of landfill gas include atmospheric nitrogen and oxygen, ammonia, and trace organic compounds.

Landfill liners are materials (both natural and manufactured) used to line the bottom area and below grade sides of a landfill. Liners usually consist of layers of compacted clay and geomembrane material designed to prevent migration of landfill leachate and landfill gas.

Landfill control facilities include liners, landfill leachate collection and extraction systems, landfill gas collection and extraction systems, and daily and final cover layers.

2.2. Common Landfilling methods

The principal methods used for landfilling of municipal solid waste are;
(1) excavated cell / trench, (2) area, and (3) canyon.

2.2.1. Excavated cell / trench method

The excavated cell/trench method of landfilling is suitable for areas where an adequate depth of cover material is available at the side and where the water table is not near the surface. Typically, solid wastes are placed in cells or trenches excavated in the soil. The excavated soil from the site is used for daily and final cover. The excavated cells or trenches are usually lined with synthetic membrane liners or low permeability clay or a combination of the two to limit the movement of both landfill gases and leachate (Tchobanoglous, 1993). A variation of this method is the artesian or zone of saturation landfill. These landfills are constructed below the naturally occurring groundwater table. Special provisions should be made to prevent groundwater from entering the landfill and to control the movement of leachate and gases from completed cells. Usually the site is dewatered, excavated and then lined. The dewatering facilities are continued until the site is filled to avoid the creation of uplift pressures which may cause the liner to heave and rupture (Adams *et al.*, 1998).

2.2.2. Area method

The area method is used when the terrain is unsuitable for the excavation of cells or trenches. High groundwater conditions necessitate the use of the area type landfills. Site preparation includes the installation of a liner and leachate control system. Cover material must be carried by truck or earthmoving equipment from adjacent land or from borrow-pit areas. In locations with limited availability of material compost produced from waste can be used as cover. Other techniques include the use of movable temporary cover materials such as soil and geomembranes. Temporarily placed soil and geomembranes over a completed cell, can be removed before the next lift is begun. (Tchobanoglous, 1993)

2.2.3. Canyon / Depression method

In this method, canyons, dry borrow pits, and quarries are used for landfills. The techniques to place and compact solid wastes in canyon/depression landfills vary with the geometry of the site, the characteristics of the available cover material, the hydrology and geology of the site, the type of the leachate and gas control facilities to be used, and the access to the site. Typically, filling for each lift starts at the head end of the canyon and ends at the mouth to prevent the accumulation of water behind the landfill. Canyon/depression sites are filled in multiple lifts, and the method of operation is the same as the area method. If a canyon floor is reasonably flat, the initial landfilling may be carried out using the excavated cell/trench method. The availability of adequate material to cover the individual lifts and to provide a final cover over the entire landfill is very important. Cover material is excavated from the canyon walls or floor before the liner system is installed. Borrow pits and abandoned quarries may not contain sufficient soil for intermediate cover, so that it may have to be important. (Tchobanoglous, 1993)

2.3. Landfill Design

The site selection of a landfill site depends on the design of a landfill. There are two major types of landfill design: (1) Sanitary landfills (2) Natural attenuation landfills. The main difference between these two types is the control of the entrapment and release of the leachate generated by a landfill. A sanitary landfill uses artificial liners to control the release of leachate while a natural attenuation landfill utilizes the surrounding environmental characteristics in order to decompose released fluids (Schwartz, 2001).

2.3.1. Sanitary Landfills

Sanitary landfills are designed to protect humans and the environment from harmful gases and fluids by using methane collection vents and leachate liners and collection pipes. Many landfills are designed for 20 or 30 year lifespan and still require post closure monitoring up to 30 years to ensure the environmental health. The landfill is usually double-lined to trap leachate. Synthetic liners include plastic geomembranes, geomats, geogrids, and geotextiles that commonly contain bentonite clays (Tchobanoglous, 1993). In a sanitary landfill, waste is contained in a cell which is covered with a layer of soil and compacted at the end of each working day. The dimensions of the cell depend on the volume of waste received and the availability of cover material. The cell thickness may range from 8 to 30 ft (2.4 – 9.1 m) but typically it is 15 ft (4.6 m). The usual slope of the working face is 3 horizontal to 1 vertical (3:1) which allows reasonable compaction and easier capping and vegetative growth on the side slopes of the landfill. The width of the working face is usually limited to 2 ft (0.6 m). The first lift of the waste is usually 5 ft (1.5 m) or less with careful removal of the oversize pieces to prevent damage of the underlying leachate collection system. The compaction equipment moves from the bottom to the top of the working face. The thickness of the daily cover is 6-12 in (150- 300 mm).

If a lift surface is expected to be exposed over 30 days then an intermediate cover is applied. The intermediate cover is typically 1 ft thick and more resistant to erosion than the daily cover (Oweis and Khera, 1990). When the landfill's operational life has ended, a final layer of soil and optimal synthetic liners are added along with a vegetative cover to limit percolation and erosion (Figure 2.1).

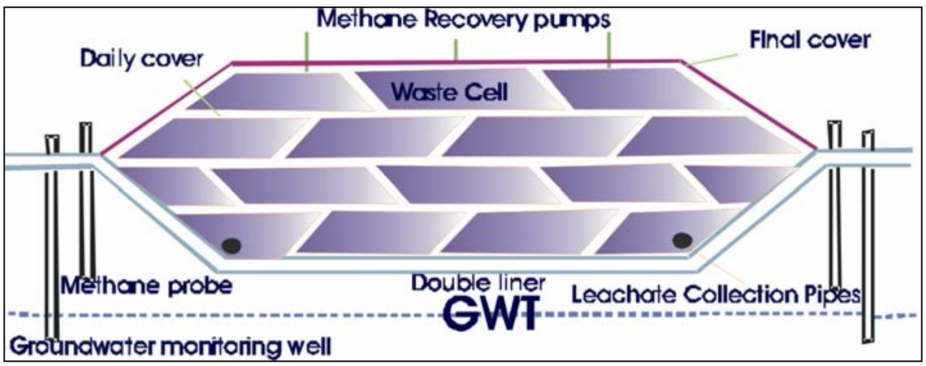


Figure 2.1. Schematic representation of a sanitary landfill with design components (Tchobanoglous *et al.*, 1993; Bagchi, 1994)

2.3.2. Natural Attenuation Landfills

A natural attenuation landfill which allows the liquid wastes to migrate from the landfill uses the natural geological and hydrogeological characteristics of the subsurface (Figure 2.2). It takes the advantage of the natural subsurface processes of biodegradation, filtration, sorption, and ion exchange which help the purification of the groundwater. The other advantages of using natural in situ geological and hydrogeological barriers are that natural barriers do not encapsulate waste and inhibit its degradation, and the natural infiltration and percolation characteristics of the subsurface are not disrupted. In addition, this method has relatively minor cost of construction, operation and maintenance compared to the sanitary landfills. Attenuation landfills are based on the dilute and disperse principle of leachate management. Natural low permeability and attenuation characteristics of geological barriers in the subsurface, especially low permeability clay rich overburden and to a lesser extent consolidated mudrocks are preferable for this method to prevent groundwater pollution (Allen, 2002).

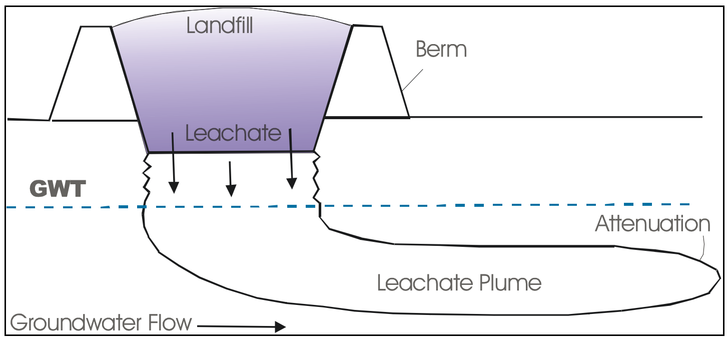


Figure 2.2. Schematic representation of a natural attenuation landfill (Tchobanoglous *et al.*, 1993; Bagchi, 1994)

2.4. Landfill Site Selection

The major goal of the landfill site selection process is to ensure that the disposal facility is located at the best location possible with little negative impact to the environment or to the population. For a sanitary landfill siting, a substantial evaluation process is needed to identify the best available disposal location which meets the requirements of government regulations and best minimizes economic, environmental, health, and social costs. Evaluation processes or methodologies are structured to make the best use of available information and to ensure that the results obtained are reproducible so that outcomes can be verified and defended (Siddiqui, 1996).

An effective technique should have the following characteristics (Lane *et al.*, 1983):

1. The technique should evaluate all land in a systematic and impartial way that can be reasonably considered available for landfill.
2. The technique should clearly establish the relative suitability of land for absolute suitability or minimum acceptable standards. These criteria or standards can vary from area to area depending on different constraints on available land or different public concerns. The technique should illustrate which lands are better or worse for sanitary landfills, rather than which lands are suitable or unsuitable.
3. The technique should be practical and be based on commonly available information.
4. The technique should be adaptable to computerized analysis.
5. The technique should be designed to explain clearly and directly the analysis and results in a format easily understandable by the officials and the general public.

The use of maps containing various landfill selection criteria is a simple and common method to determine landfill suitability. Maps containing data such as geology, soils, water quality, and floodplains are superimposed on one another to determine a final map of landfill suitability. Low technology techniques consist of the use of manual overlays and hand drawn maps in order to determine landfill suitability. Simple overlays can be produced with tracing paper or acetate. However, low technology cartographic procedures are time consuming and the accuracy of the final products depends on the cartographer (Schwartz, 2001).

Geographic Information Systems (GIS) are ideal for preliminary site selection studies because it can manage large volumes of spatially distributed data from a variety of sources and efficiently store, retrieve, analyze and display information (Siddiqui, 1996). Using GIS for site selection not only increases the objectivity and flexibility but also ensures that a large amount of spatial data can be processed in a short time. Relatively easy presentations of GIS siting results are also one of the advantages (Kao and Lin, 1996).

2.4.1. Criteria for Landfill Siting

There are a number of criteria for landfill site selection. These are environmental criteria, political criteria, financial and economical criteria, hydrologic and hydrogeologic criteria, topographical criteria, geological criteria, availability of construction material and other criteria. Each criterion will be discussed briefly in the next sections.

2.4.1.1. Environmental Criteria

2.4.1.1.1. Ecological value of the flora and fauna

The direct and indirect spatial use of a landfill will destroy the actual vegetation and fauna. When making a decision, the ecological value of the actual vegetation and fauna should be evaluated carefully for the candidate area. Ecological value is based on diversity, naturalness and characteristic feature. An example of indirect use is the disturbance of the quietness in the surroundings caused by the activities on the landfill.

2.4.1.1.2. Odour and dust nuisance

A new landfill should not be located within a distance of a housing area because of the dust and odour emissions. Dependent of the local wind direction and speed, the safe distance necessary to locate a landfill site should be determined to prevent sensing dust and odour. The problems of odour and dust can also be minimized by proper soil cover.

2.4.1.1.3. Nuisance by traffic generation

A new landfill will generate more traffic. How much more traffic depends of the distance to the collection area, the kind of transport and the use of transfer stations. Access roads passing through housing areas will cause more nuisance than access roads through the open country side. So, routing vehicle traffic through industrial, commercial or low density population areas decreases the noise impacts of landfill related vehicles.

2.4.1.1.4. Risks for explosion or fire

Because of the presence of landfill gas, there is a chance for explosion and/or fire. Soil cover also functions to smother fires and to form a barrier preventing the spreading of fires. Proper policing of incoming trucks can further reduce fire risk by minimizing the dumping of flammable loads (Wilson, 1977).

2.4.1.1.5. Other nuisance for neighbouring area

Other nuisance includes vermin that is attracted by the organic parts of the waste on the landfill (rats, mice, birds, insects), windblown litter, noise caused by construction, compaction or trucks on the landfill. The daily cover is a solution for nuisance developed by the presence of vermin. Continuous grading of soil cover to fill in low spots is essential to prevent the development of stagnant pools of water in which mosquitoes can breed.

2.4.1.1.6. Ecological, scientific or historical areas

Especially national parks and natural conservation areas and also historical areas are not suitable for the location of a landfill.

2.4.1.1.7. Tourist/recreation areas

A new landfill should not be planned within an existing recreational area or adjacent to it. However, a landfill is possible in some kinds of recreation areas like car/motor racing. Also the final use of a landfill can be planned as a recreational area.

2.4.1.2. Political Criteria

2.4.1.2.1. Acceptance by the local municipalities

The political acceptance of a new landfill location can differ in each region and sometimes the potential sites are located in different regions. The level of political acceptance has influence on the willingness of the local municipalities to make their regional physical plans and to give permission for the construction of a landfill. The unwillingness will cause to a delay of the decision on the landfill location.

2.4.1.2.2. Acceptance by the pressure groups involved

The acceptance by the public of a landfill in their own region or municipality is an important factor in the decision making process. The so-called NIMBY (not in my backyard) syndrome is becoming a common attitude. The influence of the public is significant if there are local groups which are well organized and having good relations with the local authorities and the media (papers, radio and television). The level of the public acceptance can be measured how far the local pressure groups are succeeding to delay the decision making process.

2.4.1.2.3. Property of the landfill area

The ownership of the needed land for the landfill is very important. Public ownership is easier than private ownership because the private ownership will give problems with the cost of the land. Sometimes, expropriation is needed and this procedure will cause delays.

2.4.1.3. Financial and Economical Criteria

2.4.1.3.1. Costs of land

Costs of the land depend on the land prices which can differ for each location. The actual use of the land is important for the price which influences the level of compensation for the owner or actual users. The potential landfill with the lowest costs is more preferable.

2.4.1.3.2. Costs for the access of the landfill

Costs for the access of the landfill depend on the condition and the presence of roads close to the landfill. If reconstruction of actual roads is needed, the costs will increase. Because of that road network is an important factor to locate a landfill site.

2.4.1.3.3. Transport costs

Transport costs are determined by the transport distances from the source of waste generation, the way of transport and the way of collection. The other factors affecting transport costs are the need for waste transfer stations and the possibility to use railways.

2.4.1.3.4. Costs for personnel, maintenance and environmental protection

The costs for personnel will not differ so much between the different potential landfill sites. Maintenance depends on the availability of soil needed for the daily or regular covering and for the stability of the landfill. If the soil is not available in the area, it should be imported which increases the maintenance costs. Extra technical provisions should be placed to prevent the pollution of the soil, groundwater and surface water at the landfill. Monitoring the drainage system and the quality of the leachate and surface water are also important factors in the maintenance costs. The potential landfill with the lowest maintenance costs is more suitable for a landfill.

2.4.1.3.5. Costs for the after-care

The costs for after-care is not only dependent on the kind of final use but also on provisions to monitor the groundwater quality, existence of gas, the winning of gas, the stability of the completed landfill. Needed provisions are depending on the characteristics of the filled waste, the kind of subsoil, the hydrogeological situation, and the kind of final use.

2.4.1.4. Hydrologic / Hydrogeologic Criteria

2.4.1.4.1. Surface water

The landfill site should not be placed within surface water or water resources protection areas to protect surface water from contamination by leachate. Safe distances from meandering and non-meandering rivers should be achieved to prevent waste from eroding into rivers and major streams. A landfill should not be located within 100 feet (30.48 m) of any non-meandering stream or river, and at least 300 feet (91.44 m) from any meandering stream or river. Large ponds, lakes, and reservoirs should have a buffer zone of land to prevent blown debris and runoff from harming aquatic habitats. Large bodies of water (greater than 20 acres (80937.45 m^2) of surface area) should be at least 100 feet (30.48 m) from any landfill site. If the regional drinking water is supplied by surface water impoundments, it may be necessary to exclude the entire watershed that drains into the reservoir from landfill sites (Bagchi, 1994).

In case of a high velocity of the surface flow there will be more dilution of an eventually contamination. The potential landfill location with the highest velocity of the overland flow will get the highest ranking score.

The major concern of siting landfills within floodplains is the downstream effect from waste carried away during episodes of higher water levels. Since major rivers have a higher discharge and greater downstream influence, no landfill should be sited within the floodplains of major rivers (Bagchi, 1994). The construction of a landfill within the 100-year flood stage of a minor river or stream is not safe.

2.4.1.4.2. Groundwater

To protect subsurface drinking water, landfills should not be situated over high quality groundwater resources. Fresh groundwater (total dissolved solids>1000 mg/l) should be avoided or protected with a compound liner system and monitoring wells (Bagchi, 1994). Since potential lechate leaks will travel down-gradient, landfills should be placed greater than 304.8 m (1000 feet) up-gradient from water wells. Aquifer depths less than 15.24 m (50 feet) should be considered less suitable than sites with a depth-to-groundwater of 60.96 m (50 to 200 feet) (Bolton, 1995). Table 2.2 and Table 2.3 show landfill suitability based on depth to groundwater and amount of dissolved solids.

Table 2.2. Groundwater depth and landfill suitability (Bolton, 1995)

Depth to Groundwater	Suitability
Over 60 meters(200ft)	High
15 to 60 meters	Moderate
Under 15 meters (50ft)	Low

,

Table 2.3. Groundwater quality and landfill suitability (Bagchi, 1994)

Groundwater Quality (TDS in mg/l)	Suitability
Over 10000	High
1000 to 10000	Moderate
Under 1000	Low

A high velocity of the groundwater flow is increasing the spreading of eventually leachate beneath the landfill. The velocity of the groundwater flow is dependent of porosity of the soil and the filtering speed. The potential landfill location with the lowest velocity of the groundwater flow is more suitable for a landfill.

A high groundwater level or a nearby high river level will cause more risk to pollute the groundwater or river water. The potential landfill location with the lowest groundwater or river level is more suitable for a landfill.

Impermeable layers in the subsoil are minimizing the risk of polluting the groundwater. Especially clay layers have a low permeability. The location with subsoil layers which have a high impermeability is more preferable to locate a landfill.

2.4.1.5. Topographical Criteria

The topography of an area is an important factor on site selection, structural integrity, and the flow of fluids surrounding a landfill site because it has important implications for landfill capacity, drainage, ultimate land use, surface and groundwater pollution control, site access and related operations (Wilson, 1977). Deciding the type of landfill design (area-, trench-, and depression-type landfills) is directly related to topography of a site.

Flat and gently rolling hills that are not subjected to flooding are the best sites for area- and trench-type landfills. However, this kind of topography is also suitable for other land uses like agriculture, residential or commercial development that lead to higher land prices.

Depressions such as sinkholes commonly associated with unstable caverns should be avoided because they may cause to contamination of groundwater sources of drinking water. Other topographical depressions resulting from human activities, such as stone quarries, clay pits, and strip mines can be reclaimed by using landfills. The floor of these depressions typically consists of low permeable formations such as clay, siltstone, or shale. Clay pits are more suitable for depression-type landfills whereas sand gravel pits should be avoided according to permeability, except when the bottom formations are impermeable (Schwartz, 1997).

The potential for slope failure is related to the degree or grade of the topography. Slope failure underneath or adjacent to landfills, will result in waste containment failure and release of debris into the surrounding area. Land with slopes greater than 15% should be considered unsuitable for waste disposal sites (Bagchi, 1994).

The regional topography also has a direct impact on the flow of surface run-off, run-on and drainage from a waste disposal site. Run-off refers to rainwater or leachate that drains overland away from the facility and run-on refers to drainage overland on to any part of the facility. Sites with little need for control of run-on from upland and slow run-off are preferable. Run-on is controlled by berms and stream diversion. Run-off control is affected by the velocity of water traversing the site (Oweis and Khera, 1990). To limit the potential spread of contaminated runoff, a landfill should not be located on the divides of major drainage basins (watersheds).

2.4.1.6 . Geological Criteria

The geology of an area will directly control the soil types created from the parent material, loading bearing capacity of the landfill's foundation soil, and the migration of leachate. Rock and its structure type will determine the nature of soils and the permeability of the bedrock. Geologic structure will influence the movement of leachate and potential rock-slope failure along joints and tilted bedding planes.

Comparing extreme permeability rates, unfractured crystalline rocks will transmit little (if any) fluids whereas poorly cemented sandstones will allow rapid transport of fluids. Due to higher permeability rates, sandstone is less suitable as a landfill bedrock than other sedimentary rocks such as limestone and shale. Limestones are more suitable than shales due to susceptibility of the carbonate rocks to dissolution from low pH leachate, and are commonly associated with discontinuities and karst features such as collapses, sinkholes, and caverns. Shale formations are well suited for landfill sites since shales commonly act as a retarding bed slowing or confining the transmission of fluids.

Figure 2.3 shows the influence of sedimentary rock types on the permeability rates of landfill leachate. Table 2.4. summarizes some of the various rock types of suitability for landfill siting.

Table 2.4. Landfill suitability of bedrock (Oweis and Khera, 1998)

Rock Type	Suitability
Unfractured crystalline	Very high
Shale and clay	High
Limestone	Fair to poor
Sandstone	Poor to very poor
Unconsolidated sand/gravel	Unsuitable

The structure and orientation of discontinuity planes will have a direct impact on the movement of leachate and on the structural integrity of the bedrock material. Sites composed of tilted rocks greater than 45 degree dip have the potential for rock-slope failure along discontinuities and should be considered an unstable area. Leachate flow will follow down-dip directions. To limit the spread of leachate, landfills should not be situated on the axis of anticlines and structural domes. In addition to the spreading of landfill leachate, anticlines and domes are often associated with oil and natural gas fields and should be avoided. In contrast, synclines and structural basins are the best sites for leachate to pool into. Figure 2.4 shows the influence of geologic structure on the dispersing or collection of landfill leachate (Schwartz, 2001).

Regions that are faulted are not suitable for landfill because a fault can act as a conduit of leachate transport and can reduce the structural integrity of bedrock supporting the landfill and its equipment.

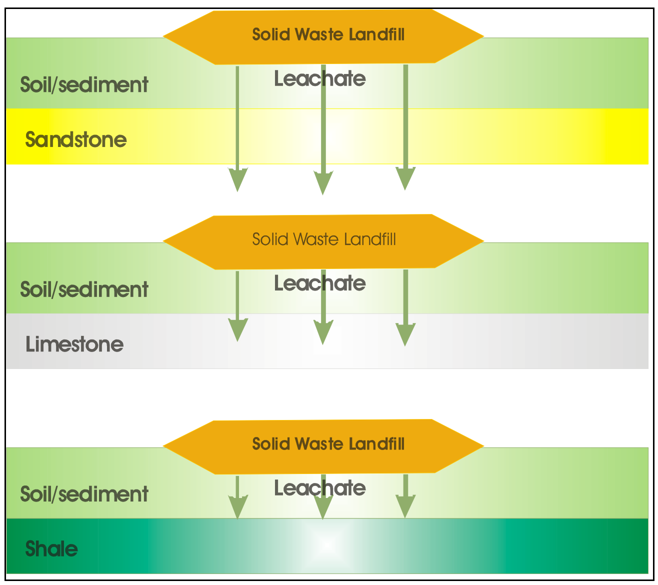


Figure 2.3. Lithologic influence on permeability rates of landfill leachate

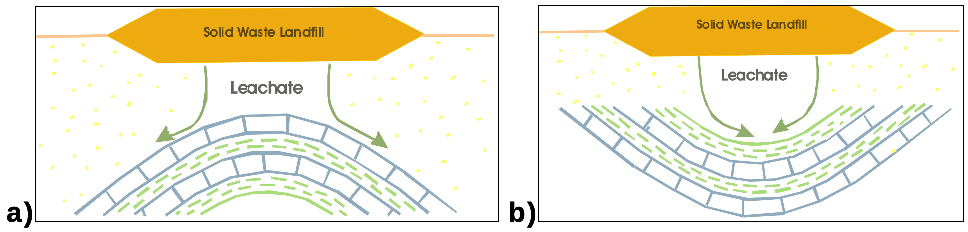


Figure 2.4. Influence of geologic structure on transport of landfill leachate
(a) spreading of leachate over anticline axis, whereas
(b) pooling of leachate within syncline

2.4.1.7. Availability of Construction Material

Sanitary landfill design usually involves an adequate source of soil with textures appropriate for daily and final covering (Brady and Weil, 1996).
Soil is important in landfill development for three basic reasons:

- Cover: Material used to cover the solid waste daily and when an area of the landfill is completed. The permeability of the final cover will greatly influence the quantity of leachate generated.
- Migration control: The material that controls leachate and methane movement away from the landfill. An impermeable formation will retard movement; a permeable soil will provide less protection and may require installing additional controls within the landfill.
- Support: The soil below and adjacent to the landfill must be suitable for construction. It must provide a firm foundation for liners, roads and other construction.

An optimal landfill soil will have moderately low permeability, sufficient bearing capacity to support equipment, a pH of at least 5, a low erodibility potential, and a high cation exchange capacity. However, a site's soil characteristics may change laterally, at depth, or the soil may not be present in sufficient volume. As shown in the Table 2.5. , fine grained soils are more suitable for landfills than coarse grained soils (Oweis and Khera, 1998). However, properties of clays including low drainage rates, shrink/swell potential, and low workability usually reduces a clay soils suitability against soils with a silty clay texture.

Table 2.5. Soil textures and landfill suitability (Oweis and Khera, 1998; Brady and Weil, 1996)

Soil Type	Suitability
Silt to very fine silty clay	Very high
Clay	High
Mixed	Moderate
Sandy	Low
Clean sand/gravel	Unsuitable

A high susceptibility to soil consolidation (peat and clay soils) is causing an unstable foundation of the landfill. An unstable foundation can lead to damages of the bottom liners and/or the drainage system. The location with the lowest susceptibility to soil consolidation is more suitable for a landfill.

2.4.1.8. Other Criteria

2.4.1.8.1. Residental and urban areas

Landfills may not be constructed on sites within a distance of less than 1000 m to settlements according to regulation on solid waste control in Turkey (Waste Disposal Directive of Turkey, 1991). Only if there are natural barriers like hills, trees or forests between the landfill site and the settlements, the construction of landfills in a distance less than 1000 m to settlements may be allowed after approval of the Ministry of Environment and upon order of the highest local authority and the concerned municipality.

2.4.1.8.2. Military areas

Areas used for the testing of military equipment or training of military personnel are not open for public usage.

2.4.1.8.3. Airports

The presence of birds is a real danger for airplanes. Because birds are attracted especially by organic waste, landfills should be located at a certain distance from airports.

2.4.1.8.4. Industrial areas

Industrial areas are not principally excluded as location of a landfill. Dependent of the kind of industry such as not sensible for dust or food factories, an industrial area or close to it is suitable for a landfill. An advantage of an industrial area is the presence of infrastructural provisions.

2.4.1.8.5. Difficult infrastructural provisions

If the location of the new landfill come across with existing infrastructural provisions such as cables, roads or existing plans for drainage, it is very difficult to make the location suitable for the use as a landfill.

2.4.1.9. Climate

The site selection process must consider climate characteristics such as prevailing winds, precipitation, evapotranspiration and temperature variations because they are related to odours, dust, leachate generation, blowing litter, cover soil and erosion (Wilson, 1977).

CHAPTER 3

MULTICRITERIA DECISION ANALYSIS

3.1. Spatial Multicriteria Decision Analysis (MCDA)

Decision Analysis is a set of systematic procedures for analyzing complex decision problems. These procedures include dividing the decision problems into smaller more understandable parts; analyzing each part; and integrating the parts in a logical manner to produce a meaningful solution (Malczewski, 1997). In general, MCDA problems involve six components (Keeney and Raiffa, 1976; Pitz and McKillip, 1984):

- A goal or a set of goals the decision maker want to achieve,
- The decision maker or a group of decision makers involved in the decision making process with their preferences with respect to the evaluation criteria,
- A set of evaluation criteria (objectives and/or physical attributes)
- The set of decision alternatives,
- The set of uncontrollable (independent) variables or states of nature (decision environment)
- The set of outcomes or consequences associated with each alternative attribute pair.

MCDA techniques can be used to identify a single most preferred option, to rank options, to list a limited number of options for subsequent detailed evaluation, or to distinguish acceptable from unacceptable possibilities (Dodgson, 2000).

There are many MCDA approaches which differ in how they combine and utilize the data. MCDA approaches can be classified on the basis of the major components of multicriteria decision analysis. Three different classifications can be made as (Figure 3.1):

(1) multiobjective decision making (MODM) versus multiattribute decision making (MADM)
(2) individual versus group decision maker problems, and
(3) decisions under certainity versus decisions under uncertainity

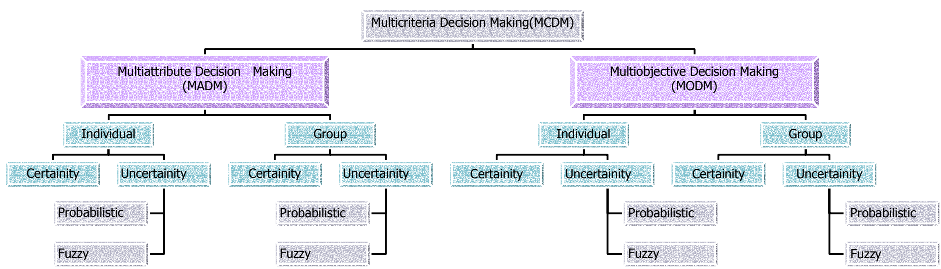


Figure 3.1. Classification of multicriteria decision problems (Malczewski, 1999).

The distinction between MADM and MODM is based on the evaluation criteria which are the standards of judgments or rules on which the alternatives are ranked according to their desirability. Criterion is a general term and includes both the concepts of attributes and objectives.

An attribute is a measurable quantity whose value reflects the degree to which a particular objective is achieved. An objective is a statement about the desired state of the system under consideration (Chankong and Haimes, 1983). It indicates the directions of improvement of one or more attributes. Objectives are functionality related to, or derived from a set of attributes (Malczewski, 1999).

There might be formal relationship between objectives and attributes, but usually the relationship is informal. To assign an attribute to a given objective, two properties which are comprehensiveness and measurability should be satisfied.

An attribute is comprehensive if its value sufficiently indicates the degree to which the objective is met. And it is measurable if it is reasonably practical to assign a value in a relevant measurement scale. The ratio, interval, ordinal and binary scales are suitable for measurement of attributes, whereas nominal scale is not since it does not allow an ordering of the alternatives (Janssen, 1992).
MADM problems require that choices be made among alternatives described by their attributes. The set of attributes is given explicitly and multiattribute problems have a finite set of feasible alternatives. Unlike MADM, MODM problems require that means-ends relationships be specified, since they deal explicitly with the relationship of attributes of alternatives to higher level objectives. MODM involves designing the alternatives and searching for the best decisions among an infinite or very large set of feasible alternatives. Each alternative is defined implicitly in terms of the decision variables and evaluated by means of objective functions (Malczewski, 1997) (Table 3.1).

Table 3.1. Comparison of MODM and MADM Approaches (Hwang and Yoon, 1981; Starr and Zeleny, 1977)

	MODM	MADM
Criteria defined by:	Objectives	Attributes
Objectives defined:	Explicitly	Implicitly
Attributes defined:	Implicitly	Explicitly
Constraints defined:	Explicitly	Implicitly
Alternatives defined:	Implicitly	Explicitly
Number of alternatives	Infinite (large)	Finite (small)
Decision maker's control	Significant	Limited
Decision modeling paradigm	Process-oriented	Outcome-oriented
Relevant to:	Design/search	Evaluation/choice
Relevance of geographical data structure	Vector-based GIS	Raster-based GIS

Both MADM and MODM problems can be further classified as individual and group decision making depending on the goal-preference structure. If there is a single goal preference, the problems is considered as individual decision making regardless of the number of decision makers involved in the process. However, if the individual or interest groups are characterized by different goal preferences, the problem becomes the group decision making (Malczewski, 1997).

The other classification depends on the certainity of the decision. If the decision maker has perfect knowledge of the decision environment and the amount of knowledge available is enough, then the decision is considered as decision under certainity. However, most of the real world decisions involve some aspects that are unknown and difficult to predict. This type of decisions is referred as decisions under uncertainity. The decisions under uncertainity can be further subdivided into fuzzy and probabilistic decision making (Leung, 1988 and Eastman, 1993). The probabilistic decisions are handled by probability theory and statistics. And the outcome of a stochastic event is either true or false. However, if the situation is ambiguous, the problem is structured as the degree of how much an event belongs to a class. This type of problems is handled by fuzzy set theory (Zadeh, 1965).

3.1.1. Steps of Spatial Multicriteria Decision Analysis (MCDA)

Any spatial decision problem can be structured into three major phases: intelligence which examines the existence of a problem or the opportunity for change, design which determines the alternatives and choice which decides the best alternative (Simon, 1960). The major elements involved in spatial decision making process are discussed below.

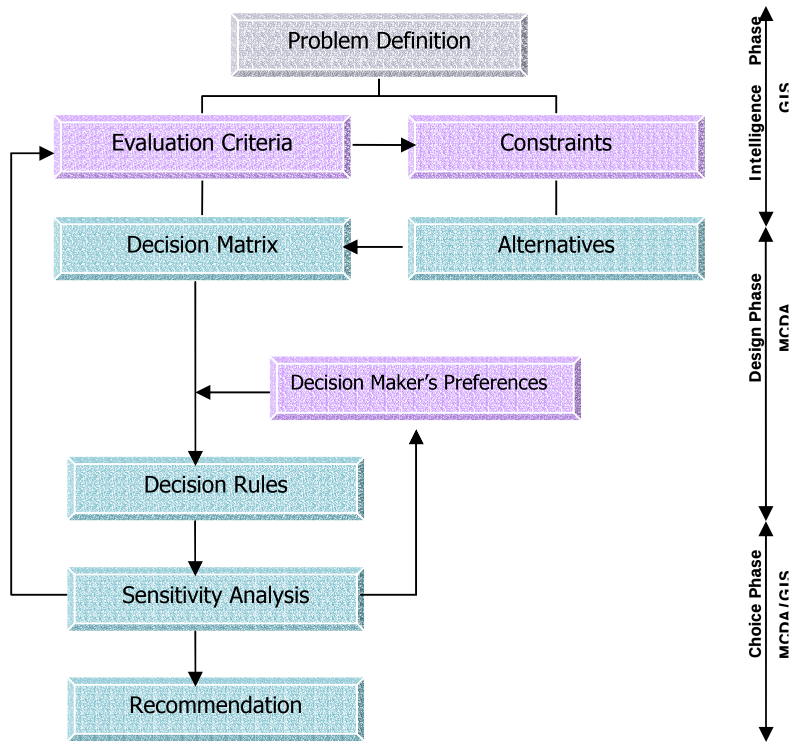


Figure 3.2. Framework for spatial multicriteria decision analysis (Malczewski, 1999).

3.1.1.1. Problem Definition

A decision problem is the difference between the desired and existing state of the real world. It is a gap which is recognized by a decision maker. Any decision making process begins with the recognition and the definition of the problem. This stage is in the intelligence phase of decision making and it involves searching the decision environment for conditions, obtaining, processing and examining the raw data to identify the problems. The GIS capabilities for storage, management, manipulation and analysis are used in this stage which provides major support (Malczewski, 1999).

3.1.1.2. Evaluation Criteria

After the determination of the problem, the set of evaluation criteria which includes attributes and objectives should be designated (Keeney and Raiffa, 1976). This stage involves specifying a comprehensive set of objectives that reflects all concerns relevant to the decision problem and measures for achieving those objectives which are defined as attributes. Because the evaluation criteria are related to geographical entities and the relationships between them, they can be represented in the form of maps which are referred as attribute maps. GIS data handling and analyzing capabilities are used to generate inputs to spatial decision making analysis (Malczewski, 1999).

3.1.1.3. Criterion Weights

A weight can be defined as a value assigned to an evaluation criterion which indicates its importance relative to other criteria under consideration. Assigning weights of importance to evaluation criteria accounts for (i) the changes in the range of variation for each evaluation criterion, and (ii) the different degrees of importance being attached to these ranges of variation (Kirkwood, 1997). There are four different techniques when assigning the weights: Ranking, Rating, Pairwise Comparison and Trade of Analysis Methods (Table 3.4).

3.1.1.3.1. Ranking Methods

This is the simplest method for evaluating the importance of weights which includes that every criterion under consideration is ranked in the order of decision maker's preferences. Due to its simplicity, the method is very attractive. However, the larger the number of criteria used, the less appropriate is the method. Another disadvantage is lack of theoretical foundation.

3.1.1.3.2. Rating methods

The method requires the decision maker to estimate weights on the basis of a predetermined scale. One of the simplest rating methods is the point allocation approach. It is based on allocating points ranging from 0 to 100, where 0 indicates that the criterion can be ignored, and 100 represents the situation where only one criterion need to be considered. Another method is ratio estimation procedure which is a modification of the point allocation method. A score of 100 is assigned to the most important criterion and proportionally smaller weights are given to criteria lower in the order. The score assigned for the least important attribute is used to calculate the ratios. Again the disadvantage of this method like ranking method is the lack of theoretical foundation. And also the assigned weights might be difficult to justify.

3.1.1.3.3. Pairwise Comparison Method

The method involves pairwise comparisons to create a ratio matrix. It takes pairwise comparisons as input and produced relative weights as output. The pairwise comparison method involves three steps:

(1) Development of a pairwise comparison matrix: The method uses a scale with values range from 1 to 9. The possible values are presented in Table 3.2.

Table 3.2. Scale for pairwise comparison (Saaty, 1980)

Intensity of importance	Definition
1	Equal importance
2	Equal to moderately importance
3	Moderate importance
4	Moderate to strong importance
5	Strong importance
6	Strong to very strong importance
7	Very strong importance
8	Very to extremely strong importance
9	Extreme importance

(2) Computation of the weights: The computation of weights involves three steps. First step is the summation of the values in each column of the matrix. Then, each element in the matrix should be divided by its column total (the resulting matrix is referred to as the normalized pairwise comparison matrix). Then, computation of the average of the elements in each row of the normalized matrix should be made which includes dividing the sum of normalized scores for each row by the number of criteria. These averages provide an estimate of the relative weights of the criteria being compared.

(3) Estimation of the consistency ratio: The aim of this is to determine if the comparisons are consistent or not. It involves following operations:

a) Determine the weighted sum vector by multiplying the weight for the first criterion times the first column of the original pairwise comparison matrix, then multiply the second weight times the second column, the third criterion times the third column of the original matrix, finally sum these values over the rows,
b) Determine the consistency vector by dividing the weighted sum vector by the criterion weights determined previously,
c) Compute lambda(λ) which is the average value of the consistency vector and Consistency Index (CI) which provides a measure of departure from consistency and has the formula below:

$$CI = (\lambda - n)/(n-1)$$

d) Calculation of the consistency ratio (CR) which is defined as follows:

$$CR = CI / RI$$

Where RI is the random index and depends on the number of elements being compared (Table 3.3, Figure 3.3). If $CR < 0.10$, the ratio indicates a reasonable level of consistency in the pairwise comparison, however, if $CR \geq 0.10$, the values of the ratio indicates inconsistent judgments.

Table 3.3. Random inconsistency indices (RI) for n=1,2,.....,15 (Saaty, 1980)

n	RI	n	RI	N	RI
1	0.00	6	1.24	11	1.51
2	0.00	7	1.32	12	1.48
3	0.58	8	1.41	13	1.56
4	0.90	9	1.45	14	1.57
5	1.12	10	1.49	15	1.59

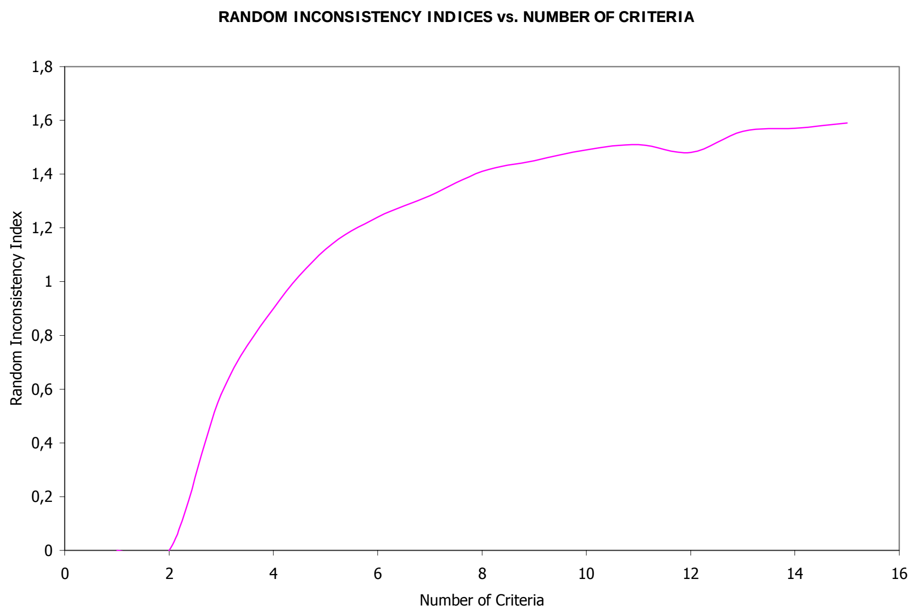


Figure 3.3. The graph of random inconsistency indices vs. number of criteria

The advantages of this method can be summarized that only two criteria have to be considered at a time, it can be implemented in a spreadsheet environment (Kirkwood, 1997) and it is incorporated into GIS based decision making procedures (Eastman *et al.*, 1993, Janskowski, 1995). On the other hand, the relative importance of evaluation criteria is determined without considering the scales on which the criteria are measured. Another disadvantage is that if you have many criteria, the amount of pairwise comparisons that should be made will be very large.

3.1.1.3.4. Trade-off Analysis Method

In this method, decision maker is required to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. Trade-offs define unique set of weights that will allow all of the equally preferred alternatives in the trade-offs to get the same overall value/utility. There is an assumption in this method that the trade-offs the decision maker is willing to make between any two criteria do not depend on the levels of other criteria (Malczewski, 1999).

The weakness of this method is the decision maker is presumed to obey the axioms and can make fine grained in difference judgements. On the other hand, the method can be implemented within the spreadsheet environment (Kirkwood, 1997).

3.1.1.4. Decision Rules

The criterion map layers and weightings must be integrated to provide an overall assessment. This is accomplished by an appropriate decision rule or aggregation function (Chankong and Haimes, 1983). Since a decision rule provides an ordering of all alternatives according to their performance with respect to the set of evaluation criteria, the decision problem depends on the selection of best outcome. The most often used decision rules are discussed below (Table 3.5 and Table 3.6):

Table 3.4. Comparison of the methods used in estimating weights (Pitz and McKillip (1984), Schoemaker and Waid (1982) and Kleindorfer *et al.*, 1993)

Methods/ Features	Ranking	Rating	Pairwise Comparison	Trade-off Analysis
# of judgements	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	Logical Decision
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

3.1.1.4.1. Simple Additive Weighting (SAW)

Simple additive weighting which is also known as weighted linear combination or scoring methods is a simple and most often used mulltiattribute decision technique (Malczewski, 1997; Janssen, 1992; Eastman, 1993). The method is based on the weighted average. An evaluation score is calculated for each alternative by multiplying the scaled value given to the alternative of that attribute with the weights of relative importance directly assigned by decision maker followed by summing of the products for all criteria. The simple additive weighting method evaluates each alternative, A_i, by the following formula:

$$A_i = \sum w_j * x_{ij}$$

Where x_{ij} is the score of the ith alternative with respect to the jth attribute, w_j is the normalized weight.

If the scores for the criteria are measured on different measurement scales, they must be standardized to a common dimensionless unit before the SAW method. The simplest procedure for standardizing the raw data is to divide each raw score by the maximum value for a given criterion.

$$x'_{ij} = x_{ij} / x_i^{\max}$$

where x'_{ij} is the standardized score for the i[th] alternative and j[th] attribute, x_{ij} is the raw score, and x_i^{max} is the maximum score for the j[th] attribute.

The advantage of this method is that it is a proportional linear transformation of the raw data which means that the relative order of magnitude of the standardized scores remains equal. One disadvantage is that the lowest standardized value does not necessarily equal to zero which makes the interpretation of the least attractive criterion score difficult.

Another method is the score range procedure in which the standardized scores are calculated by dividing the difference between the max raw score and a given raw score by the score range.

$$x'_{ij} = x_j^{\max} - x_{ij} / x_j^{\max} - x_j^{\min}$$

where x'_{ij} is the standardized score for the i[th] alternative and j[th] attribute, x_{ij} is the raw score, and x_i^{max} and x_i^{min} is the maximum and score for the j[th] attribute, respectively.

Other standardization procedures are division by the sum of the scores of each criterion, division by ideal or target values, or vector normalization (Voogd, 1983).

The SAW methods can be implemented using any GIS having overlay capabilities. The GIS based Simple Additive Weighting method involves the following steps:

1. Definition of the set of evaluation criteria (map layers) and the set of feasible alternatives,
2. Standardization of each criterion map layer,
3. Definition of the criterion weights,
4. Construction of the weighted standardized map layers,
5. Generation of the overall score for each alternative using the overlay operation,
6. Ranking of the alternatives according to the overall performance score (Malczewski, 1999).

There are two assumptions in the SAW method; the linearity and additivity of attributes which are very difficult to meet in many spatial decision situations (Hwang and Yoon, 1981; Bodily, 1985; Lai and Hopkins, 1989). Linearity means that the desirability of an additional unit of an attribute is constant for any level of that attribute. For example, this assumption implies that an additional 10 ha in a parcel of land is valued the same regardless of whether it is added to a land of 100 or 1000 ha[2]. Whereas additivity means that there is no interaction (complementary) effect between attributes (Malczewski, 1997).

The SAW method is quite widely used in real world due to its easiness. It can be implemented both in raster and vector GIS environment and operationalized using any GIS system having overlay capabilities or implemented in a spreadsheet environment (Kirkwood, 1997) However, the ignorance of the definition of the units of measurement and little theoretical foundation are the disadvantages of this method.

3.1.1.4.2. Analytical Hierarchy Process (AHP)

The AHP developed by Saaty (1980) is a technique for analyzing and supporting decisions in which multiple and competing objectives are involved and multiple alternatives are available. The method is based on three principles: decomposition, comparative judgment and synthesis of priorities.

In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Erkut and Moran, 1991). When developing a hierarchy, the top level is the ultimate goal of the decision. The hierarchy decreases from the general to more specific until a level of attributes are reached. Each level must be linked to the next higher level. Typically a hierarchical structure includes four levels: goal, objectives, attributes and alternatives. The alternatives are represented in GIS database. Each layer consists of the attribute values assigned to the alternatives (cell or polygon) which are related to the higher level elements (attributes).

Once decomposition is completed, cardinal rankings for objectives and alternatives are required. This is done by using pairwise comparisons which reduces the complexity of decision making since two components are considered at a time. It involves 3 steps: (1) development of a comparison matrix at each level of hierarchy (2) computation of weights for each element of the hierarchy and (3) estimation of consistency ratio which is mentioned in Pairwise comparison section.

The final step is to combine the relative weights of the levels obtained in the above step to produce composite weights. This is done by means of a sequence of multiplications of the matrices of relative weights at each level of the hierarchy. First, the comparison matrix is squared and the row sums are calculated and normalized for each row in the comparison matrix. This process is continued when the difference between the normalized weights of the iterations become smaller than a prescribed value (Saaty, 1990).

The AHP has widespread use due to its flexibility, easy to use. It is also incorporated into GIS environment (Banai-Kashani, 1989; Eastman, 1993; Jankowski, 1995; Siddiqui *et al.*, 1996) and can be used in two distinctive ways within GIS to derive weights and combine them with attribute map layers and to aggregate the priority for all levels of the hierarchy structures. In addition, the AHP can even be implemented in spreadsheet environment (Kirkwood, 1997). However, ambiguity in relative importance, inconsistent judgments by decision maker and the use of 1 to 9 scale can be thought as the disadvantages of this method. The ratio scale makes sense when dealing with something like distance, or area which are natural ratio scales, but not when dealing with like comfort, image, or quality of life, for which no clear reference levels exists. Furthermore, for large problems too many pairwise comparisons must be performed (Malczewski, 1999).

3.1.1.4.3. The value/utility function methods

The method is based on multiattribute utility theory (Keeney and Raiffa, 1976). The value function approach is applicable in the decision situation under certainity (deterministic approach) which assumes that the attributes are known with certainity whereas the utility function approach is convenient for the uncertainity conditions (probabilistic in nature).

The GIS based value/utility function involves the following steps:

1. Determination of the set of attributes (attribute map layers) and the set of feasible alternatives.
2. Estimation of the value (utility) function for each attribute and use the function to convert the row data to the value (utility) score map layer
3. Derivation of the scaling constants or weights for the attributes
4. Construction of the weighted value (utility) map layers; that is, multiply the weights of importance by the value (utility) map layers
5. Combination of the weighted value (utility) maps by summing the weighted value (utility) map layers

6. Ranking of the alternatives according to the aggregate value (utility); the alternative with the highest value (utility) is the best alternative.

The value/utility function involves two elements: (1) the single attribute utility/value function to transform attribute levels into an interval utility/value scale, (2) the trade off analysis for defining the weights (Keeney, 1980). By multiplying the utilities by the weights, the trade-offs among the attribute utilities are taken into account in the multiattribute utility function. The overall utility or value for any alternative is a weighted average of the single attribute utilities. This method is similar to SAW method except the score x_{ij} is replaced by a value or utility derived from the value/utility function.

There are two assumptions of preferential independence which refers that the relative preferences of attributes are not altered by changes in other attributes and utility independence which means that the utility function over single attribute does not depend on the other attribute (Malczewski, 1999).

One of the most important advantages of this method is the above assumptions which enables decision maker to focus initially on deriving utility function for one attribute at a time. The method provides a better theoretical foundation for describing the utilities. However, the method is impractical and it is difficult to obtain a mathematical representation of decision maker's preferences, because assessing utility functions with even a moderate number of criteria is very time consuming and tedious. In addition, the method neglects the existence of spatial relationships among spatial alternatives (Malczewski, 1997).

3.1.1.4.4. The Ideal Point Methods

In the ideal point method the alternatives are ranked according to their separation from an ideal point. The ideal point is defined as the most desirable, weighted, hypothetical alternative (decision outcome). The alternative, closest to the ideal point is the best alternative. The separation is measured in terms of metric distance (Janssen, 1992; Malczewski, 1997).

One of the most popular ideal point methods is the Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS) developed by Hwang and Yoon (1981).

The GIS based ideal point method involves the following steps:

1. Determine the set of feasible alternatives,
2. Standardize each attribute map layer,
3. Define the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w = 1$),
4. Construct the weighted standardized map layer by multiplying each value of the standardized layer by the corresponding weight,
5. Determine the max value for each of the weighted standardized map layers (the values determine the ideal point),
6. Determine the mean value for each weighted standardized map layer (the values determine negative ideal point),
7. Using a separation measure, calculate the distance between the ideal point and each alternative,
8. Using the same separation measure, determine the distance between the negative ideal point and each alternative,
9. Calculate the relative closeness to the ideal point,
10. Rank the alternatives according to the descending order of ideal point.

Although the ideal point methods can be implemented both in raster and vector GIS, the technique is especially suitable for the raster GIS (Carver, 1991; Janskowski and Ewart, 1996; Malczewski, 1996). The method provides complete ranking and information on the relative distance of each alternative to the ideal point. In this method, an alternative is treated as an inseparable bundle of attributes which makes the method an attractive approach when the dependency among attributes is difficult to test or verify (Malczewski, 1997).

3.1.1.4.5. Outranking Methods

These methods which are also known as concordance methods are based on a pairwise comparison of alternatives. They provide an ordinal ranking and sometimes only a partial ordering of the alternatives which means that it can only express which alternative is preferred but cannot indicate how much.

The best known outranking method is the Elimination and Choice Translating Reality (ELECTRE I) and several modifications of this method have been suggested (ELECTRE II, III, IV, PROMETHEE I and II) (Goicoechea *et al.*, 1982; Vincke, 1989).

The basic elements of this method is concordance measures which are the set of all criteria for which alternative i is not worse than the competing alternative i' and disconcordance measures which are the set of all criteria for which alternative i is worse than the competing alternative i' (Nijkamp and van Delft, 1977). These indicators are calculated for all pairs of alternatives and then the alternatives with the highest concordance value and with the lowest disconcordance value are found. There are formulas suggesting to determine overall score for each alternative based on these indicators (Massam, 1988).

The GIS based outranking method involves several steps:

1. Determination of the set of feasible alternatives
2. Standardization of each attribute
3. Definition of the weights assigned to each attribute ($0 \leq w \leq 1$, $\Sigma w = 1$)
4. Generation of the concordance matrix by calculating the concordance indices for each pair of alternatives
5. Summation of the rows of the concordance matrix to obtain the overall score for each alternative
6. Ranking the alternatives according to the descending order of the sum of the concordance indices (C_i), the alternative with the highest value of C_i is the best alternative (Malczewski, 1999).

The advantages of this method include that least amount of information from decision maker is required and it can consider both objective and subjective criteria. However, complete ranking of the alternatives may not be achieved and since the method requires comparison across alternatives, it can not be implemented directly by using cartographic modeling techniques in a GIS (especially for raster GIS). The method provides an ordinal ranking (Malczewski, 1999).

3.1.1.4.6. Ordered Weighted Average (OWA)

The OWA method has been developed in the context of fuzzy set theory (Yager, 1988). There are three basic types of aggregation operators on fuzzy sets (1) operators for the intersection of fuzzy sets (the MIN operations), (2) operators for the union of fuzzy sets (the MAX operations), and (3) averaging operators (Eastman *et al.*, 1993). Yager (1988) introduced an aggregation technique based on the ordered weighted averaging (OWA) operator, which is a generalization of the three basic aggregation functions. OWA is a weighted sum with ordered evaluation criteria. Thus, in addition to the criterion weights which are assigned to evaluation criteria to indicate their relative importance, order weights are used. The order weights are associated with the criterion values on the location by location basis. They are assigned to a given location's attribute values in decreasing order without considering from which attribute map the value comes (Malczewski, 1997; Malczewski, 2002).

3.1.1.4.7. Goal Programming

The goal programming method was originally proposed by Charnes and Cooper (1961). It is a form of linear programming for multiple goals (evaluation criteria). Linear programming identifies from the set of feasible solutions the point which optimizes a single objective, whereas goal programming determines the point that best satisfies the set of goals in the decision problem which aims to minimize the deviations from the goals.

Three basic approaches to goal programming can be distinguished:

(1) weighted goal programming: The objective is to find a solution that minimizes the weighted sum of the goal deviations. The weights represent additional information reflecting the decision maker's preferences with respect to the deviation variables (Malczewski, 2002).

(2) Chebyshev goal programming: It can be considered as a specific form of the weighted goal programming approach which seeks the solution that minimizes the worst unwanted deviation from any single goal. Instead of using subjective notations to set the aspiration levels for the objectives, a set of single optimization problems is solved to arrive at the best and worst possible weights of each objective. The best values are then used as aspiration levels for the objectives. Then, the deviation from those aspiration levels should be minimized so that the worst deviation from any single goal aspiration level is minimized (Malczewski, 1997).

(3) Lexicographic goal programming: In this method, the objective functions are ordered according to their importance. The most important function is minimized first, then on the set of optimal solutions with respect to the first function the second function is minimized, and so on, until a unique solution is obtained or all the specified functions are minimized (Carver, 1991).

The major advantage of this method is its computational efficiency. Goal programming approach provides an efficient linear programming environment and can be incorporated into GIS procedures by integrating standard mathematical programming software such as LINDO (Malczewski, 1997). However, the standard goal programming methods require the decision maker specify fairly detailed information about priorities and the importance of goals in the form of weights which is a difficult task to provide meaningful preference weights on a cardinal scale (Nijkamp, 1979). The cardinal weight and lexicografic methods have a strong tendency to generate inefficient solutions. This inefficiency problem seriously limits the utility of goal programming methods (Malczewski, 1997).

3.1.1.4.8. Compromise Programming

It is a MODM method based on the displaced ideal concept which assumes that the choice among alternatives depends on the point that is used as a reference (Zeleny, 1982). This point is the ideal point which defines the optimal value for each objective considered separately. Compromise programming attempts to minimize the distance from the ideal solution.

The advantage of this method is its simple conceptual structure. The set of preferred compromise solutions can be ordered between the extreme criterion outcomes and consequently, an implicit trade off between criteria can be performed. However, there is no clear interpretation of the various values of the parameter p which gives the importance of the maximal deviation from the ideal point. Therefore, the selection of the best alternative within the reduced set of compromise alternatives must be made based on intuition (Malczewski, 1997).

3.1.1.5. Sensitivity Analysis

In many decision rules it is assumed that complete information is available so that the criterion outcomes of each alternative are precisely known. However, in real world situations, this is not the case and analysis should be made to investigate whether the preliminary conclusions are robust or not. Sensitivity analysis aims to identify the effects of changes in the inputs which are geographical data and the decision maker's preferences on the outputs, in other words, on the ranking of alternatives. If the changes do not significantly affect the outputs, then the ranking is assumed as robust and satisfactory. If the result is unsatisfactory, it should be return to the problem formulation step (Malczewski, 1999; Belton *et al.*, 2002).

Table 3.5 A summary of the most often used MODM

MODM Method	Input	Output	Types of Decisions	DM Interaction	Assumptions
Value/utility models	Value/utility functions, weights	Best alternative	Individual DM, deterministic, probabilistic	Moderate/high	Very restrictive
Goal programming	Aspiration levels, priorities, weights	Best alternative	Individual DM, deterministic, fuzzy	High	Very restrictive
Interactive programming	Aspiration, reservation	Satisfying alternative	Individual DM, deterministic, fuzzy	Moderate, increases with problem size	Moderately restrictive
Compromise programming	Ideal point, weights	Compromise alternative, cardinal ranking	Individual and group DMs, probabilistic, fuzzy	Moderate	Moderately restrictive
Data envelopment analysis	Set of evaluation inputs and outputs	Cardinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy	Low	Moderately restrictive

Table 3.6 A summary of the most often used MADM

MADM Method	Input	Output	Decision Types
Scoring (SAW)	Attribute scores, weights	Ordinal ranking	Individual DM, deterministic
Multi-attribute value	Value functions, weights	Cardinal ranking	Individual and group DMs, deterministic, fuzzy
Multi-attribute utility	Utility functions, weights	Cardinal ranking	Individual and group DMs, probabilistic, fuzzy
Analytic hierarchy process	Attribute scores, pairwise comparisons	Cardinal ranking (ratio scale)	Individual and group DMs, deterministic, probabilistic, fuzzy
Ideal point	Attribute scores, weights, ideal point	Cardinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy
Concordance	Attribute scores, weights	Partial or ordinal ranking	Individual and group DMs, deterministic, probabilistic, fuzzy
Ordered weighted averaging	Fuzzy attribute, weights, order weights	Cardinal or ordinal ranking	Individual and group DMs, fuzzy

3.2. Implementation of GIS and MCDA for Landfill Site Selection

Different methods of site selection for waste disposal have been developed over the last decades to provide more efficient waste disposal allocation.

Conventional location models for solid waste management in the late 1960s focused on financial optimism (Esmali, 1972; Helms and Clark, 1970) which includes the operation costs of the facility, the costs of the transportation of waste to the facility and the revenues generated by the facility such as energy. During the 1980s and 1990s, people became aware of the potential of pollution due to waste disposal which led to more restrictive environmental regulations and to increase the emphasis given to the recycling and waste reduction (Leao *et al.*, 2003). One of the preliminary researches on this approach is cited as Lane and McDonald (1983) and they had considered only environmental properties of the sites on a map layer based approach. Whereas DRASTIC (Gebhardt and Jankowski, 1986; Noble, 1992) and LeGrand methods (Canter *et al.*, 1993) evaluated the sites by focusing only on a single parameter which is for example groundwater potential.

As the landfill site selection process depends on a variety of laws, regulations and factors, large volume of spatial data should be evaluated and processed. To overcome this difficulty, GIS is commonly used to select suitable sites for landfill (Baban and Flannagan, 1998; Allen *et al.*, 2002).

For general GIS, although it is very useful in siting experiences, lacks the ability to locate an optimal site when compactness and other factors are considered at the same time. For this purpose, a mixed integer programming model was developed to obtain a site with optimal compactness by Kao and Lin (1996) and extended to include multiple siting factors. However, because the computational time with a conventional mixed integer programming package for solving the model is time consuming and impractical, a raster based C program for landfill siting with optimal compactness was developed (Kao, 1996).

A multiobjective optimization model is developed to determine the efficient aggregation of land parcels to use as a solid or hazardous waste landfill by Minor and Jacobs (1994). A constraint which measures compactness and contiguity as a function of the outside perimeter and area of the subregion is introduced in this model which optimally selects and sizes the landfill site and considers land purchase cost, compactness and contiguity.

A network geographic information system (GIS) was developed to improve the effectiveness of a complex municipal solid waste landfill siting procedure and make siting related information available to the general public (Kao *et al.*, 1996).

Because of the complexity and dependency of different decision groups, design of solid waste management systems requires consideration of multiple alternative solutions and different criteria. Multicriteria Decision Analysis (MCDA) approach is commonly used to solve the landfill site selection problem and provide decision makers the most satisfactory and preferable alternative. In the study done by Cheng *et al.* (2002) Simple Weighted Addition method, Weighted Product method, TOPSIS (Technique for Order Preference by Similarity to the Ideal Solution), Cooperative Game Theory and ELECTRE methods of MCDA were used and compared to get the most preferable solution of solid waste management.

To overcome the weakness of different multi objective programming models which is the ignorance of qualitative and subjective considerations such as environmental and socio-economic factors an integrated multicriteria decision analysis and inexact mixed integer linear programming approach for solid waste management was developed and the five MCDA methods which were used in the pervious study of authors were adopted to evaluate the landfill site alternatives (Cheng *et al.*, 2003).

A decision modelling procedure is developed based on the Analytical Hierarchy Process to locate obnoxious facilities by Erkut and Moran (1991). For preliminary landfill site screening, fuzzy set theory and the Analytical Hierarchy Process (AHP) are integrated into a raster-based geographical information system (Charnpratheep *et al.*, 1997).

Siddiqui *et al.* (1996) developed a methodology to find best locations for landfills by integrating GIS and Analytical Hierarchy Process (AHP) which is called spatial-AHP. The evaluation of the land suitability was based on the environmental characteristics of the site and proximity to the populations.

A GIS based weighted linear combination (WLC) is created for selecting suitable sites for animal waste using a raster GIS. The selected factors affecting the suitability of the site are weighted using the Analytical Hierarchy Process (AHP) which employed and objectives oriented comparison technique to formulate the pairwise comparison matrix (Basnet *et al.*, 2001).

For the identification of potential areas for the disposal of marble and granite, fuzzy logic and multicriteria analysis (Weighted Linear Combination and Ordered Weighted Average) are aggregated (Calijuri *et al.*, 2004).

CHAPTER 4

PRODUCTION OF INPUT DATA

4.1. Elevation

The elevation data is derived from the 1:25.000 scale topographical maps obtained from General Command of Mapping, Turkish Army. The study area is covered by four 1:25.000 scale topographical maps. Each of them are scanned, imported to TNTmips and registered by using at least four Ground Control Points that were read from UTM graticules maps. For registration process, projection as UTM, zone as 36 and datum as European 1950 Mean is used. Then, the contours with 10 meter interval are digitized and elevation values read from the topographical maps are entered into database table. The last step to generate digital contour map is that each contour is assigned to appropriate elevation value. The digital contour map of the study area is shown in Figure 4.1.a. The elevation map of the study area is divided into two regions. The areas with elevations between 750m and 1000m are defined as suitable areas for a landfill site and the remaining areas as unsuitable by assigning 1 and 0, respectively (Table 4.1). Then, the elevation map is converted to a binary raster map (Figure 4.1.b).

Table 4.1. Classes produced for the elevation criteria according to the suitability for landfill

Topography	Ranking	# of pixels	Area (%)
750 m – 1000 m	0	313721	32.61
< 750 m, > 1000 m	1	648271	67.39

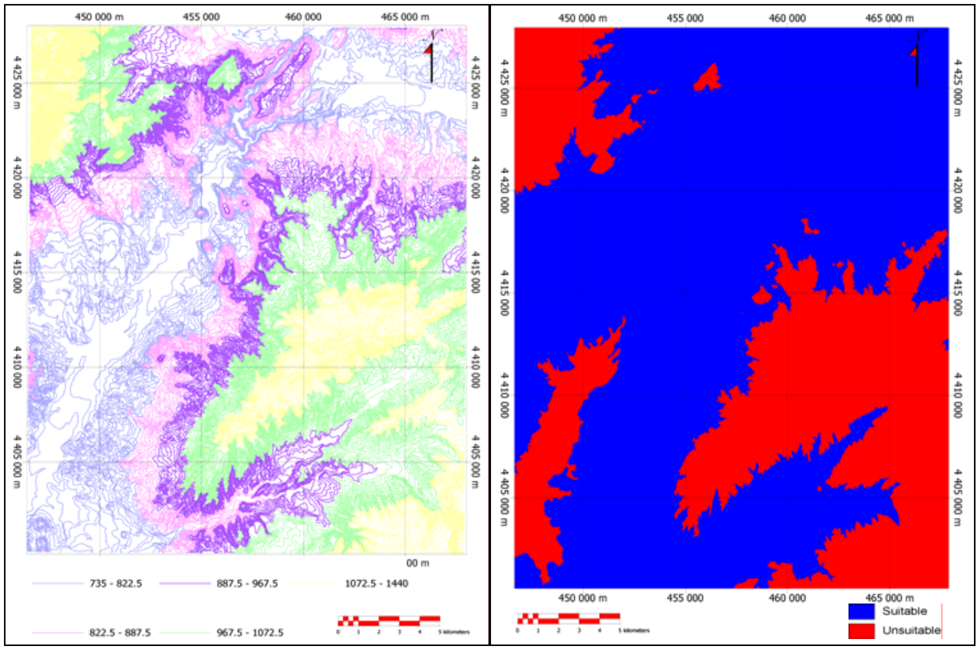


Figure 4.1. (a) Digital contour map of the study area
(b) Elevation parameter map

4.2. Digital Elevation Model

Digital Elevation Model (DEM), also referred as the Digital Terrain Analysis, is a digital representation of earth's topography in a continuous way. (Hengl, *et al.* 2003)

There are two common data structures to generate DEMs:

(1) Triangulation based methods: The principle of these methods is to construct a set of triangles to link all the elevation points in the data set without any overlap each of which is treated as planar continuous surface.

(2) Grid based methods: The principle of these methods is that firstly the data is transformed into a regular grid of points so that each pixel carries the information on elevation. The DEMs produced by grid based methods are typically stored as a raster map. (Hengl, *et al.* 2003)

Although DEMs produced by triangulation based methods are more accurate especially in structural features like peaks, slope breaks and conic pits, the grid based methods are more preferred because they are easier to manipulate, process and integrate with other GIS data. (Hengl, *et al.*, 2003)

In this study, several methods like minimum curvature, kriging, profiles and triangulation are utilized and minimum curvature is preferred depending on the accuracy assessment for DEM generation.

The principle of the Minimum Curvature method is to fit a smooth surface to the input elevation values by applying a two dimensional cubic spline function. To obtain a result of a smooth surface with a minimum amount of curvature, a number of iterations are required to adjust the surface. The input objects can be in the form of vector points, vector contours, a TIN or a database (TNTmips Manual, 2000). In this study, digitized vector contours of 10 m interval are used as input and the grid size is selected as 25 m. The produced DEM is then used as a reference map layer for the other input layers after the validation of its accuracy.

The quality of a DEM means that how accurate the elevation at each pixel is represented and the morphology is presented (Hengl, *et al.*, 2003). In order to check the accuracy and the quality of the DEM, some standards determined by USGS are used. A representative sampling of test points is used to verify the accuracy of a DEM. As stated by standards, test points should be well distributed, representative of the terrain, and have true elevations with accuracies within the DEM accuracy criteria. Acceptable test points include field control, aero triangulated test points, spot elevations, or points on contours from existing source maps with appropriate contour interval. A minimum number of 28 test points per DEM is required which consists of 20 interior and 8 edge points (USGS, 2004).

The vertical root-mean-square error (RMSE) statistic is used to describe the vertical accuracy of a DEM, including both random and systematic errors occurred during production of the data. The RMSE is defined as:

$$RMSE = \sqrt{\frac{\sum (Z_i - Z_t)^2}{n}}$$

where Z_i = interpolated DEM elevation of a test point

Z_t = true elevation of a test point

n = number of test points

Accuracy is computed by a comparison of linear interpolated elevations in the DEM with corresponding known elevations. The representative 155 test points (17 of them are edge points) are created in TNTmips environment on the DEM and compared with the elevations on the test points measured precisely from the topographical maps for all utilized methods. The locations of test points and the RMSE values for all generated DEMs are shown in Figure 4.2 and Table 4.2 respectively.

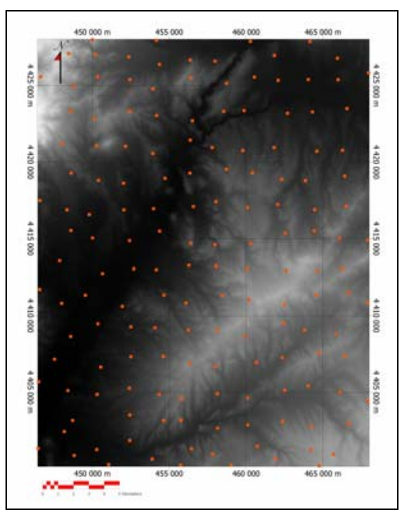


Figure 4.2. Location of the test points selected for accuracy assessment (orange spots= location of test points)

By comparing the RMSE values, minimum curvature method is selected for DEM generation and converted into a relief map for display purposes. (Figure 4.3.b)

Table 4.2. The DEM generation methods used in the study and related RMSE values

DEM Generation Method	RMSE
Profiles	1.468
Minimum curvature	1.476
Kriging	2.316
Triangulation	2.310

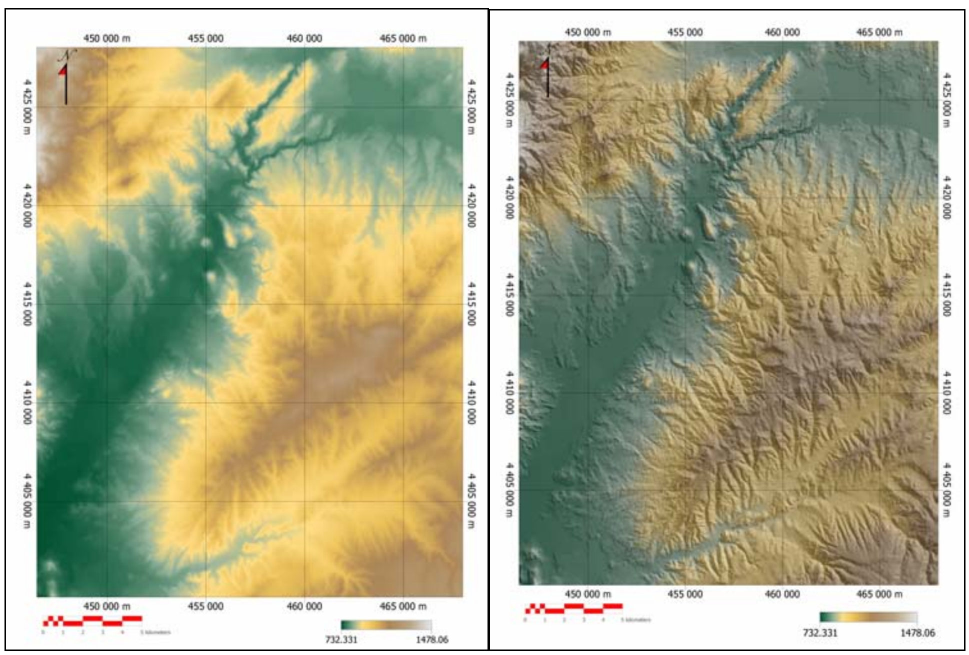


Figure 4.3. **(a)** DEM, **(b)** Relief shaded image

4.3. Settlement areas

The urban and industrial areas, villages and hamlets are digitized from the 1/25000 scale topographical maps. In this study, the settlement areas are subdivided into two layers. First layer consists of urban centers and the other villages and hamlets. The reason for this division is the necessity of applying different buffer zone distances to the urban centers or villages and hamlets.

After the digitization process, safe distances from the settlement areas are determined by literature review. According to Allen (2000), the distance from urban centers should be at least 5 km and from isolated houses 500 m to locate a landfill site. The buffer distances for towns and villages within a population greater than 500 people are determined as 1000 m, for all other identified centers of population as 500 m and for private residences, businesses, social and community buildings as 250 m by Cantwell (1999). Siddiqui (1996) suggests that no new landfill site should be located closer than 0.4 km (0.25 mi) from a collection of ten or more houses. On the other hand, the landfill site should be located within 10 km of an urban area due to the economic considerations (Serwan, M.J. et al, 1998).

By considering all the suggested safe distances in the literature, minimum distances for the study area are determined as 5 km for urban centers and 1 km for villages and hamlets. These distances are used to create buffer zones around settlement areas and excluded from the study area.

After exclusion of absolutely unsuitable areas for a landfill site, the remained areas are classified according to their suitability by ranking with the help of literature review.

The layer of villages and hamlets are classified as suitable or unsuitable by assigning values 1 and 0 respectively (Table 4.3) and shown in Figure 4.3.a.

Table 4.3. Classes produced for the villages of settlement criteria according to the suitability for landfill

Distance to villages	Ranking	# of pixels	Area (%)
0 m – 1000 m	0	389069	41.85
> 1000 m	1	540586	58.15

The layer of urban centers is divided into seven classes. The classes and related ranks can be seen in Table 4.4. The urban center layer is then prepared basing on the ranking values shown in Table 4.4 is presented in Figure 4.4.b.

Table 4.4. Classes produced for the urban centers of settlement criteria according to the suitability for landfill

Distance to urban centers	Ranking	# of pixels	Area (%)
0 m - 5000 m, >30000 m	0	215696	23.20
5000 m - 10000 m	10	205660	22.12
10000 m - 15000 m	8	257637	27.71
15000 m - 20000 m	6	200858	21.61
20000 m - 25000 m	4	49693	5.35
25000 m – 30000 m	2	111	0.01

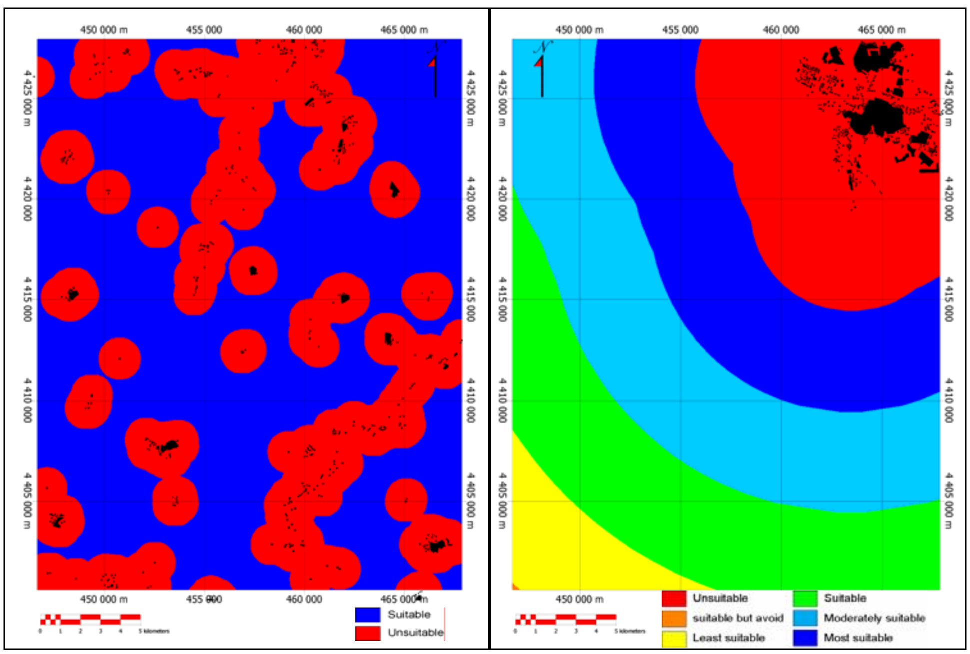


Figure 4.4. (a) Buffer zones determined for villages and hamlets (black spots=location of villages and hamlets) **(b)** Buffer zones determined for urban centers (0-5000 m=red, 5000-10000 m=blue, 10000-15000 m=light blue, 15000-20000 m=green, 20000-25000 m=yellow, 25000-30000 m=orange, black spots=location of urban centers)

4.4. Roads

The roads are digitized from the 1:25.000 scaled topographical maps. Like in the case of settlement areas, the roads are subdivided into two layers. First layer consists of Highway E90 (intercity highway) and the other smaller roads. The reason for this division is the necessity of applying different buffer zone distances according to the importance of the roads.

There are many suggested buffer zone distances in literature. Minimum distance from the network is imported in order to avoid visual impact and other nuisances. Roads plus 100 m around them should be applied as a buffer zone (Leao, S. *et al.*, 2003). As stated by Cantwell (1999), all roads including primary, secondary, regional and third class roads should be avoided and have a buffer of at least 30 m on both sides. According to Allen (2000), distance greater than 1 km from main roads and highways should be avoided. On the other hand, the landfill site should not be placed too far away from existing road networks to avoid the expensive cost of constructing connecting roads (Lin, H.-Y., 1999). Distance from main access roads should be smaller than 3 km according to Allen (2000) and between 0.2 km and 10 km of a major road according to Serwan (1998).

By considering these suggested values, the buffer zones and related ranks are determined separately for Highway E90 and other roads which are shown in Table 4.5 and Table 4.6 respectively.

Table 4.5. Classes produced for the Highway E90 of road criteria according to the suitability for landfill

Distance to Highway E90	Ranking	# of pixels	Area (%)
0 m – 500 m	0	32489	3.49
500 m - 1000 m	3	33094	3.56
1000 m - 2000 m	2	63455	6.83
> 2000 m	1	800617	86.12

Table 4.6. Classes produced for the other roads of road criteria according to the suitability for landfill

Distance to Roads	Ranking	# of pixels	Area (%)
0 m – 100 m	0	77812	8.37
100 m - 500 m	3	271202	29.17
500 m -1000 m	2	244670	26.32
> 1000 m	1	335971	36.14

Based on the ranking divisions in Tables 4.5 and 4.6, the respective buffer zones are created in TNTmips environment. The values on the tables given above are entered to the database and each value is assigned to the related class. Finally, the vector maps are converted to raster maps shown in Figure 4.5 to become ready for the analysis.

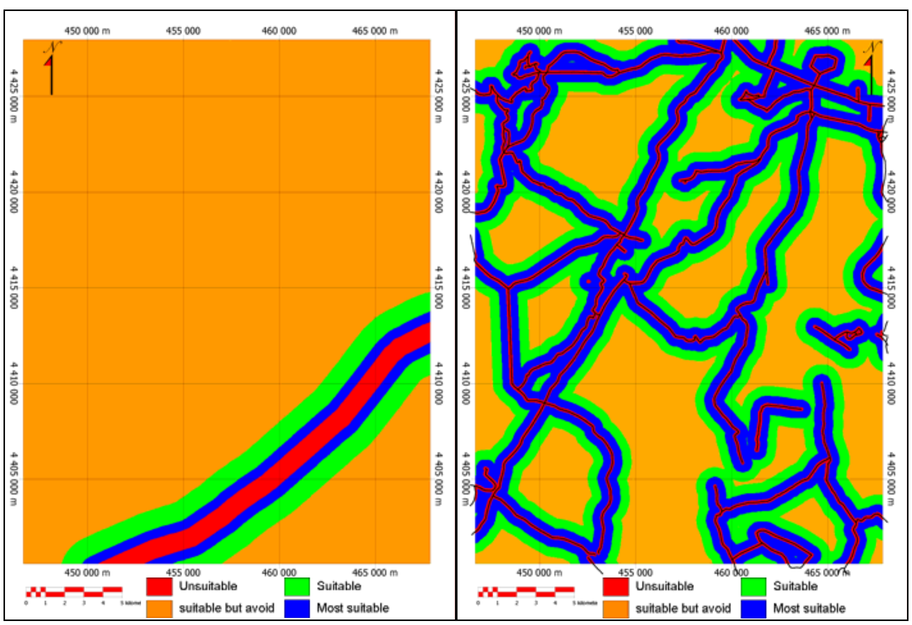


Figure 4.5. (a) Buffer zones determined for Highway E90 (0-500 m=red, 500-1000 m=blue, 1000-2000 m=green, >2000 m=orange) **(b)**Buffer zones determined for village roads (0-100 m=red, 100-500 m=blue, 500-1000 m=green, >1000 m=orange)

4.5. Railways

The railways are digitized from the 1:25.000 scaled topographical maps. The necessary buffer zone distances and related rankings are obtained from the literature and directly used Table 4.7 (Serwan et. al.,1998).

The buffer zones are created, the values on the table given above are entered to the database and each value is assigned to the related class in the GIS environment. The layer of railways is classified as suitable or unsuitable by assigning values 1 and 0 respectively. Then, the vector map prepared is converted to a raster map shown in Figure 4.6 to be finalized.

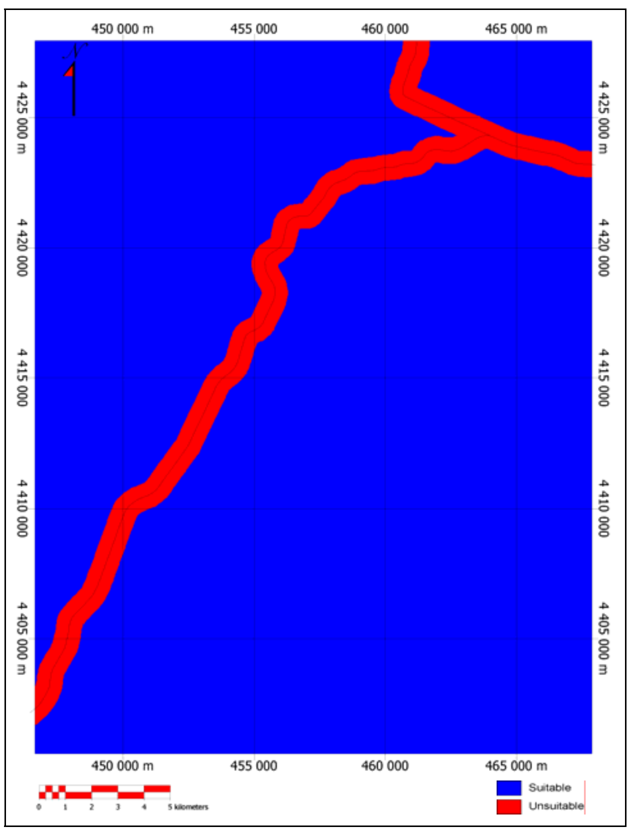


Figure 4.6. Buffer zones determined around railways

Table 4.7. Classes produced for the railways according to the suitability for landfill

Distance to railways	Ranking	# of pixels	Area (%)
0 m – 500 m	0	64280	6.91
> 500 m	1	865375	93.09

4.6. Airports

Although no airport is located in the study area, there is a military airport called Mürted Airport at the northeast. The coordinates of the airport is read from the 1:25.000 scale topographical maps and entered to the GIS environment.

In literature, there are different values related to the safe distances from airports like 3.000 m according to Chalkias (1997), 3.050 m according to the Jesus *et al.* (1997) and 3.048 m according to Bagchi (1994). As stated by Allen (2000), distance of 10 km-13 km from flight path should be considered as a buffer zone.

By considering these suggested values, the safe distance for an airport is determined as 10.000 m. The layer of airport is classified as suitable or unsuitable for a landfill site by assigning values 1 and 0 respectively (Table 4.8) which is shown in Figure 4.7. To finalize the map for analysis, the vector map is converted to raster map.

Table 4.8. Classes produced for airport according to the suitability for landfill

Airport	Ranking	# of pixels	Area (%)
Not suitable	0	15459	1.66
Suitable	1	914196	98.34

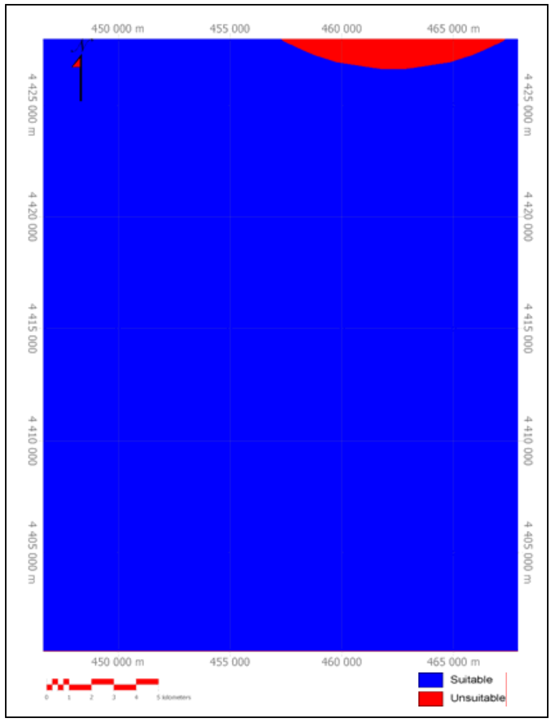


Figure 4.7. Buffers zones determined for airports

4.7. Wetlands

The wetlands are digitized from the 1:25.000 scale topographical maps. The necessary buffer zone for swamp areas is determined as 250 m. The layer of wetlands is classified as suitable or unsuitable by assigning values 1 and 0, respectively (Table 4.9). The buffer zones are created and the study area is divided into two classes in the GIS environment. Then, the vector map prepared is converted to a raster map shown in Figure 4.8.

Table 4.9. Classes produced for wetlands according to the suitability for landfill

Swamp	Ranking	# of pixels	Area (%)
Not suitable	0	17126	1.84
Suitable	1	912529	98.16

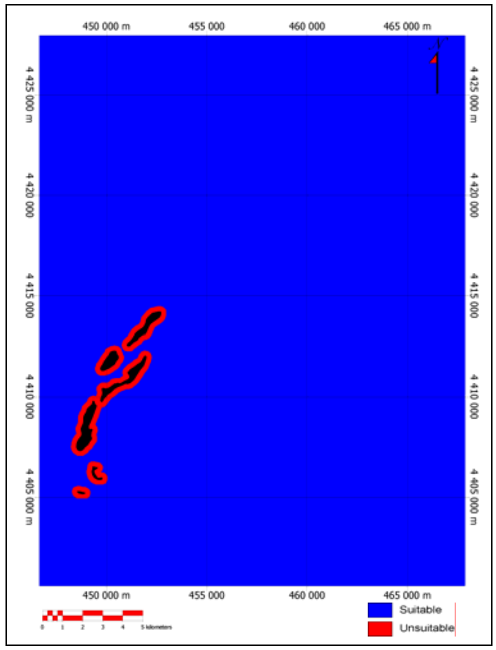


Figure 4.8. Buffer zones determined for wetlands (black regions=location of wetlands)

4.8. Infrastructures

4.8.1. Pipelines

There is a natural gas pipeline passing through the study area in the east west direction. The pipeline is digitized from the 1:25.000 scale topographical maps. The necessary buffer zone for pipeline is determined as 250 m on both sides. The pipeline layer is classified as suitable or unsuitable for a landfill site by assigning values 1 and 0, respectively (Table 4.10). After the creation of buffer zones, the vector map prepared is converted to a raster map shown in Figure 4.9 to be used as an input map in the analysis.

Table 4.10. Classes produced for pipelines according to the suitability for landfill

Pipeline	Ranking	# of pixels	Area (%)
Not suitable	0	19736	2.12
Suitable	1	909919	97.88

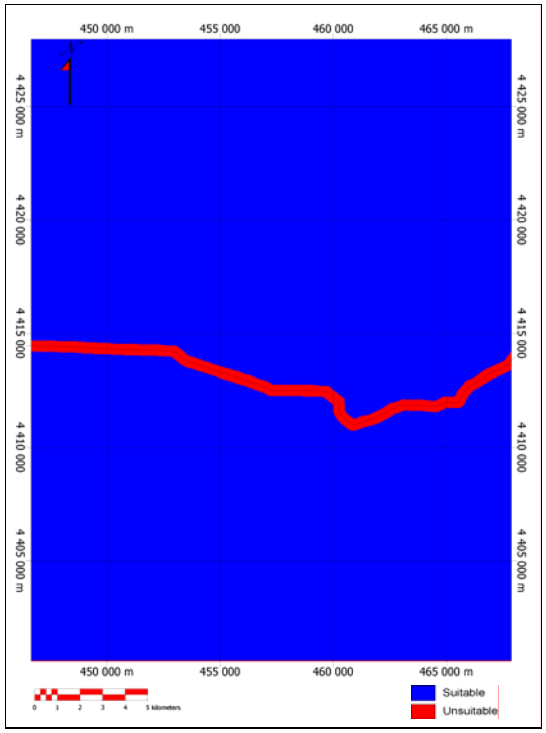


Figure 4.9. Buffer zones determined around pipelines

4.8.2. Power Lines

The high voltage power lines are digitized from the 1:25.000 scale topographical maps. The necessary buffer zone distance is obtained from the literature. According to Cantwell (1999), it should be avoided to disrupt the infrastructures and all high voltage power lines should have a buffer of 30 m on both sides.

The buffer zones are created in the GIS environment. The layer of power lines is classified as suitable or unsuitable for a landfill site by assigning values 1 and 0 respectively (Table 4.11). Then, the vector map prepared is converted to a raster map shown in Figure 4.10.

Table 4.11. Classes produced for high voltage power lines according to the suitability for landfill

Power lines	Ranking	# of pixels	Area (%)
Not suitable	0	18967	2.04
Suitable	1	910688	97.96

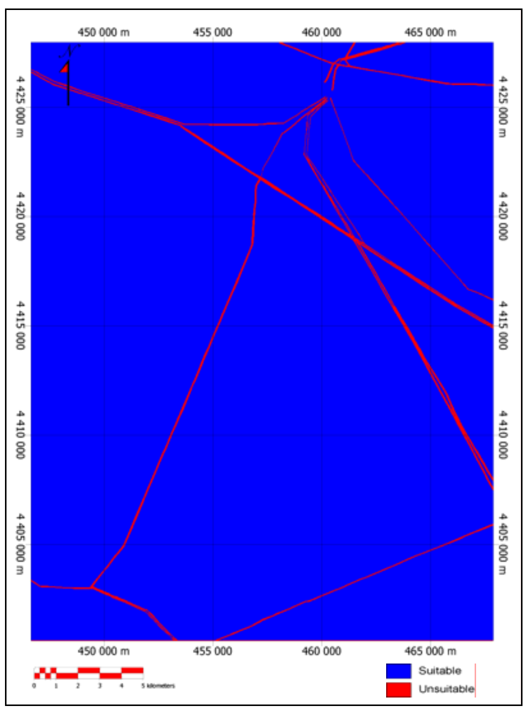


Figure 4.10. Buffer zones determined for high voltage powerlines

4.9. Slope

Slope map is generated from Digital Elevation Model (DEM) which is shown in Figure 4.11.a. The distribution of slope values in the study area ranges between 0 and 63° and can be seen in the histogram of the study area in Figure 4.12.

Table 4.12. Classes produced for slope according to the suitability for landfill

Slope Value (°)	Ranking	# of pixels	Area (%)
0 - 5	5	490327	52.85
6 - 10	4	267326	28.82
11 – 15	3	117799	12.70
> 15	0	52260	5.63

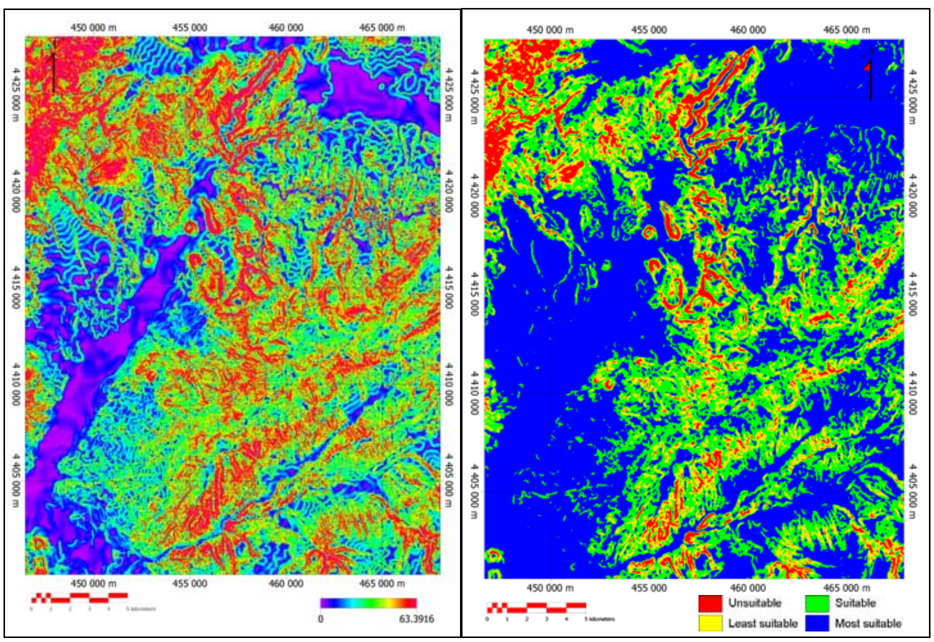


Figure 4.11. (a) Slope map of the study area **(b)** Classes determined for slope according to decreasing suitability (0-5°=blue, 5-10°=green, 10-15°=yellow, >15°=red)

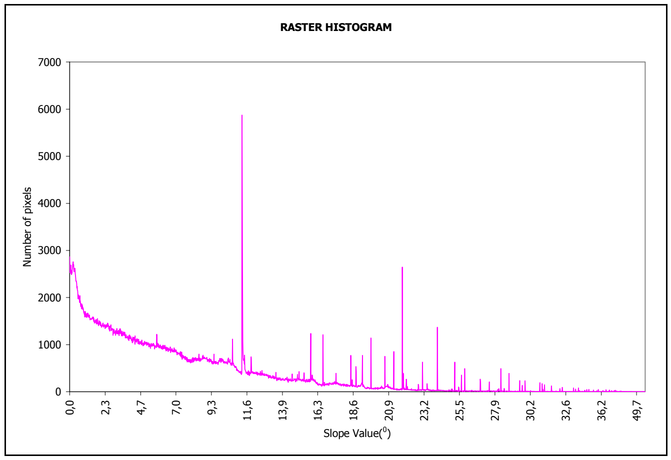


Figure 4.12. Raster histogram of slope

There are many suggestions about slope in the literature. As stated by Allen (2000) and Oweis *et al.* (1990) and applied in the study, areas with slopes greater than 15° should be avoided for a landfill site. According to Lin(1999), the appropriate slope for constructing a landfill is about 8-12%, because too steep of a slope would make it difficult to construct and maintain and too flat of a slope would affect the runoff drainage. High slopes can favour leachate drainage to flat areas and water bodies and cause contamination. Areas whose slope is greater than 20% are not suitable to allocate landfills (Leao *et al.*, 2003).

By considering the suggestions in the literature, slope map is classified into four groups. The groups and related rankings are shown in Table 4.12. The final map ready for analysis is shown in Figure 4.11.b.

4.10. Geology

The geological map of the study area is compiled from available reports and maps obtained from MTA. Geology map prepared is scanned, registered and digitized. A database including lithology, symbol and description is created and attached to the map. In the study area, there are fourteen different lithologies and a database including symbol, lithology and description is prepared (Figure 4.13) in the GIS environment.

The lithologies are grouped and ranked according to their suitability for a landfill site which is given in Table 4.14. The vector map of lithology is then converted to a raster map to be finalized for analysis. The raster map is shown in Figure 4.14.

The study area is composed of sedimentary and volcanic rocks formed between Triassic and Holocene. Description of various lithological units is given below.

4.10.1. Elmadağ Formation (Trael)

Elmadağ Formation crops out along southwest-northeast trending belt in the study area. The formation is first named by Akyürek *et al.* (1982, 1984). Elmadağ Formation comprises conglomerate, sandstone, mudstone, sandy limestone, arenites, agglomerates and volcanics. The formation also contains Carboniferous and Permian blocks of various sizes. The formation is intensely folded. Folding is mostly pronounced within thin bedded and fine grained members of the formation.

Elmadağ Formation overlies Emir Formation and underlies Keçikaya Formation. At the Elmadağ and Keçikaya boundary, sandstone and sandy limestone alternation can be seen. Elmadağ Formation laterally passes into Ortaköy Formation. The age of Elmadağ Formation is Triassic (Akyürek *et al.*, 1997).

4.10.2. Permian Limestone (Pkb)

This unit has been differentiated from the Elmadağ and Ortaköy Formations because of its widespread occurrences. The Permian limestones are grey and white, recrystallized, locally highly fractured and thin to medium bedded (Akyürek *et al.*, 1997).

4.10.3. Günalan Formation (Jg)

The unit is first defined near Günalan and Karaali villages by Akyürek *et al.* (1996). The Günalan Formation is composed of alternation of various volcanic rocks including agglomerates, volcarenites and in between red colored, thin layered limestone (Hörç Limestone-Jgh). The age of Hörç limestone member is determined as Liassic based on its rich fossil content. Along the boundary of volcanic rocks and limestones, pillow lavas are seen (Akyürek *et al.*, 1997).

4.10.4. Akbayır Formation (Ja)

This formation is represented by thin to medium bedded, hemipelagic, biomicritic limestone with chert. It was first defined by Akyürek (1982). The formation crops out at Alacaatlı and Ballıkuyumcu villages in the west and at Dereköy and Deveci villages in the south-west of the study area.

Akbayır formation is composed of white-cream locally reddish, thin to medium bedded clayey limestone and/or biomicritic limestone frequently containing clusters and bands of chert. The lower sections of Akbayır formation consist of yellow, brown-green marl, siltstone and clayey limestone alternation which is transitional with marine levels of the Hasanoğlan formation near Derincedere, north-east of Alacaatlı village. At the top of the clay and silt rich layers hemi-pelagic limestone layers are found, which forms the main rock type in the formation. Tectonic deformations (fracturing and folding) and primary sedimentary structures (slump and slope breccia) are seen in the limestone layers having porcelain appearance. In the mid-levels of the unit, turbiditic calcarenite is also found at the Alacaatlı region (Akyürek *et al.*, 1982).

The typical features of the formation are 5-40 cm. thick layers and the presence of grey-brown chert lenses and bands. Radiolaria, Spongia, Echinodermata and Calpionellide fossils and fragments are commonly seen within the formation.

The upper most lithology of the Akbayır Formation consists of green marl and olistostromal lenses. The olistostroms are composed of micritic limestone and cherts of the Akbayır Formation having diameters within the range of 2-15 cm (Akyürek *et al.*, 1997).

4.10.5. Karadağ Formation (Kkk)

The unit is first defined by Akyürek *et al.* (1982, 1984). Karadağ Formation is represented by sandstone with volcanic particles and gravel alternation at the bottom, which is followed by sandstone, mudstone alternation and clayey limestone with an increasing content of pelagic clayey limestone.

Karadağ Formation is transition with Hisarköy Formation at the bottom and Ilıcapınar and Haymana Formations at the top. At the transition zone, Hisarköy volcanics and sandstone, siltstone alternation of Karadağ Formation can be seen (Akyürek *et al.*, 1997).

4.10.6. Haymana Formation (Kh)

The name of Haymana Formation is first proposed by Righi and Cortesini (1959). The unit is composed of conglomerate, sandstone and shale alternation. Between the Günalan and Karaali Villages, there are also basaltic lava and tuff levels. Volcanic rocks are differentiated as volcanics (Khv) where possible. Conglomerate is greenish, yellowish and brown, well compacted and medium-to-thick bedded. The base of the layers is eroded. Conglomerate layers show regular and lensoidal structures. Locally, they are poorly graded and show thick layers with coarse gravels. Most of the gravels are derived from ophiolites. Sandstones are green, yellow and brown, compacted and thin-to-medium bedded. In sandstones, grading, parallel lamination, cross lamination and convolute lamination can be seen. Shales are dark grey, loose, thin bedded and locally laminated. The age of the Haymana formation is Maastrichtian (Akyürek *et al.*, 1997).

4.10.7. Volcanics (Khv)

Volcanic rocks of the Haymana Formation are separated as a member and mapped separately. They are commonly observed between Ünalan and Karaali Villages and are placed in the mid regions of Haymana Formation as tuff and sills. Volcanics are porphyritic, pink, beige, greenish brown and locally show pillow structure. They consist of phonolithic- tephrite, tephritic- melaphonolith and crystallized lithic tuff (Akyürek *et al.*, 1997).

4.10.8. Malboğazı Formation (Km)

The unit is firstly named by Birgili *et al.* (1975). Malboğazı Formation is composed of yellowish grey sandstone, thin bedded conglomerate, sandy limestone and reefal limestone. Sandstones are thin bedded and have abundant fossils and carbonaceous matrix. Malboğazı Formation shows lateral transition with Haymana Formation at the bottom. The age of the formation is Maastrichtian (Akyürek *et al.*, 1997).

4.10.9. Hançili Formation (Th)

Hançili Formation is firstly named by Akyürek *et al.* (1980). The unit includes clayey limestone, marl, siltstone, conglomerate and tuff alternation and gypsum and bituminous shale in some regions. In addition, andesite sills are also seen in the formation. Clayey limestones and marls are white; yellowish white and thin-to-medium bedded and has alternation with siltstones and sandstones. Siltstones are grey, loose, thin bedded and show lamination. Hançili Formation is transitional with Kumartaş Formation and Mamak Formation in the horizontal direction. The formation is covered by Mamak and Gölbaşı Formations. Hançili Formation is deposited in streams and lakes in a terrestrial environment in which alluvial fans are developed at the margins. Lake environment is more dominant than stream environment (Akyürek *et al.*, 1997).

4.10.10. Tekke Volcanics (Tt)

The formation is first named by Akyürek *et al.* (1982, 1984). It is composed of andesite, trachyandesite, basalt, tuff, agglomerate and dacite in less amount. Andesites are red, pink, grey and black. In andesites, flow structures can be seen. Tuffs are grey and white, fine grained and mostly seen as levels between andesites and agglomerates. Tekke volcanics show transition with Mamak Formation. It can be seen as sills in Kumartaş and Hançili Formations. The unit is formed at different phases and its age is accepted as Late Miocene (Akyürek *et al.*, 1997).

4.10.11. Mamak Formation (Tma)

Mamak Formation is composed of agglomerate, tuff, andesite and basalt. Agglomerates are white, grey and red and composed of blocks of different sizes of andesite, dacite and basalt embedded within a tuffaceous matrix. Tuffs between the agglomerates are thin bedded and have different colors. Andesites can be seen as sills in agglomerates. Mamak Formation shows lateral transition with Kumartaş Formation, Tekke volcanics and Hançili Formation. The Formation is covered by Bozdağ Basalt at the top. The age of the Mamak Formation is accepted as Late Miocene (Akyürek *et al.*, 1997).

4.10.12. Bozdağ Basalt (Tb)

The unit is firstly defined by Akyürek *et al.* (1982, 1984). Bozdağ basalt is dark gray to black, hard, massive and vesicular. The vesicles are filled by calcite. Within the basalts, flow structures are locally observed. Andesite, basaltic tuff and agglomerate are also seen in small amounts. Bozdağ basalt is mostly seen over Miocene volcanics and sedimentary rocks. Thus, the age of the unit is accepted as Pliocene. Bozdağ basalt is the latest product of volcanic activity in the region. The andesitic volcanism which was dominant in Miocene time has continued in basic character during Pliocene (Akyürek *et al.*, 1997).

4.10.13. Gölbaşı Formation (Tg)

The unit is first named by Akyürek *et al.* (1982, 1984). It is composed of grey, red colored, compacted or loose conglomerate, sandstone and mudstone. The unit is poorly bedded; however, in some regions it shows horizontal layering. The grains of conglomerates and sandstones consist of quartzite, basalt, different kinds of limestones, diabase, metamorphic rock particles, serpentinite and gabbros. The matrix is clay and carbonate. Gölbaşı Formation overlies Bozdağ Basalt and the older units with an unconformity and its upper boundary cannot be seen. The age of the formation is accepted as Pliocene (Akyürek *et al.*, 1997).

4.10.14. Alluvium (Qa)

The alluviums are composed of sand, silt and gravel deposited within the channels of the main streams. In the study area, well developed alluviums are observed along the Ankara Stream (Akyürek *et al.*, 1997).

Table 4.13. The formations of the study area and their descriptions

Symbol	Lithology	Description	Ranking
Ja	Akbayır Formation	White, cream and red colored limestone with silicified bands and nodules	1
Jg	Günalan Formation	Volcanics with large feldspars, agglomerate, volcanogenic sandstone, limestones with ammonites	3
Kh	Haymana Formation	Alternation of conglomerate, sandstone, shale	3
Khv	Volcanics	Basalt	2
Kkk	Karadağ Formation	Alternation of sandstone, conglomerate, mudstone, calciturbite interbeds	2
Km	Malboğazı Formation	Reefal limestone, sandstone	1
Pkb	Limestone	Limestone block of Permian age	1
Qa	Alluvium	Sand, gravel	0
Tb	Bozdağ Basalt	Basalt	2
Tg	Gölbaşı Formation	Conglomerate, sandstone, mudstone	9
Th	Hançili Formation	Sandsone, siltstone, marl, clayey limestone, tuff, gypsum, bituminous shale	10
Tma	Mamak Formation	Agglomerate, tuff, andesite	5
Trael	Elmadağ Formation	Metaconglomerate, metasandstone, sandy limestone, sandstone, limestone	4
Tt	Tekke Volcanics	Andesite, trachyandesite, tuff, agglomerate	5

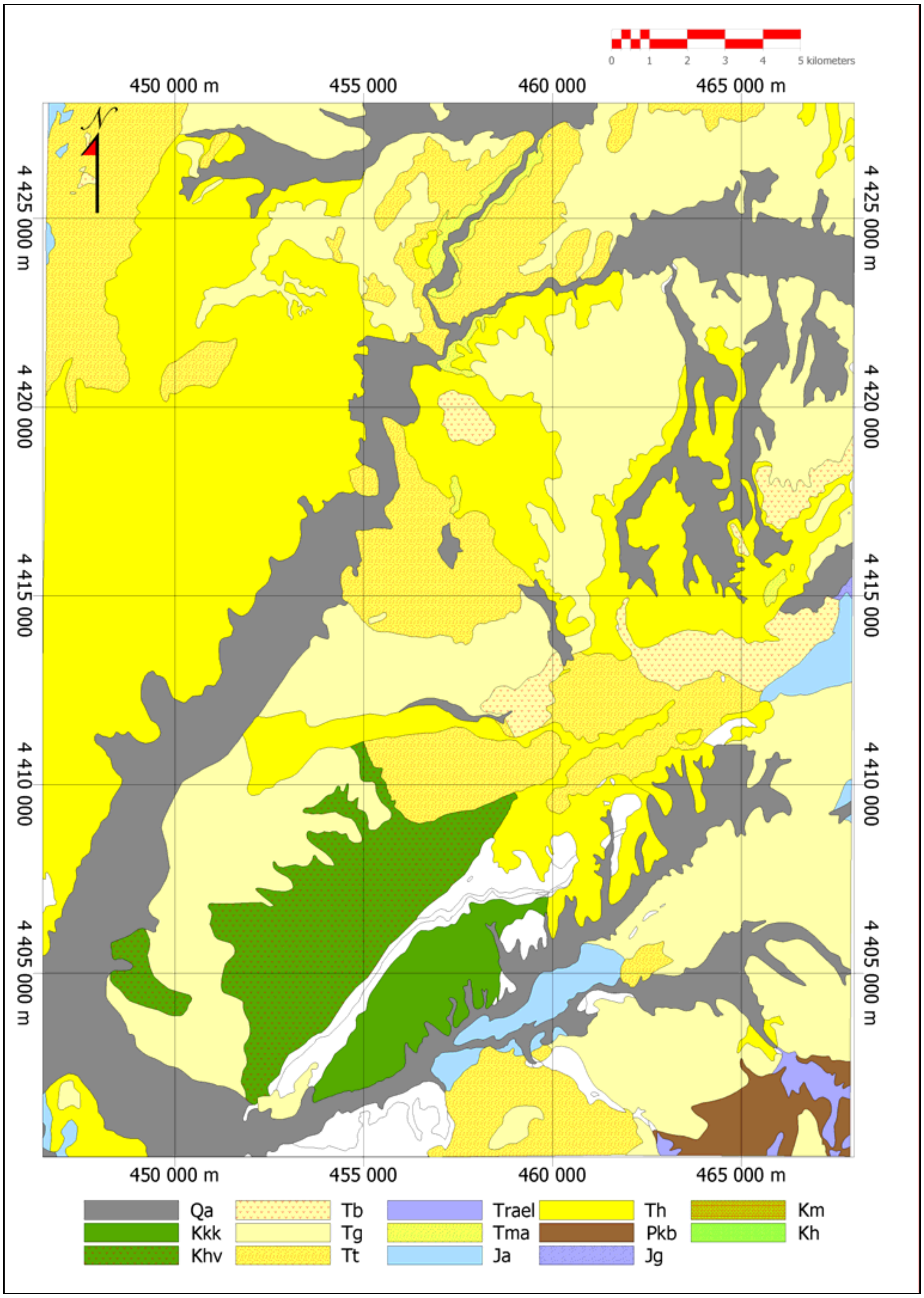


Figure 4.13. The lithological map of the study area

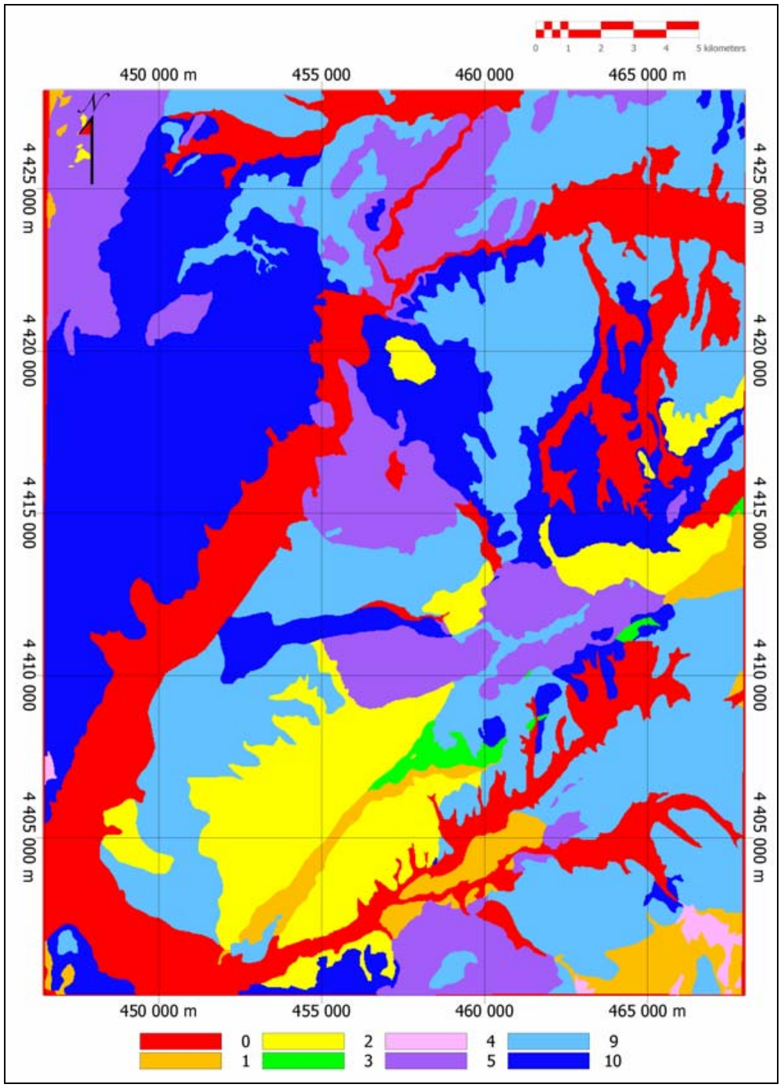


Figure 4.14. Classes determined for lithology

Table 4.14. The rankings and the percentages of the formations

Lithology	Ranking	# of pixels	Area (%)
Qa	0	190005	19.75
Ja, Km, Pkb	1	31941	3.32
Khv, Kkk, Tb	2	89965	9.35
Jg, Kh	3	5435	0.56
Trael	4	3741	0.39
Tma, Tt	5	136649	14.20
Tg	9	272440	28.32
Th	10	231816	24.10

4.11. Land use

The 1:50.000 scale land use map obtained from a report of MTA is scanned, imported to GIS environment, registered and then digitized. A database is created and attached to the map (Table 4.15). In the study area, there are thirteen different land use types (Figure 4.14.a).

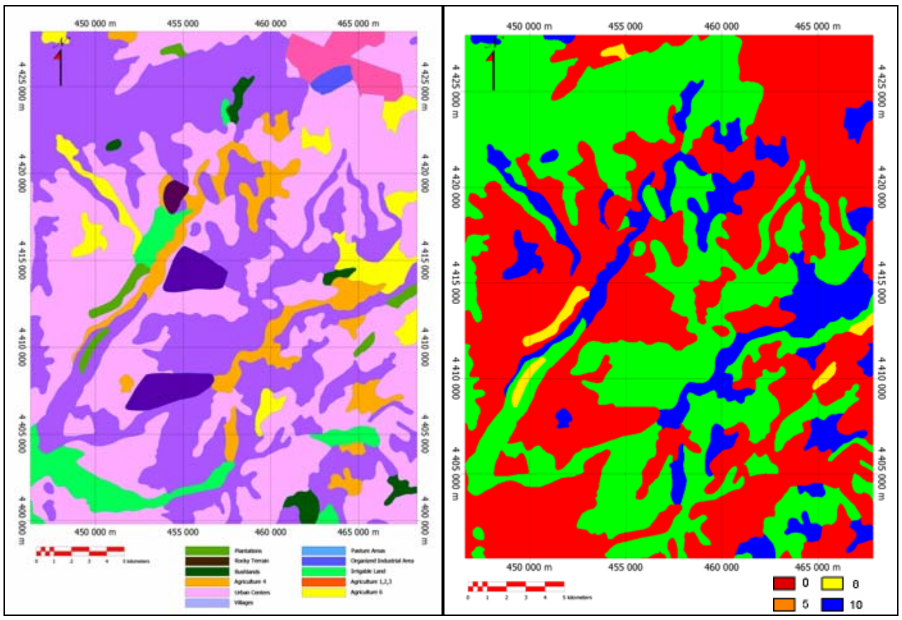


Figure 4.15. (a) The land use map of the study area
(b) Classes determined for land use according to suitability

The land use types are grouped and ranked according to their suitability for a landfill site (Table 4.16). The land use vector map is then converted to a raster map (Figure 4.14.b).

Table 4.15. Land use types and their rankings

Land Use Type	Symbol	Ranking
Alternative Organized Industrial Area	AOIA	0
Waste Water Treatment Plant	WWTP	0
Agricultural lands of grade 1, 2 and 3	AG 1,2,3	0
Urban Centers	UC	0
Villages	V	0
Organized Industrial Area	OIA	0
Irrigable Lands	IL	0
Plantations	P	5
Pasture areas	PA	8
Rocky Terrain	RT	10
Bushlands	B	10
Agricultural land of grade 4	AG 4	10
Agricultural lands of grade 6 and 7	AG 6,7	10

Table 4.16. The rankings and the percentages of the land use types

Land use type	Ranking	# of pixels	Area (%)
AOIA, WWTP	0	453835	48.82
P	5	9299	1.00
PA	8	360329	38.76
AG 6,7, AG 4,B, RT	10	106192	11.42

4.12. Floodplain

For the preparation of flood layer, geology map is used as a reference map. In literature, there is a common suggestion that floodplains should be avoided in the case of landfill site selection to reduce the risk of contaminating overland drainage (Lin, 1999). If land slope is less than 15 % and alluvial soil, floodplain exists (Kao *et al.*, 1996). According to Bagchi (1994), the landfill site should not be placed within 100-year floodplain. It can be placed within floodplains of secondary streams if any embankment is built. However, the floodplains of major rivers should be avoided.

In this study, the alluvial planes of major streams are regarded as unsuitable and the remaining area as suitable by assigning 0 and 1, respectively (Figure 4.15 and Table 4.17).

Table 4.17. The rankings and the percentages of floodplain and non-floodplain areas

Floodplain	Ranking	# of pixels	Area (%)
Floodplain	0	174807	18.80
Non-floodplain	1	754848	81.20

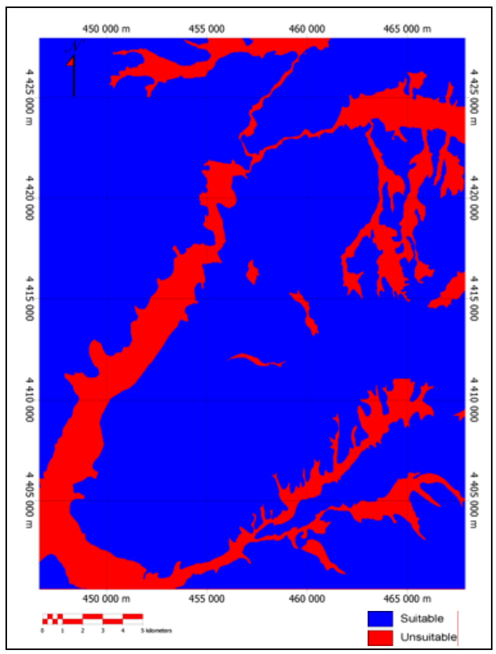


Figure 4.16. Classes determined for floodplain according to suitability

4.13. Aquifer

For the preparation of aquifer layer, the springs and fountains in the study area are digitized from 1:25.000 scale topographical maps as a point data to have an idea about the water bearing properties of the rocks. By combining the geology map and the data of springs and fountains, the study area is divided into three different classes of minor aquifer, major aquifer and non-aquifer according to the water bearing properties of the rocks. The classes and related rankings are obtained from literature (Serwan, 1998) and shown in Table 4.18. The vector map of aquifer property is then converted to a map (Figure 4.16)

Table 4.18. The rankings and the percentages of the aquifer types

Aquifer Type	Ranking	# of pixels	Area (%)
Major Aquifer	0	177798	19.13
Minor Aquifer	5	452612	48.69
Non-Aquifer	10	299245	32.19

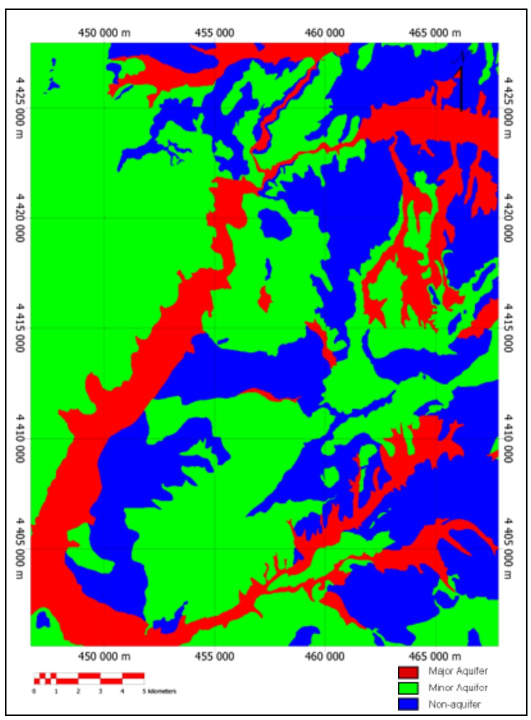


Figure 4.17. Classes determined for aquifer according to suitability

4.14. Surface water

To have an input map for surface water criteria, first streams are digitized as line data from 1:25.000 scale topogaphical maps (Figure 4.17.a). The line data is converted into points with a distance of 25 m by "poly2pnt" utility of MapInfo software and imported back to TNTmips environment because a script written in Visual Basic is used to obtain drainage density which requires point data as input. The drainage density is calculated by the script which counts the points in a 1 km^2 window at each time so that it covers the whole study area. The maximum count obtained by drainage density analysis is 313. The raster map produced for drainage density is divided into three classes of high density, medium density and low density drainage by examining the raster histogram (Figure 4.18) and assigned 0, 5 and 10, respectively (Figure 4.17.b and Table 4.19).

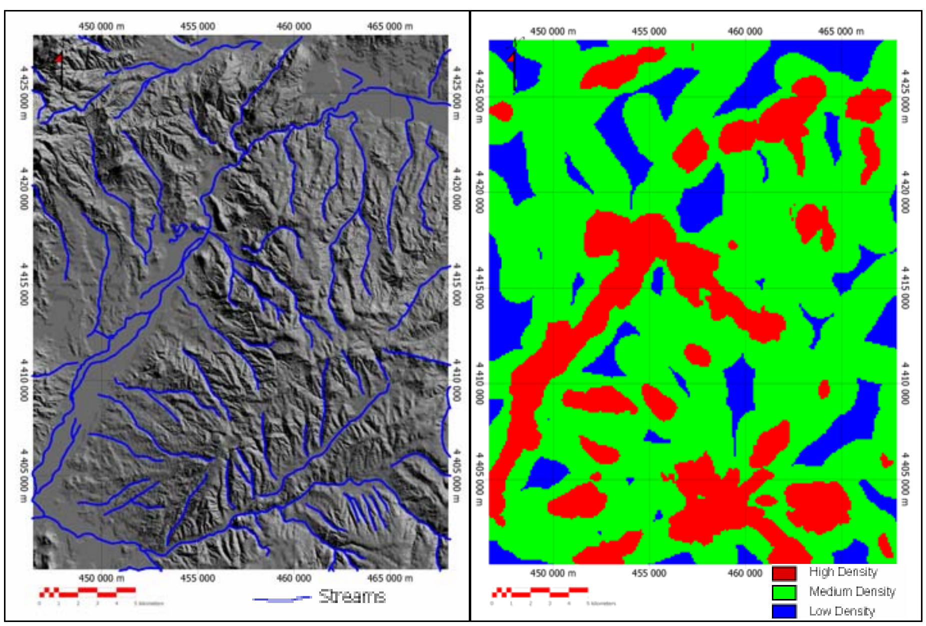


Figure 4.18. (a) The streams of the study area
(b) The drainage density map of the study area (high density=red, medium density=green, low density=blue)

Table 4.19. The rankings and the percentages of the density classes

Drainage Density	Ranking	# of pixels	Area (%)
High density	0	194776	20.95
Medium density	5	607721	65.37
Low density	10	127158	13.68

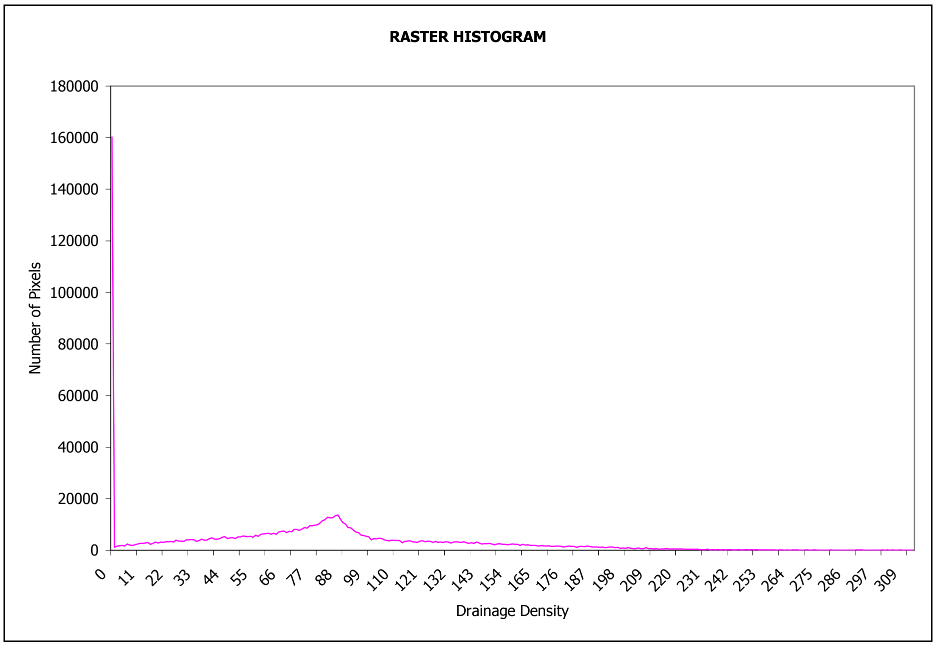


Figure 4.19. Raster Histogram of drainage density

CHAPTER 5

ANALYSIS

In this chapter, after the preparation of all input data layers, two methods are selected among the decision rules presented in Chapter 2 to analyze the data for landfill site selection by using Geographic Information Systems. Selected methods are Simple Additive Weighting method and Analytical Hierarchy Method. The output maps produced by both methods include the multiplication of data layers, weights and constraints as represented in Figure 5.1.

Before the application of both methods, the areas restricted by rules and physical constraints are excluded from the study area which are assigned 0 during the data preparation stage. The exclusion of certainly unsuitable areas is done by mask operation. To prepare a mask of unsuitable areas, all data layers are multiplied by each other so that if any pixel has a value of 0 coming from any layer, then the value of that pixel will become 0 which means that the pixel is completely unsuitable to locate a landfill site. The white areas in the mask are excluded areas shown in Figure 5.2. All data layers converted to raster are multiplied by mask to become ready for ranking.

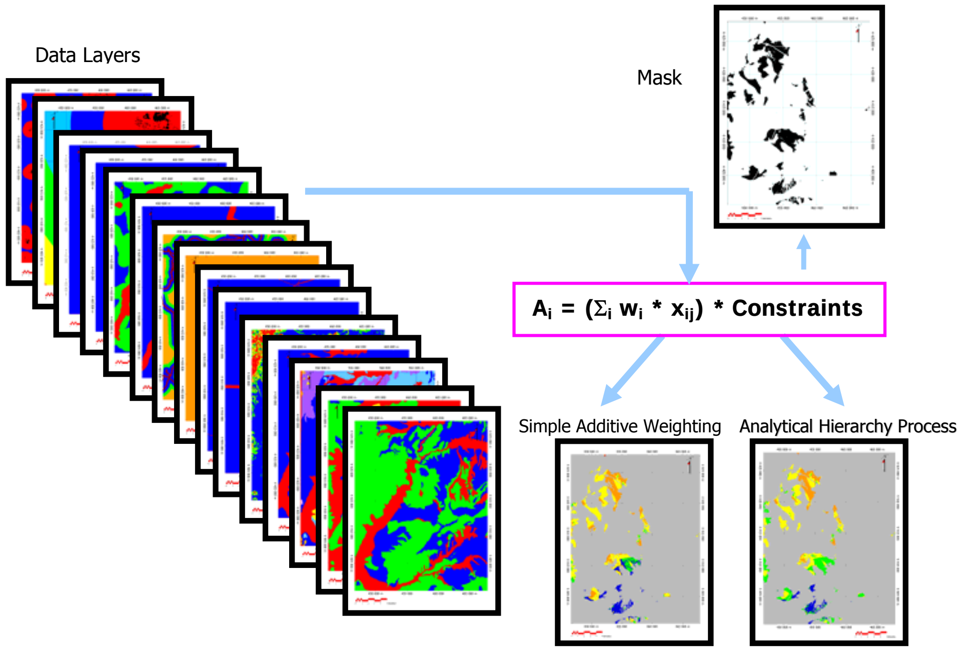


Figure 5.1. The procedure for both MCDA methods

5.1. The implementation of Simple Additive Weighting Method

Simple Additive Weighting method is the simplest and most often used multiattribute decision technique. The first step of GIS based Simple Additive Weighting method is defining the set of evaluation criteria, in other words, map layers and the set of feasible alternatives. The 16 map layers each of which defines a criterion necessary to be considered in landfill site selection are prepared and mentioned in Chapter 4. The set of feasible alternatives which are the pixels of the map suitable for landfill siting are obtained by exclusion of the areas restricted by rules and physical constraints. Because the scores of the criteria are given on different scales, they must be standardized to a common dimensionless unit. For this process, the score range procedure is selected and applied.

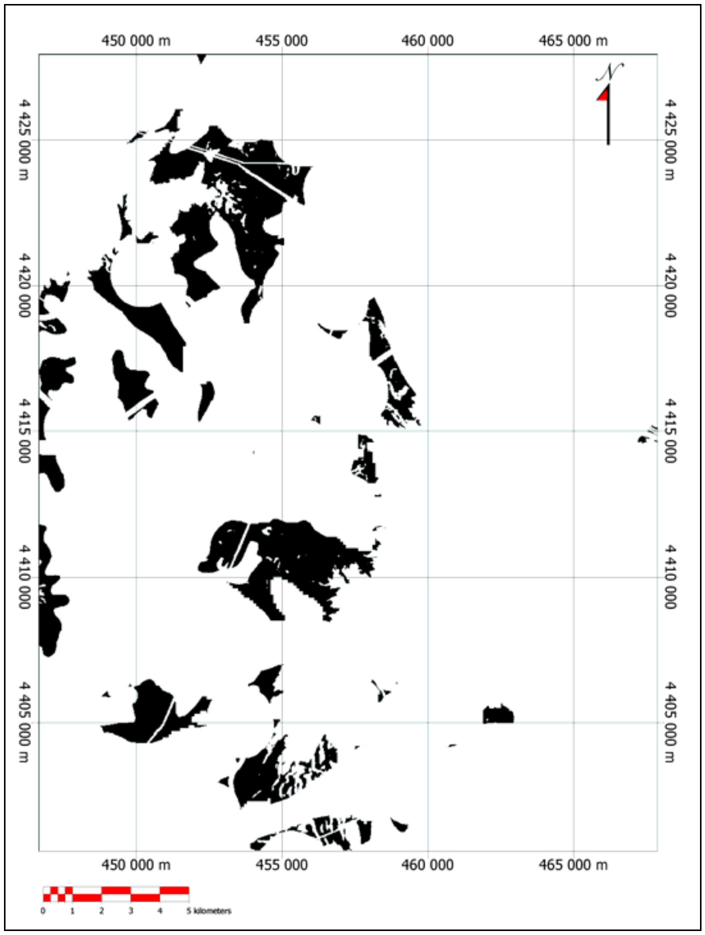


Figure 5.2. Mask prepared to exclude the restricted areas (white areas masked areas)

In the score range procedure, the standardized scores are calculated by dividing the difference between the maximum raw score and a given raw score by the score range.

$$X'_{ij} = \frac{X_j - X_{ij}}{X_j^{\max} - X_j^{\min}}$$

Where x'_{ij} is the standardized score for the i[th] alternative and j[th] attribute, x_{ij} is the raw score, and x_i^{max} and x_i^{min} is the maximum and score for the j[th] attribute, respectively. This procedure is applied to each input raster in GIS environment by using geoformula operation.

After the standardization of scores in each map layer, the criterion weights are defined as shown in the Table 5.1. The criterion weights are normalized to generate the overall score for each alternative. To do this a geoformula is created and used. Then, the output map is produced as a result of this geoformula. The score value histogram of this resultant map is evaluated (Figure 5.2) and the output values are divided into six classes, one of which is the masked areas with value of 0 and defined as restricted areas for landfill siting. The other classes in terms of increasing suitability are suitable but avoid, least suitable, suitable, moderately suitable, most suitable areas. The output map produced by the method of Simple Additive Weighting is given in Figure 5.4.

Table 5.1. The criterion weights defined for Simple Additive Weighting Method

Data Layer	Weight	Normalized Weights
Urban Centers	10	0,1136
Villages	9	0,1023
Surface Water	8	0,0909
Flood	8	0,0909
Swamp	8	0,0909
Geology	7	0,0795
Aquifer	7	0,0795
Landuse	6	0,0682
Slope	5	0,0568
Pipeline	5	0,0568
Electricity	3	0,0341
Elevation	3	0,0341
Highway E90	3	0,0341
Airport	3	0,0341
Village Road	2	0,0227
Railway	1	0,0114

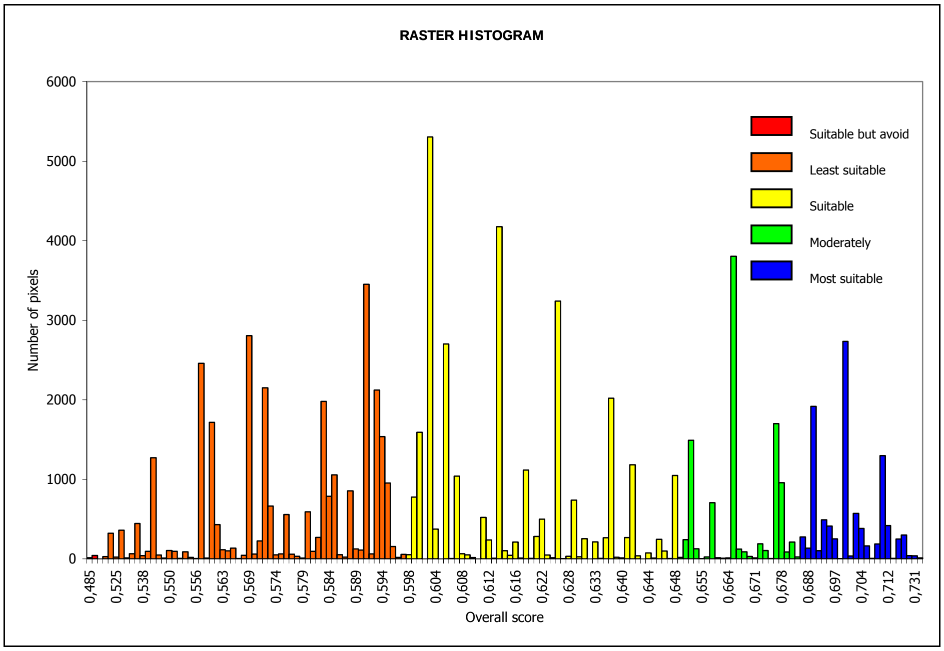


Figure 5.3. The histogram of result map prepared by Simple Additive Weighting Method

As it can be seen from Figure 5.4, the areas belong to the suitable but avoid class covers 0.073 %, least suitable class 38.2%, suitable class approximately 36.1 %, moderately suitable and most suitable classes approximately 12.8 % of the unmasked area.

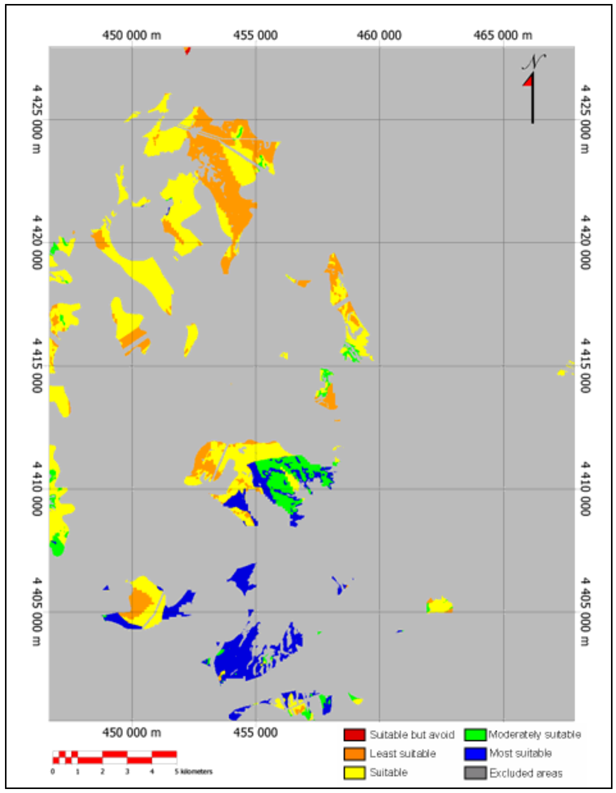


Figure 5.4. The result map prepared by Simple Additive Weighting Method

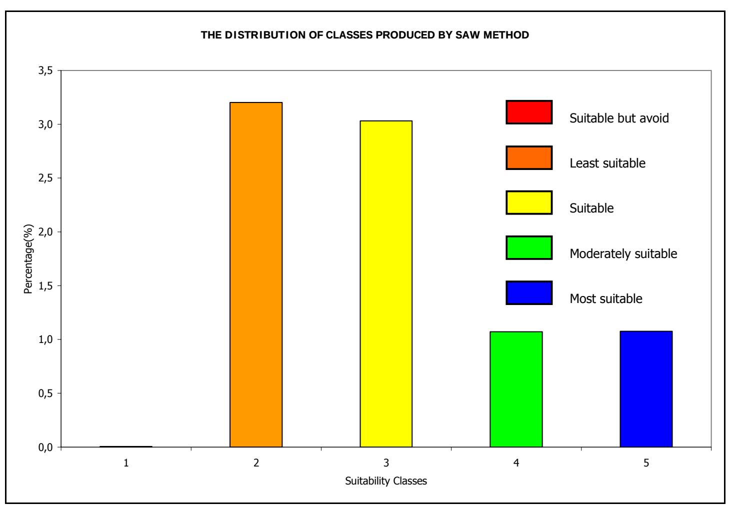


Figure 5.5. The distribution of classes in the study area produced by SAW method

5.2. The implementation of Analytic Hierarchy Process

In the AHP, the first step is that a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy (Figure 5.6). When developing a hierarchy, the top level is the ultimate goal which is in this case landfill site selection.

After the decomposition stage is completed, cardinal rankings for criteria are determined which is done by pairwise comparisons. Two alternatives and the importance relation between them are considered at a time which provides easier ranking. The comparison matrix developed for 16 criteria is shown in Figure 5.7. After the comparison matrix is developed, the composite weights are produced by means of a sequence of multiplication.

First, the decision matrix is squared, the row sums are calculated and then normalized. This procedure is continued till the differences between normalized weights of the iterations are reached to a very small value. After the weights for each criterion is obtained, the geoformula operation is used to generate the overall score of the alternatives in the GIS environment. Following this to maintain the harmony relative to SAW result map the same 6 unit classification scheme is again applied to the resultant map after the evaluation of the histogram of AHP score map (Figure 4.9).

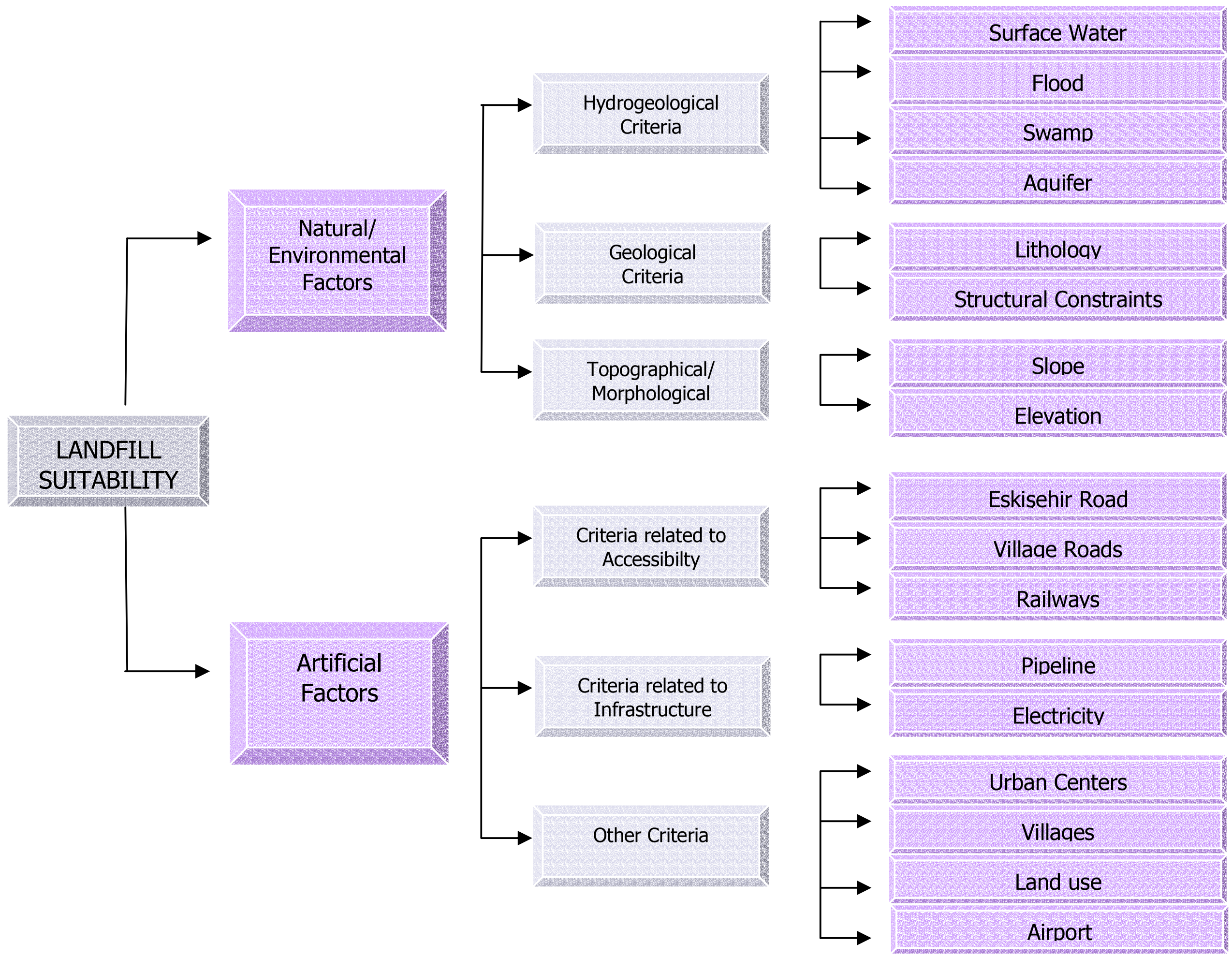


Figure 5.6. The decision tree developed for the landfill site selection problem

	Urban Centers	Villages	Surface Water	Flood	Swamp	Geology	Aquifer	Landuse	Slope	Pipeline	Electricity	Elevation	Eskisehir Road	Airport	Village Road	Railway
Urban Centers	1	2	3	3	3	4	4	5	5	5	7	7	7	7	9	9
Villages	1/2	1	2	2	2	3	3	4	5	5	7	7	7	7	9	9
Surface Water	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Flood	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Swamp	1/3	1/2	1	1	1	2	2	3	4	4	5	5	5	5	7	7
Geology	1/4	1/3	1/2	1/2	1/2	1	1	2	3	3	4	4	4	4	5	5
Aquifer	1/4	1/3	1/2	1/2	1/2	1	1	2	3	3	4	4	4	4	5	5
Landuse	1/5	1/4	1/3	1/3	1/3	1/2	1/2	1	2	2	3	3	3	3	4	4
Slope	1/5	1/5	1/4	1/4	1/4	1/3	1/3	1/2	1	1	2	2	2	2	3	3
Pipeline	1/5	1/5	1/4	1/4	1/4	1/3	1/3	1/2	1	1	2	2	2	2	3	3
Electricity	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Elevation	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Eskisehir Road	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Airport	1/7	1/7	1/5	1/5	1/5	1/4	1/4	1/3	1/2	1/2	1	1	1	1	2	2
Village Road	1/9	1/9	1/7	1/7	1/7	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1/2	1	1
Railway	1/9	1/9	1/7	1/7	1/7	1/5	1/5	1/4	1/3	1/3	1/2	1/2	1/2	1/2	1	1

Figure 5.7. The comparison matrix developed for the landfill site selection problem

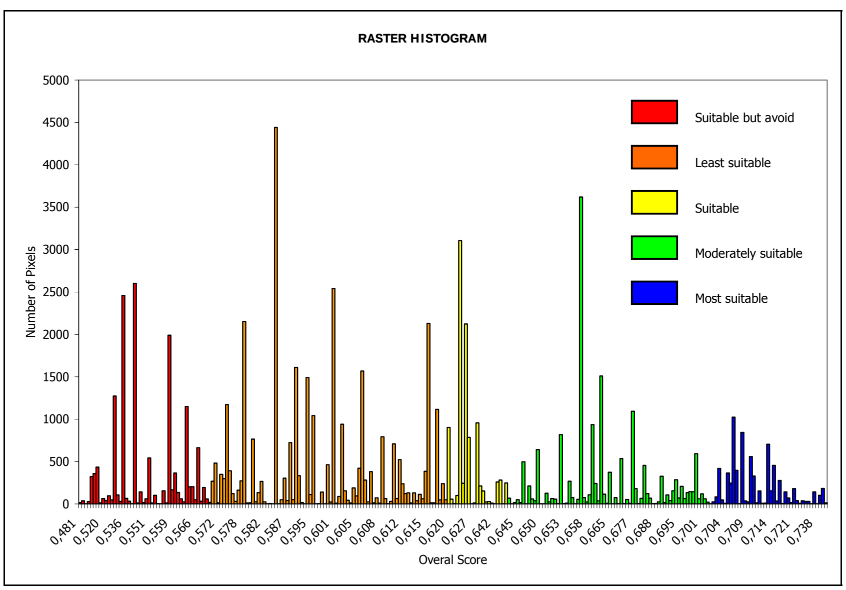


Figure 5.8. The histogram of result map prepared by Analytical Hierarchy Process

Figure 5.9 shows the distribution of the classes. The areas belong to the suitable but avoid class covers 18.4 %, least suitable classes 41.7 %, suitable classes approximately 11 %, moderately suitable 19.3 % and most suitable class approximately 9.6 % of the unmasked area.

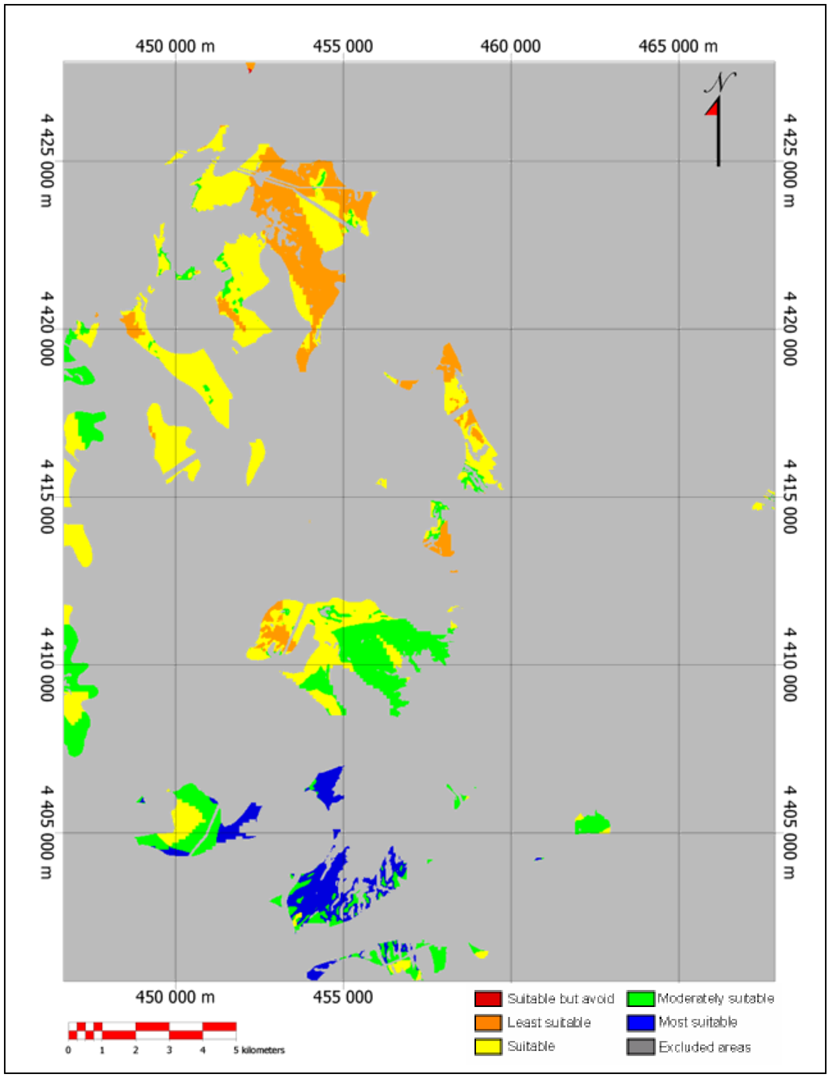


Figure 5.9. The result map prepared by Analytical Hierarchy Process

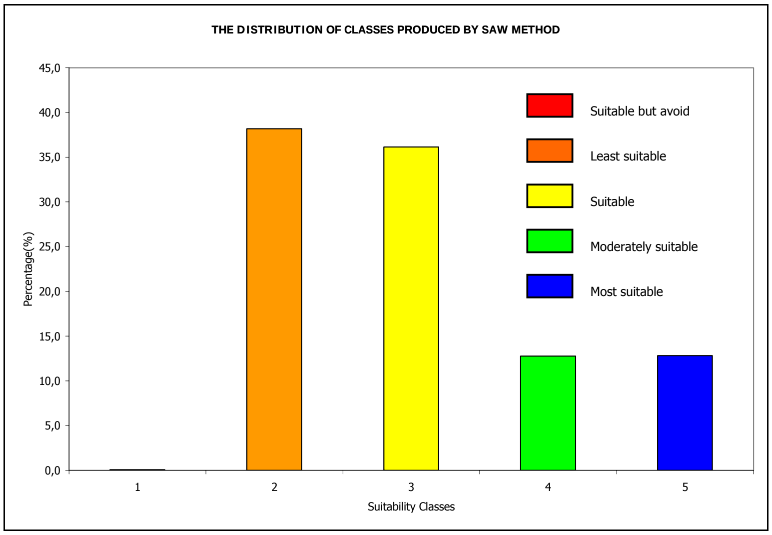


Figure 5.10. The distribution of classes in the study area produced by AHP

5.3. Comparison of two maps

To compare the output maps of two methods, geoformula is written for both of the methods separately to classify the unmasked sites ranging from suitable but avoid areas to most suitable areas. For SAW method, each class is given a number changing from 0 to 5 and for AHP ranging from 0 to 50. After the preparation of the maps of 6 classes, they are added so that the matrix shown in Table 5.2 is established.

Table 5.2. .The matrix created for the comparison of two applied methods

AHP/SAW	1	2	3	4	5
10	11(0.07%)	12(18.33%)	13	14	15
20	21	22(19.83 %)	23(21.90%)	24	25
30	31	32	33(10.00%)	34(1.01%)	35
40	41	42	43(4.23%)	44(11.77%)	45(3.31%)
50	51	52	53	54(0.03%)	55(9.51%)

Mismatched class Acceptable class Correct class

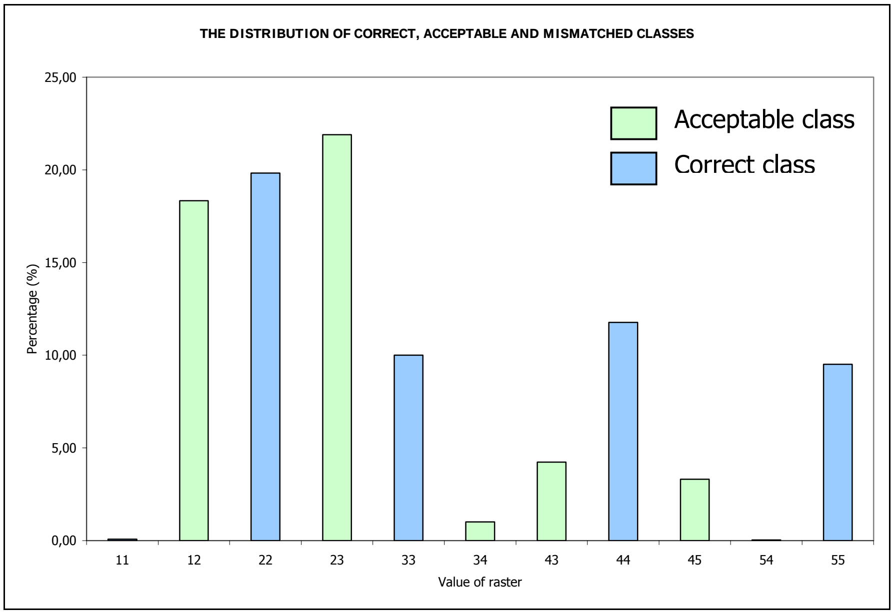
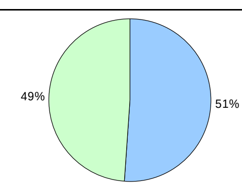


Figure 5.11. The histogram of correct, acceptable and mismatched classes

The blue areas shown in the matrix and histogram are the correct pixels in the output map with a percentage of 51.18. The green areas are acceptable pixels with a percentage of 48.82. If the acceptable and correct pixel percentages are summed, it can be said that two methods are conformable with a percentage of 100%.

Table 5.3. The percentage of correct, acceptable and mismatched classes

	Percentages(%)
Correct class	51.18
Acceptable class	48.82
Mismatched class	0.00



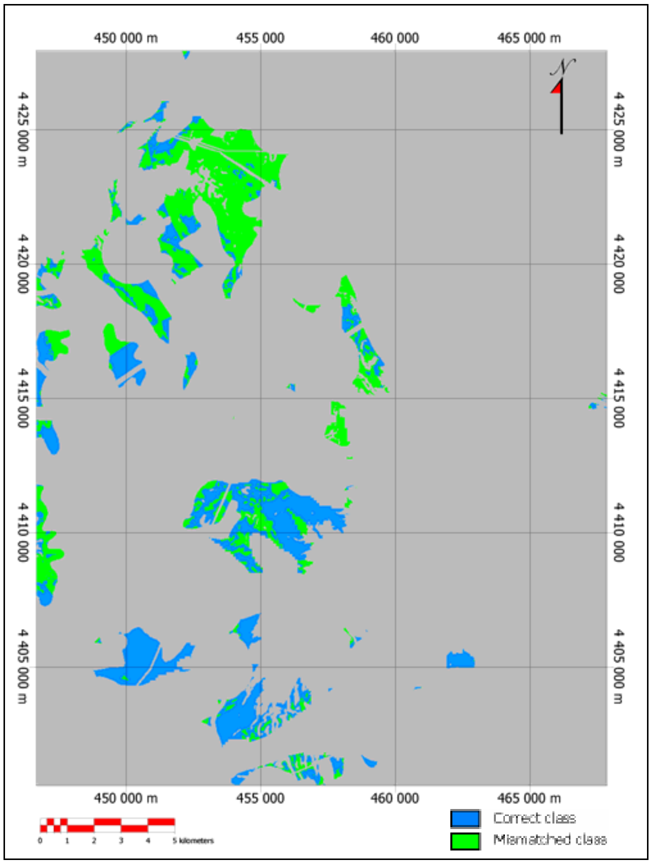


Figure 5.12. The correct and acceptable areas of comparison

5.4. Field check of candidate sites

After the comparison of two output maps by the SAW method and AHP, a number of candidate sites have been revealed. In order to check the suitable areas derived from the analysis, field check is performed out to determine the accuracy and suitability of candidate sites. Four candidate sites are determined for further detailed geotechnical and hydrogeological investigations. The locations of the candidate sites are given in Figure 5.13.

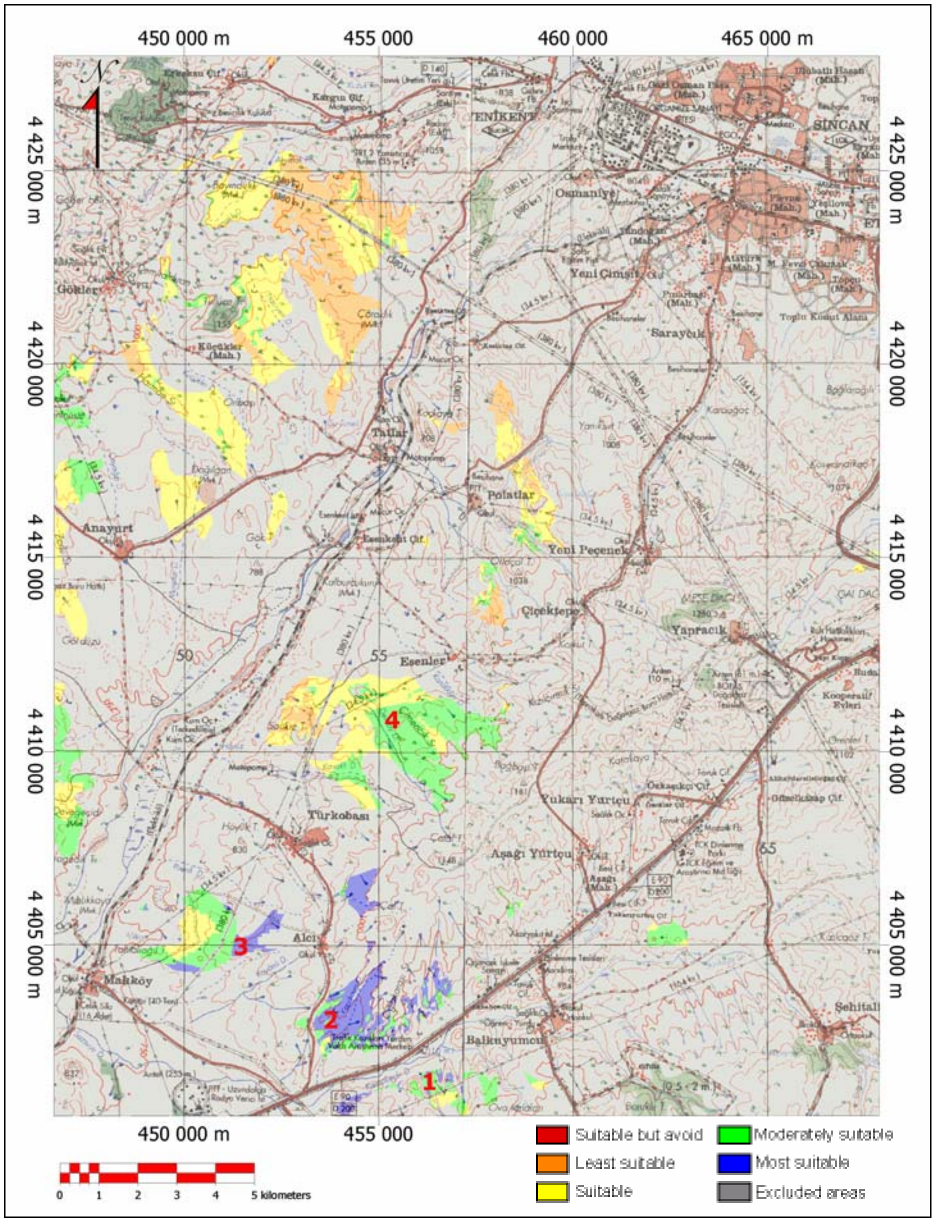


Figure 5.13. Locations of the candidate sites

In candidate site 1, the gently rolling hills and flat hill top areas dominate the region (Figure 5.14.). In terms of criteria used in the analysis, the area is suitable because the lithology, altitude and slope are convenient to landfill siting. However, it is not possible to locate a landfill site on a mesa structure. It is seen that slope layer alone is not sufficient to eliminate these kinds of areas, where as the spatial location of the suitable slope regions should also be incorporated into such kind of decision support systems. Apart from these flat hill tops, gently rolling valley bottoms in the area can be used as a landfill site (Figure 5.14.).

Figure 5.14. Panoramic view of Candidate Site 1

The candidate site 2 shown in Figure 5.15 is found to be the most suitable area among the candidate sites after the field studies. However this candidate site also has some flaws as: the site is inside a valley (Figure 5.16.a) and the base of the valley is used as an agricultural land (Figure 5.16.b), which should become a management problem in the future exploitation of this site as a sanitary landfill site.

Figure 5.15. Panoramic view of Candidate Site 2

Figure 5.16. (a)-(b) Close up views of Candidate Site 2

The next candidate site (candidate site 3, Figure 5.17) is also observed as a suitable site for sanitary landfill site, but it has a considerable distance from the major Ankara-E90 Highway. The waste loaded trucks should reach the sites by passing through village road of 3 – 4 km which increases the transportation costs, consequently the village road needs to be improved.

Figure 5.17. Panoramic view of Candidate Site 3

The candidate site 4 (Figure 5.18) is located on a second to third grade agricultural land. Although the site is not determined as one of the most suitable areas for landfill site, during the field work it is considered as quite suitable. This site indicates that although the model gives some lower scores for some sites, all of them should have to be field checked as even the lowest score site is suitable for landfilling. This is due to the fact that the models give out only results related to suitability.

Figure 5.18. Panoramic view of Candidate Site 4

Figure 5.19. The area used for wild storage of wastes in the study area

During the field work, site used as wild waste disposal site is shown in Figure 5.19, which may cause severe environmental problems and destroy the ecological balance in the neighboring areas. Also the unpleasant appearance is another subject that should be considered.

CHAPTER 6

DISCUSSION

In this study, all input data required for the analyses are generated from three map sources, which are topographical maps, geological maps and land use maps. The topographical maps are used to derive 12 input data layers such as surface water, wetlands, slope, elevation, Highway E90, village roads, railway, natural gas pipeline, electricity, urban centers, villages and airport. The geological map layer and land use layer are compiled from available maps.

During the preparation of geological map layer of the study area, four map sheets are compiled. Three of them were at the scale 1:25.000 and the last one (area covered by I 28 b2) was 1:100.000. Due to the lack of the coordinate system in the geological maps, the registration process is carried out by using the lithological boundaries, roads, streams and settlement areas with the help of topographical base maps. After geological compilation studies are completed, aquifer and flood input data layers are generated.

During the selection of the landfill siting criteria, the data availability is considered. The political and financial/economical criteria are excluded because these are out of the scope of this study. The ecological value of the flora and fauna could not be considered due to the lack of data for the study area. The climatic characteristics of the region are determined, however, they are not used as a layer because similar climatic conditions prevail throughout the area. The availability of construction material is not considered as a separate layer, however, during ranking of the lithological units this factor is taken into consideration.

The size of the pixels is selected for all produced maps as 25 by 25 m by rule of thumb and all the input data maps are resampled according to a reference raster which is the Digital Elevation Model.

Two different MCDA methods, Simple Additive Weighting(SAW) Method and the Analytical Hierarchy Process(AHP), are used to locate the candidate landfill sites. However, the input data layers used for the analysis are the same. The input layers are produced by ranking method which is the simplest. The method includes ranking of every class in a map under consideration in the order of decision maker's preferences. However, this method can be criticized for the lack of the theoretical foundation.

The Simple Additive Method as mentioned in Chapter 3 has two assumptions of linearity and additivity, which are very difficult to apply in real world situations. The additivity assumption implies that there is no interaction, in other words, no complementary effect between the layers. In this study, the interaction between layers was tried to be kept at minimum. For example, geology has a direct control on topography, but they are used as different layers because geology and topography layers have different impacts on the site selection process. In this study, when applying the GIS based SAW procedure, which is an expert dependent method, the weights are directly assigned between 1 and 10 by the expert.

The Analytical Hierarchy Process decomposes the complex decision problem into simpler decision problems which provides easiness during decision making. Furthermore, it uses pairwise comparisons for determining the weights of the criteria by which two components are considered at a time resulted in the reduction of complexity. The pairwise comparison for the determination of weights is more suitable than direct assignment of the weights, because one can check the consistency of the weights by calculating the consistency ratio in pairwise comparison; however, in direct assignment of weights, the weights are depending on the preference of decision maker. One difficulty in this study was the number of criteria which were set as 16. Too many criteria means large amount of pairwise comparisons.

After the production of the output maps by two methods, a comparison is made and it is seen that AHP method creates more conservative results.

During field checks, some interesting results are obtained. It is seen that additional parameters need to be included in the model which have not been thought before the field work. Some of the parameters were given more credit than they actually deserve. One of the candidate sites is located at the plane surface of a hill top. Although the lithology, altitude and slope are suitable in terms of values, it is not practical to transport the wastes to this site. This shows that the slope layer needs to be defined to avoid such inconsistencies. In addition, some sites determined as suitable in the analysis have bedrock close to the surface, which is not convenient in terms of excavatability. The reason for this is that the geological map and the reports used in this study did not include sufficient data on surficial deposits. Thus, a special purpose geological map is needed, which takes surficial materials, their distributions and thickness into consideration.

It is important to realize that GIS analysis is not a substitute for field analysis; however, it does identify areas that are more suitable and directs efforts to these areas rather than areas that are unsuitable or restricted by regulations or constraints. The use of GIS during the study provides objective zone exclusion based on a set of screening criteria and effective graphical representation.

At the end of the analyses, a number of candidate sites are identified. These sites generally satisfy the minimum requirements of the landfill sites. Among these candidate sites “potential landfill” sites are selected through careful field checks. The selection of the final site, however, requires further geotechnical and hydrogeological boring and testing.

CHAPTER 7

CONCLUSIONS AND RECOMMENDATIONS

Landfill site selection is a complex procedure which involves evaluating numerous factors like regulations, environmental, socio-cultural, engineering and economic factors. Using GIS for locating landfill sites is an economical and practical way as they have capabilities of producing useful, high quality maps for landfill site selection in a short period of time. And the multicriteria decision analysis is also a useful tool in making landfill siting decisions in the area by supplying consistent ranking and weightings to the potential areas.

In this study, firstly the necessary criteria including regulations and constraints are gathered through literature review. According to data availability, 16 different criteria are defined to select a suitable site for a landfill and prepared as input map layers. A method which integrates both GIS and MCDA is used for the analysis. To compare the results and check the accuracy, two methods of MCDA which are Simple Additive Weighting and Analytic Hierarchy Process are used. The output maps are divided into 6 classes from unsuitable to most suitable areas. After the production of output maps, field checks are required to determine the candidate sites. Four candidate sites are distinguished for further investigations.

Between the candidate sites, the candidate site 2 is determined as the most suitable site in the study area due to its easy accessibility and convenient morphology and lithology.

During the studies, it is proved that GIS is a powerful tool in handling large amounts of data and narrowing areas of interest for potential landfill sites.

The map layers related with geology, hydrogeology, and land use are based on available data. Because they are not specifically prepared for landfill site selection purpose, the information provided from these maps were not quite satisfactory. It is understood that rather than general purpose lithological map, the maps showing distribution, thickness, and characteristics of the unconsolidated surficial deposits are more helpful. Thus, for landfill siting studies special purpose engineering geological and hydrogeological maps are required.

The slope layer need to be refined to exclude that areas along the ridges and the hill tops.

For future studies it is recommended to include excavability and construction material availability layer to the proposed model.

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