

GEOGRAPHICAL INFORMATION SYSTEMS BASED  
MICROZONATION MAP OF  
ESKİŐEHİR DOWNTOWN AREA

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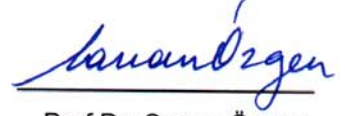
BY

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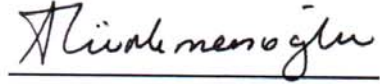
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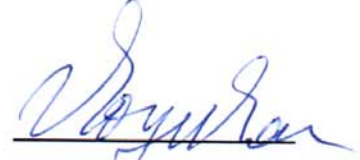
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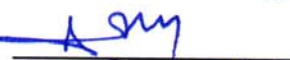
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## ABSTRACT

### GEOGRAPHICAL INFORMATION SYSTEMS BASED MICROZONATION MAP OF ESKİŐEHİR DOWNTOWN AREA

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The purpose of this study is to prepare a geotechnical microzonation map regarding the suitability of the residential areas in Eskiőehir downtown area. In order to obtain the microzonation map, Geographical Information Systems (GIS) based Multicriteria Decision Analysis (MCDA) is used. For this analysis, the slope, flood susceptibility, soil, depth to groundwater table, swelling potential and liquefaction potential layers are prepared. The weight values to the layers and rank values to the classes of each layer are assigned by applying Simple Additive Weighting (SAW) and Analytical Hierarchical Process (AHP) methods. Two geotechnical microzonation maps are obtained as outputs of these methods. The study area is categorized into three different zones regarding the foundation suitability of residential areas as: (1) Areas suitable for settlement; (2) Provisional settlement areas; (3) Areas requiring detailed geotechnical investigations. The maps prepared using SAW and AHP methods are found to be consistent with each other. The geotechnical microzonation map prepared using AHP method is recommended as the final map of the study area.

**Keywords:** Geotechnical Microzonation Map, Geographical Information Systems, Multicriteria Decision Analysis, Analytical Hierarchical Process, Eskiőehir.

## ÖZ

### ESKİŞEHİR YERLEŞİM MERKEZİ İÇİN COĞRAFİ BİLGİ SİSTEMLERİ TABANLI MİKROBÖLGELEME HARİTASI

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Bu çalışmanın amacı, Eskişehir yerleşim merkezi için yerleşime uygunluk amacıyla jeoteknik mikrobölgeleme haritasının hazırlanmasıdır. Bu çalışma kapsamında, Coğrafi Bilgi Sistemleri (CBS) tabanlı Çok Ölçütlü Karar Analizi (ÇÖKA) kullanılmıştır. Bu uygulamada eğim, sel, zemin türü, yeraltı su seviyesi derinliği, şişme potansiyeli ve sıvılaşma potansiyeli katmanları hazırlanmıştır. Her katmana ve her katmanın içindeki sınıflara birer ağırlık değeri verilmiştir. Bu değerler verilirken Basit Ağırlıklı Toplama (BAT) ve Analitik Hiyerarşi İşlemi (AHI) kullanılmış ve bu yöntemlerin sonucu olarak iki jeoteknik mikrobölgeleme haritası üretilmiştir. İnceleme alanında yerleşime uygunluk yönünden (1) Yerleşime uygun alanlar; (2) Önemli alanlar; (3) Ayrıntılı jeoteknik etüt gerektiren alanlar olmak üzere üç bölge belirlenmiştir. Söz konusu yöntemler kullanılarak hazırlanan haritaların birbirleriyle uyumlu olduğu saptanmıştır. AHI yöntemi kullanılarak üretilen jeoteknik mikrobölgeleme haritası, çalışma alanının nihai mikrobölgeleme haritası olarak önerilmiştir.

**Anahtar Kelimeler:** Jeoteknik Mikrobölgeleme Haritası, Coğrafi Bilgi Sistemleri, Çok Ölçütlü Karar Analizi, Analitik Hiyerarşi İşlemi, Eskişehir.

To My Family

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## TABLE OF CONTENTS

PLAGIARISM . . . . .	iii
ABSTRACT . . . . .	iv
ÖZ. . . . .	v
DEDICATION . . . . .	vi
ACKNOWLEDGMENTS . . . . .	vii
TABLE OF CONTENTS . . . . .	viii
LIST OF TABLES . . . . .	x
LIST OF FIGURES. . . . .	xii
CHAPTER	
1. INTRODUCTION . . . . .	1
1.1. Purpose and Scope . . . . .	1
1.2. Location of the Study Area . . . . .	2
2. BACKGROUND INFORMATION. . . . .	3
2.1. Background Information on GIS-based Site Selection . . . . .	3
2.2. Background Information on Multicriteria Decision Analysis . . . . .	7
3. METHODOLOGY. . . . .	23
3.1. Implementation of Multicriteria Decision Analysis . . . . .	23
3.1.1. Problem Definition . . . . .	25
3.1.2. Site Specific Information . . . . .	25
3.1.3. Evaluation . . . . .	25
3.1.4. Data Production and Layers . . . . .	25
3.1.5. Multicriteria Decision Analysis (MCDA) and Results. . . . .	26
3.1.5.1. Simple Additive Weighting Method (SAW) . . . . .	26
3.1.5.2 Analytical Hierarchical Process (AHP) . . . . .	27
4. DATA EVALUATION . . . . .	30
4.1. Available Data and Parameter Selection . . . . .	30
4.2. Data Sources and Layers . . . . .	32
4.2.1. Topographical Map. . . . .	32
4.2.1.1. Digital Elevation Model (DEM). . . . .	32
4.2.1.2. Slope Layer . . . . .	41



4.2.1.3. Flood Susceptibility Layer . . . . .	42
4.2.2. Lithology Map . . . . .	44
4.2.2.1. Soil Layer . . . . .	47
4.2.3. Borehole Data . . . . .	51
4.2.3.1. Depth to Groundwater Table Layer . . . . .	51
4.2.3.2. Swelling Potential Layer . . . . .	53
4.2.3.3. Liquefaction Potential Layer. . . . .	55
5. ANALYSIS . . . . .	57
5.1. Common Steps of Multicriteria Analysis Applications . . . . .	57
5.2. Simple Additive Weighting (SAW) . . . . .	60
5.2.1. Assigning Weight and Rank Values . . . . .	60
5.2.2. Standardization of Rank and Weight Values . . . . .	63
5.2.3. Result Map of SAW . . . . .	64
5.3. Analytical Hierarchical Process (AHP) . . . . .	67
5.3.1. Assigning Weight Values . . . . .	68
5.3.2. Assigning Rank Values . . . . .	69
5.3.3. Obtaining Overall Weight and Rank Values . . . . .	72
5.3.4. Consistency Ratio . . . . .	74
5.3.5. Result Map of AHP. . . . .	81
5.4. Comparison of Microzonation Maps . . . . .	83
6. DISCUSSION . . . . .	87
7. CONCLUSION AND RECOMMENDATIONS.. . . . .	89
REFERENCES . . . . .	91

## LIST OF TABLES

### TABLES

Table 2.1. Summary of methods for assessing criterion weights (Malczewski, 1999) . . . . .	15
Table 2.2. Multiattribute Decision Rules. (Modified from Malczewski, 1999) . . . . .	17
Table 2.3. Multiobjective Decision Rules. (Modified from Malczewski, 1999) . . . . .	20
Table 3.1. Advantages and disadvantages of AHP method . . . . .	28
Table 4.1. The calculated RMSE values for different surface fitting methods for section 1 . . . . .	39
Table 4.2. The calculated RMSE values for different surface fitting methods for section 2 . . . . .	39
Table 4.3. Unified Soil Classification System (Cernica, 1995) . . . . .	48
Table 4.4. Groundwater table elevation values . . . . .	52
Table 5.1. Assigned weight and rank values for the layers/classes of the study area . . . . .	62
Table 5.2. Standardized rank values and normalized weight values . . . . .	63
Table 5.3. Comparison judgments from a fundamental scale of absolute numbers for assigning weight / rank values (Saaty, 2004) . . . . .	68
Table 5.4. The pairwise comparison table for assigning weight values . . . . .	68
Table 5.5. Pairwise comparison matrix for liquefaction thematic map . . . . .	70
Table 5.6. Pairwise comparison matrix for flood thematic map . . . . .	70
Table 5.7. Pairwise comparison matrix for soil thematic map . . . . .	71
Table 5.8. Pairwise comparison matrix for depth to groundwater table thematic map . . . . .	71
Table 5.9. Pairwise comparison matrix for swelling thematic map . . . . .	72
Table 5.10. Pairwise comparison matrix for slope thematic map . . . . .	72
Table 5.11. The computed weight and rank values . . . . .	73
Table 5.12. Random inconsistency indices (RI) for n=1,2,.....,15 (Saaty, 1980). . . . .	75
Table 5.13. The weighted sum vector and the consistency vector of the weight values assigned to layers . . . . .	76

Table 5.14. The weighted sum vector and the consistency vector of the rank values assigned to the classes of liquefaction layer . . . . .	77
Table 5.15. The weighted sum vector and the consistency vector of the rank values assigned to the classes of flood layer . . . . .	77
Table 5.16. The weighted sum vector and the consistency vector of the rank values assigned to the classes of soil layer . . . . .	78
Table 5.17. The weighted sum vector and the consistency vector of the rank values assigned to the classes of depth to groundwater table layer . . . . .	79
Table 5.18. The weighted sum vector and the consistency vector of the rank values assigned to the classes of swelling layer . . . . .	79
Table 5.19. The weighted sum vector and the consistency vector of the rank values assigned to the classes of slope layer . . . . .	80
Table 5.20. The numbers assigned to the classes of both microzonation maps . . . . .	84
Table 5.21. Possible result numbers of the addition process with the corresponding percentages . . . . .	84

## LIST OF FIGURES

### FIGURES

Figure 1.1. Location map of the study area . . . . .	2
Figure 2.1. The classification of multicriteria decision problems (Malczewski, 1999) . . . . .	9
Figure 2.2. Framework for spatial multicriteria decision analysis (Malczewski, 1999) . . . . .	10
Figure 3.1. Flowchart for the preparation for the microzonation map of study area using MCDA . . . . .	24
Figure 4.1.a Result of classification. . . . .	31
Figure 4.1.b. Special color composite (RGB:531) . . . . .	31
Figure 4.2. The digitized contour lines and the study area boundary. . . . .	33
Figure 4.3. The correlation coefficients versus cell sizes graph . . . . .	35
Figure 4.4. The chosen sample points of the study area . . . . .	37
Figure 4.5.a. Differences between topographical and interpolated elevations of sample points: For profiles surface fitting method . . . . .	38
Figure 4.5.b. Differences between topographical and interpolated elevations of sample points: For minimum curvature surface fitting method. . . . .	38
Figure 4.6. The boundary of the two sections of the study area . . . . .	38
Figure 4.7. Examples of the errors in profiles surface fitting method for section 2 . . . . .	40
Figure 4.8. The digital elevation model (DEM) of the study area . . . . .	40
Figure 4.9. Histogram of the slope map . . . . .	41
Figure 4.10. Slope layer of the study area. . . . .	42
Figure 4.11. Flood susceptibility layer of the study area . . . . .	43
Figure 4.12. Lithology map of the study area (Ayday <i>et al.</i> , 2001) . . . . .	45
Figure 4.13. District map of the study area (Ayday <i>et al.</i> , 2001) . . . . .	45
Figure 4.14. Location of the boreholes used in the preparation of soil layer . . . . .	49
Figure 4.15. Plasticity chart used in the preparation of soil layer . . . . .	50
Figure 4.16. Soil layer of the study area . . . . .	50

Figure 4.17. Location of boreholes used in the preparation of depth to groundwater table layer . . . . .	52
Figure 4.18. Depth to groundwater table layer of the study area . . . . .	53
Figure 4.19. Location of boreholes used in the preparation of swelling potential layer . . . . .	54
Figure 4.20. Activity chart used in the preparation of swelling potential layer . . . . .	54
Figure 4.21. Swelling potential layer of the study area . . . . .	55
Figure 4.22. Liquefaction potential layer of the study area (modified from Ayday et al, 2001) . . . . .	56
Figure 5.1. Schematic diagram of layers, classes, assigned weight and rank Values . . . . .	58
Figure 5.2. Simplified flowchart for assigning weight and rank values . . . . .	58
Figure 5.3. The histogram of the microzonation map obtained from the weight and rank values assigned by using SAW method . . . . .	64
Figure 5.4. Histogram showing the boundaries of the three zones of microzonation map . . . . .	65
Figure 5.5. The microzonation map prepared by using the SAW method . . . . .	66
Figure 5.6. The hierarchical structure used in the preparation of the microzonation map . . . . .	67
Figure 5.7. Schematic diagram of consistency ratio calculation . . . . .	75
Figure 5.8. Histogram of the microzonation map obtained from the weight and rank values assigned by using AHP method . . . . .	81
Figure 5.9. Histogram showing the boundaries of the three zones of the microzonation map . . . . .	82
Figure 5.10. The microzonation map prepared by using the AHP method . . . . .	83
Figure 5.11. The locations of the comparison classes. Inset shows portion of correct classification to misclassification . . . . .	86

## CHAPTER 1

### INTRODUCTION

#### 1.1. Purpose and Scope

Eskişehir is one of the most rapidly growing and industrialized cities of Turkey. It is also known for its rich industrial raw materials. The population of Eskişehir is rapidly increasing due to its location at the junction of main transportation routes, namely the highways and railroads of Ankara, İstanbul and İzmir. Two major universities are also located in Eskişehir, therefore the new residential areas are highly needed and the city is continually expanding. During planning stage of expansion, geological and geotechnical data are required.

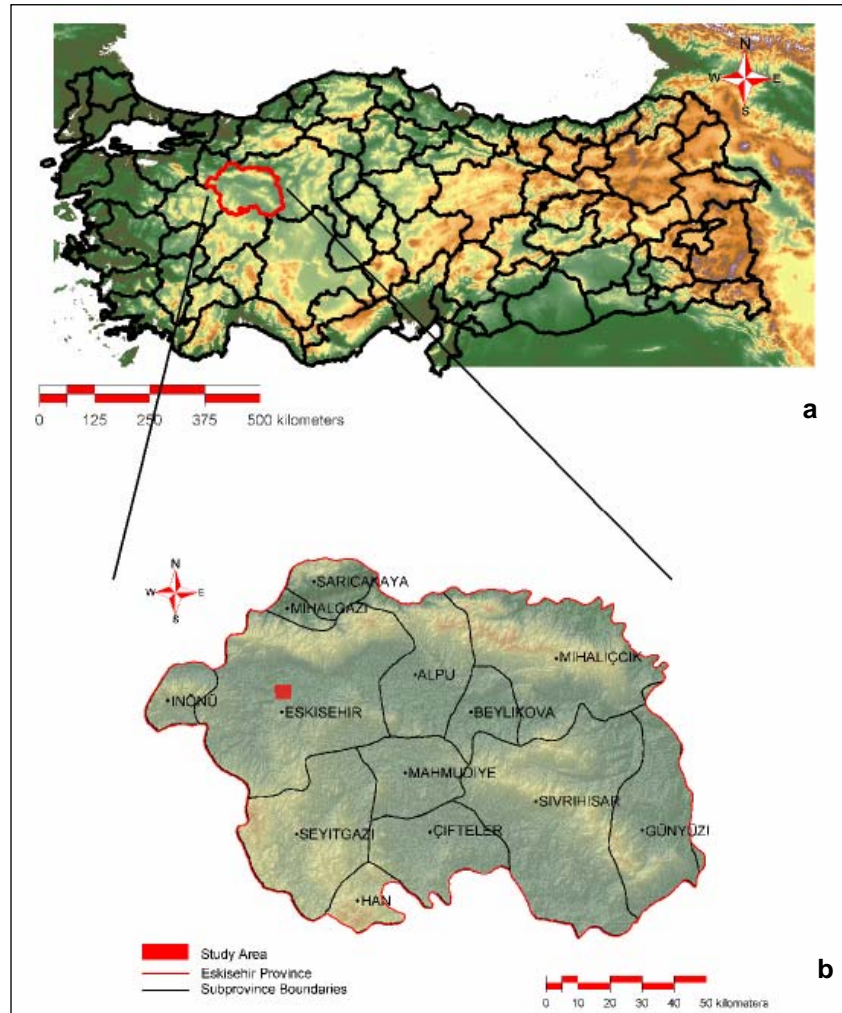
The purpose of the study is to prepare a geotechnical microzonation map for a chosen sub-section in Eskişehir downtown. The microzonation map is prepared in order to determine the suitability of the foundation of residential areas. Since the study area is already densely settled, this study will also contribute to already settled areas to see if further precautions are needed for a safer planning studies.

In order to obtain the microzonation map of the study area regarding the geotechnical suitability of the foundations of residential areas, Geographical Information Systems (GIS) based Multicriteria Decision Analysis (MCDA) is used.

For this analysis, firstly slope, flood, soil, depth to groundwater table, swelling and liquefaction layers were prepared, afterwards the weight and rank values were assigned to the layers and the classes of each layer respectively. The assignment of the weight and rank values and the analysis are performed by application of two different decision models, namely Simple Additive Weighting (SAW) and Analytical Hierarchical Process (AHP) methods.

## 1.2. Location of the Study Area

Eskişehir is located in the northwest part of the Central Anatolian Region of Türkiye; approximately 250 km's west of Ankara (Figure 1.1). The study area is bounded by the coordinates 4408165.986 N and 283627.999 E in the northwestern edge and 4403717.716 N and 288712.344 E in the southeastern edge in Universal Transverse Mercator (UTM) projection (Zone 36N, European Mean Datum 1950). The study area covers approximately 22.5 km<sup>2</sup>.



**Figure 1.1.** Location map of the study area. a) Color coded digital elevation model of Turkey and boundaries of provinces, b) Location map of the study area within the Eskişehir province.

## CHAPTER 2

### BACKGROUND INFORMATION

#### 2.1. Background Information on GIS-based Site Selection

Traditionally, simple land suitability studies have been used to select new settlement areas, waste disposal sites, areas for open pits and septic tanks, and identify possible routes. First, the physical criteria for the study were identified. In early applications, these criteria were depicted on transparent maps which are overlaid, and according to the goal suitable sites with the most desirable features were identified. In 1980's, Geographical Information Systems (GIS) is started to be used in the environmental assessment of site planning. Most of these geotechnical site selection applications require an enormous amount of data which must be geographically related. Consequently, there is a necessity of a system where all of these large quantities of data could be manipulated and archived. GIS, being a computer-based system that enables acquisition, storage, retrieval, modeling, manipulation and analysis of geographically related data (Worboy, 1995; Aronoff, 1993), has brought out a complimentary solution for this requirement.

The importance and easiness of GIS is stated by Basso *et al.* (2000). According to them, the needed data for an evaluation is very assorted, so that the integration of data and the relationships amongst the factors are not easily resolved issues. However, through an integrated, multi-level approach, different stages, different points of view, and the existing interactions amongst the individual components can be evaluated. The GIS also enhances data analysis, increasing the interpretability of the data, by enabling cross analysis procedures and various classifications to be performed. Therefore, appropriate stimulations can be applied rapidly.

In various geotechnical applications, including site selection, the usage of different algorithmic procedures by means of GIS, allowed engineers to make predictions based on a given knowledge of in-situ conditions. GIS also facilitated rapid information, communication of data to the users, and enabled the production of many scenarios.



GIS applications are capable of managing large amounts of spatially related information, providing the ability to integrate multiple layers and additional information. In recent decades, the use of GIS-based site selection with engineering geological evaluation has gained acceleration. Using the GIS model as part of the site selection process can help to make the selection of a potential site more transparent.

Many geotechnical applications involve determination of 3-dimensional (3D) distribution of geological/geotechnical materials. To deal with the difficulties involving a greater understanding of the 3D spatially, concerned functionalities must include enhanced visualization. Available data relevant to local geology, subsurface layering and soil geotechnical characteristics can be compiled and implemented as layers in the GIS and a 3D-geotechnical model can be generated based on this information. Therefore, available maps, geotechnical data, and interpolations from them, are increasingly being incorporated into digital 3D geotechnical models. (Culshaw *et al.*, 2002, Real, 1993, and Jimenez *et al.*, 2002)

To develop a more systematic approach to site selection, it is opportune to use highly-sophisticated computerized GIS systems, and digital map data. Such an approach should ideally combine computerized GIS and geotechnical site investigation methodologies. The combination of these methodologies allows a rigorous approach to be adopted towards site selection, and can accelerate the evaluation of the site selection process and so reduce costs. In dealing with these procedures, the following objectives should also be considered:

- To ensure that the most environmentally suitable site is selected, in terms of technical criteria,
- To integrate the site selection into an overall program of regional development taking into account economic factors (Allen *et al.*, 2002)

There are two approaches of solving the site selection problem: an academic one, where the tools of GIS were placed in order to obtain a multi-attribute solution; and the practical one, where the effective locations of sites are analyzed. (Corrêa *et al.*, 2002)

Calijuri *et al.* (2001), used GIS for information storage and spatial analysis, either graphical or descriptive. Topographic and hydrographic data, street system and location of the point were converted into digital format. This digital topographic information was then used to obtain a digital model of the terrain and slope charts.

Site selection decision problems involve a set of geographically defined alternatives, from which a choice of one or more alternatives is to be made on the basis of multiple, conflicting and incommensurate evaluation criterion. The alternatives are geographically defined in the sense that results of the analysis (decisions) depend on their spatial

arrangement. Accordingly, many real-world spatial planning and management problems give rise to GIS-based multicriteria decision making or spatial multicriteria decision analysis (MCDA).

The combination of GIS and MCDA capabilities is of critical importance in spatial multicriteria analysis. GIS provides the capabilities of data acquisition, storage, retrieval, manipulation and analysis of the data to obtain information for making decisions. However, GIS systems have a limited capability as far as the analysis of the value structure is concerned. The MCDA techniques provide the tools for aggregating the geographical data and the decision maker's preferences into unidimensional value or utility of alternative decisions (Thill, 1999).

Several applications for the geotechnical site selection using GIS-based MCDA techniques are given below in chronological order:

Navarro and Garcia (1996) used a decision support system called Integrated Planning Decision Support System to combine Geographic Information System, Geographic Resource Analyses Support System and engineering numerical models within a Geographic User Interface, which provides geologic hazards, vulnerability and risk assessment modeling. As a result, considering information about topography, geology, hydrogeology, geotechnics, land cover, land use and historical data about hazards, a hazard assessment is done. In this assessment all information are evaluated according to the weight values, given due to their influence in the hazard risk. All of the factors that are considered important for the process are combined with the following stages; the natural physical factors to be included in the evaluation are selected and the land units to be used in recording and processing information are defined. Rating values to conditions of features for each physical factor and weight to each of the map factors are assigned and the resultant categories after weighted average of map factors are evaluated. Finally, colors to represent different hazard categories on a map are defined and hazard susceptibility maps are developed to identify the areas that are under high risk and areas that are suitable for feature urban development, in the evaluation of the potential site.

A study by Siddiqui *et al.* (1996), was important to understand the application of spatial Analytical Hierarchical Process (AHP) in decision making studies. In this study, spatial-AHP was used to rank potential landfill areas based on a wide variety of criteria for preliminary site assessment. It also analyzes the effects of varying the relative importance of various siting criteria, landfill size, and location restriction severity.

Bell *et al.* (2000), have stated that even without formal calibration projections for urban planning (PUP), provide a useful framework for scenario generation and exploratory analysis. The facility to explore alternative zoning patterns by altering the classification of

land provides a useful tool for strategic planning and decision-support. In a similar way, raising or lowering the aggregate regional forecast can provide a ready indication of how the rate of growth impact on the timing of demand for facilities and services in particular locations. At a broader level, the ability to examine the effects of accessibility to multiple user-defined factors illustrates the flexibility of the modeling shell. A wide range of scenarios have been generated with various combinations of input data, adjacency and accessibility parameters.

Joerin and Musy (2000), proposed MAGISTER (Multicriteria Analysis with GIS for TERritory) model for land management, which is based on geographical information systems and multicriteria analysis. In land use problems, the study area is described by a set of homogenous zones to reduce the number of alternatives. The homogeneity quality is assessed by use of a valued closeness relation developed in the domain of rough set theory. This function is then used to select the best zones, or classify them in predefined category.

Dai *et al.* (2001), illustrated a GIS-aid to the geo-environmental evaluation for urban land-use planning for the urban area of Lanzhou City and its vicinity in Northwest China. This study incorporates topography, surficial and bedrock geology, groundwater conditions and historical geologic hazards. Multicriteria analysis is performed to evaluate development suitability of the geo-environment for each category, according to appropriately measured and weighted factors. A suitability map for each category is developed using an algorithm that combines factors in weighted linear combinations. It is demonstrated that the GIS methodology has high functionality for geo-environmental assessment.

Çiftçi *et al.* (2001), performed a site selection for an industrial complex on the area of Demirtaş, Bursa, Turkey. For an automotive factory as industrial complex, decision rules are generated according to the needs of the factory and the location of the study area. The geotechnical data, landcover, slope, depth to groundwater table, permeability and the road network layers are analyzed in GIS environment. Each layer is given several weight and rank values to evaluate different scenarios of site suitability according to the decision rules. The scenarios are used in selection of candidate sites and the most suitable site is selected as the potential site of the automotive factory.

The project "Some examples of artificial recharge of aquifers by flood water spreading in Iran" (Ghayoumian *et al.*, 2002) has the purpose of selecting proper areas for flood spreading from the engineering geological point of view. Artificial recharge which is an optimal utilization of floodwater, was used, since it is an inexpensive mean of flood mitigation and can result in large return for relatively small investment. All of the layers were classified into several classes based on existing criteria. All of these thematic

layers were analyzed and integrated using a decision support system, in a GIS environment.

Allen *et al.* (2002) proposed a selection procedure for the location of landfill sites, combining GIS technologies with rigorous site investigation methodologies. For the site selection process, it is necessary to establish criteria on a scale of hierarchies, with weightings assigned to the different criteria, so that in the final selection process, the various site options can be ranked objectively in order of suitability. The GIS model enables the end user to evaluate the residual areas on the basis of multiple and conflicting criteria. The model has been kept flexible to allow the user to input weights based on other methods or knowledge.

Geneletti (2003) described a methodological approach based on the integrated use of GIS and Decision Support Systems to identify nature conservation priorities among the remnant ecosystems within an alpine valley. In this study, the ecosystems are first assessed by means of landscape ecological indicators, and then ranked by using multicriteria analysis techniques. Several conservation scenarios are generated so as to simulate different evaluation perspectives. The scenarios are then compared to highlight the most conflicting sites and to propose a conservation strategy for the area under evaluation. The effectiveness of spatial decision-support techniques in land-use planning for nature conservation is discussed.

## **2.2. Background Information on Multicriteria Decision Analysis (MCDA)**

Multiple objectives are essential to many 'real' systems. Frequently, these multiple objectives conflict with each other (as one objective is improved, the others may deteriorate). Dimensional analysis can help the decision maker to make better decisions under such circumstances (Starr and Stein, 1976).

In decision-making context, a criterion would imply some sort of standard by which one particular choice or course of action could be judged to be more desirable than another. Actually in the real life, every decision requires the balancing of multiple factors (i.e. 'criteria' in the above sense) – sometimes explicitly, sometimes without conscious thought – so that in one sense, everyone is well practiced in multicriteria decision making. However, the human brain can only simultaneously consider a limited amount of information, so that all factors cannot be resolved in one's head. (Belton and Stewart, 2002)

The very nature of multicriteria problems is that, there is much information of a complex and conflicting nature, often reflecting differing viewpoints and often changing with time. One of the principal aims of MCDA approaches is to help decision makers organize and synthesize such information in a way which leads them to feel comfortable and confident about the potential for post-decision regret by being satisfied that all factors have properly been taken into account. Thus, the expression MCDA is used as an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. MCDA is an aid to decision making, a process which seeks to:

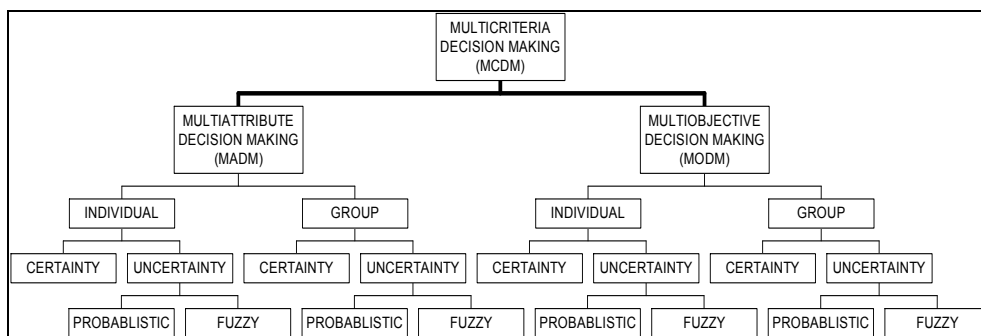
- Integrate objective measurement with value judgment;
- Make explicit and manage subjectivity.

Subjectivity is inherent in all decision making, in particular in the choice of criteria on which to base the decision, and the relative 'weight' given to those criteria. MCDA does not dispel that subjectivity; it simply seeks to make the need for subjective judgment explicit and to process by which they are taken into account transparent. (Belton and Stewart, 2002)

Simply stated, the major role of formal analysis is to obtain good decision making. Formal analysis is meant to serve as an aid to the decision maker, not as a substitute for him. As a process, it is intended to force hard thinking about the problem area.

Among the alternatives, clearly there must be a decision to be made. Consideration of different choices becomes a multicriteria decision making (MCDM) problem.

MCDM problems can be classified on the basis of the major components of multicriteria decision analysis. Three dichotomies can be distinguished: (i) multiobjective versus multiattribute decision problems; that is, MODM versus MADM, (ii) individual versus group decision problems, and (iii) decisions under certainty versus decision under uncertainty. This classification is shown in Figure 2.1, and explained below (Thill, 1999):



**Figure 2.1.** The classification of multicriteria decision problems (Malczewski, 1999).

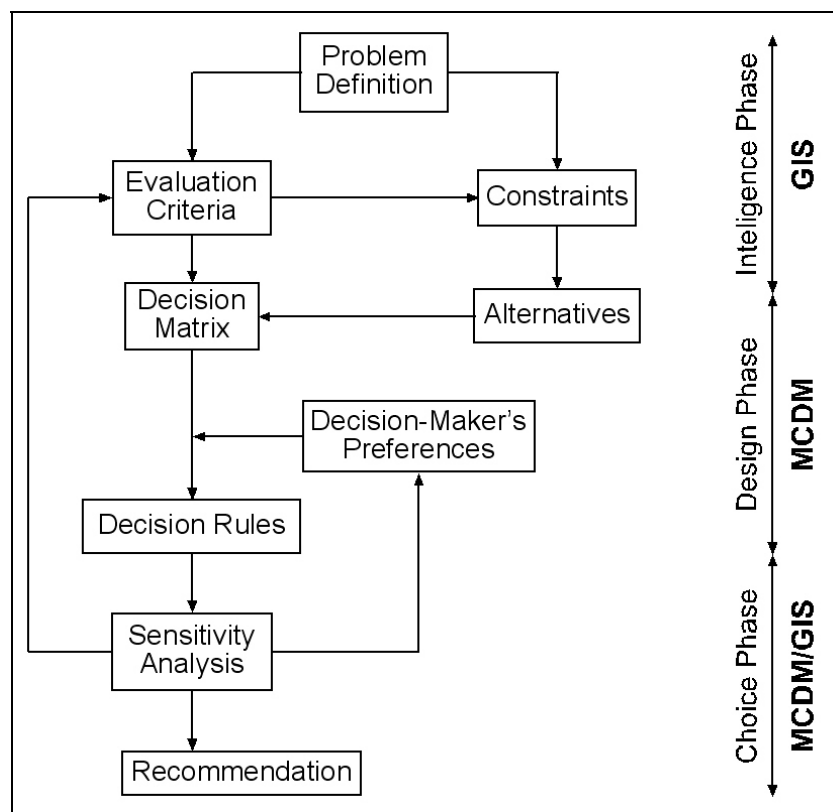
The distinction between MADM and MODM is based on the classification of evaluation criteria into attributes and objectives. An attribute is a measurable quantity or quality of a geographical entity or a relationship between geographical entities. An objective is a statement about the desired state of the system under consideration. It indicates the directions of improvement of one or more attributes. The decision modeling is outcome-oriented in MADM, and it is process-oriented in MODM. Furthermore MADM is relevant for evaluation/choice processes, while MODM is relevant for design/search processes.

The complexity of a particular MCDM (MADM or MODM) problem depends on the number of individuals (interest groups, decision makers) involved in the decision making process and the data and information available to handle the decision problem. To this end, MCDM can be categorized as single decision maker problems and group decision problems, and these two categories can, in turn, be subdivided into deterministic, probabilistic, and fuzzy decisions. The deterministic decision problems assume that the required data and information are known with certainty and there is a known deterministic relationship between every decision and the corresponding decision consequence. The probabilistic analysis deals with the decision situation under uncertainty about the state of the environment and about the relationship between the decision and its consequences. Whereas probabilistic analysis treats uncertainty as randomness and likelihood, it is also appropriate to consider the meaning of the information involved in decision making. Fuzzy decision analysis deals with the type of uncertainty.

Spatial multicriteria decision analysis can be thought of as a process that combines and transforms spatial and non-spatial data (input) into a resultant decision (output). The MCDM decision rules define a relationship between the input maps and the output map.

The procedures involve the utilization of geographical data, the decision maker's preferences, and the manipulation of the data and preferences according to specified decision rules. They aggregate multidimensional geographical data and information into one-dimensional values of alternative decisions. This implies that the results of the analysis depend not only on the geographical distribution of events (attributes) but also on the value judgments involved in the decision making process (Thill, 1999). Accordingly, two considerations are of critical importance for spatial multicriteria decision analysis: (i) the GIS capabilities of data acquisition, storage, retrieval, manipulation, and analysis, and (ii) the MCDM capabilities for aggregating the geographical data and the decision maker's preferences into uni-dimensional values of alternative decisions (Carver, 1991; Jankowski, 1995).

Framework of the spatial multicriteria decision analysis can be classified into 3 phases (intelligence, design and choice) as can be seen in Figure 2.2.



**Figure 2.2.** Framework for spatial multicriteria decision analysis (Malczewski, 1999).

Although each stage of the spatial multicriteria analysis involves both GIS and MCDM methodologies, the stages differ in terms of the degree to which these two methodologies are used (Janssen, 1992; Malczewski, 1999). In the earlier stages, GIS techniques play the major role, while in the latter stages the MCDM techniques are of major importance. This is related to the support offered by GIS and MCDM during the process of making a spatial decision. To this end, GIS should be considered as a special-purpose digital database in which a common spatial coordinate system is the primary means of storing and accessing data and processing the data to obtain information for decision making and that of an ultimate aim of GIS is to provide support for decision making decisions (Densham, 1991). This can be achieved by integrating the MCDM and GIS capabilities (Diamond and Wright, 1988; Keller, 1996; Carver, 1991; Eastman *et al.*, 1995; Jankowski, 1995 ). MCDM provides a methodology for guiding the decision maker(s) through the critical process of clarifying evaluation criteria (attributes and/or objectives), and of defining values that are relevant to the decision situation. Since the spatial decision making typically involves a large number of alternatives evaluated on the basis of multiple and conflicting criteria, some systematic method of identifying the best alternatives (of classifying or ranking the alternatives) is required. MCDM methods are designed to help the decision maker under these conditions. They provide the means of performing complex trade-offs on multiple evaluation criteria while taking the decision maker's preferences into account (Hobbs, 1980; Goicoechea *et al.*, 1982). The major elements involved in the spatial multicriteria decision analysis (Figure 2.2.) are explained below (Thill, 1999):

Problem definition:

A problem definition as a situation where individual or group perceives a difference between a present state and a desired state. Problem recognition involves the following questions; which of the real-world entities should be observed, selected, filtered, classified, and recorded as data items and which items are relevant to subsequent spatial decision problems.

Evaluation Criteria:

This step involves specifying:

- A comprehensive set of objectives that reflects all concerns relevant to the decision problem,
- Measures for achieving those objectives. Such measures are called attributes.



The attributes are associated with geographical entities and relationships between entities and therefore can be represented in the form of maps. For this reason, the evaluation criterion maps are also referred to the attribute maps (or thematic maps or data layers in the GIS terminology).

Evaluation criteria should be *complete* (the attributes should cover all aspects of a decision problem), *operational* (they can be meaningfully used in the analysis), *decomposable* (they can be broken into parts to simplify the process), *non-redundant* (they avoid problems of double counting), and *minimal* (the number of criteria should be kept as small as possible).

### Alternatives and Constraints

Decision alternatives are the alternative courses of action among which the decision maker must choose. Each spatial decision alternative consists of at least two basic elements: *action* (what to do?) and *location* (where to do it?). An alternative is completely specified by defining the values of the decision variables. In other words, to each alternative there is assigned a decision variable. The constraints determine the set of feasible alternatives. From the GIS perspective, the constraints are used to eliminate objects characterized by certain attributes and/or certain values of attributes from consideration.

### Criterion Weights

Multicriteria Decision Problems involve criteria of different importance; therefore it is required to have information about the relative importance of each criterion. This is usually achieved by assigning to each criterion a weight that indicates the criterion importance relative to the other criteria under consideration.

In the case of  $n$  criteria, a set of weights can be defined as follows:

$$W = (w_1, w_2, \dots, w_n) \text{ where } w_i \geq 0 \text{ and } \sum w_i = 1$$

Some of the most popular procedures include Ranking, Rating, Pairwise Comparison, and Trade-Off Analysis as explained below (Malczewski, 1999). The procedures differ in terms of their accuracy, easiness to use, and theoretical foundation.

- *Ranking Methods*

Ranking methods have the simplest procedure in which every criterion is ranked in the order of decision maker's preferences such as:

- Straight ranking (most important=1, second important=2,...) or,
- Inverse ranking (least important=1, next least important=2,...)

The most widely used ranking methods are; Rank Sum, Rank Reciprocal and Rank Exponent Methods.

The advantage of ranking methods is its simplicity to apply, and the disadvantages are lack of theoretical foundation and when the larger the number of criteria used, the method becomes less appropriate.

- *Rating Methods*

The rating methods require the decision maker to estimate weights on the basis of a predetermined scale such as a scale of 0 to 100 can be used.

One of the simplest rating methods is the Point Allocation approach. This approach 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. This method is modified to form the Ratio Estimation procedure. In this method,

- A score of 100 is assigned to the most important criterion. Proportionately smaller weights are then given to criteria lower in the order.
- The score of each criterion is divided by the lowest score. As a result this ratio expresses the relative desirability of a change from the worst level.

The disadvantages of these methods are cited as: lack of theoretical foundation, assigned weights might be difficult to justify and ignorance of the definition of the unit and zero

- *Pairwise Comparison Method*

This method involves pairwise comparisons to create a ratio matrix and takes pairwise comparisons as input and produces the relative weights as output. The

weights are determined by normalizing the eigenvector associated with the maximum eigenvalue of the ratio matrix. This method involves 3 steps:

- development of a comparison matrix
- computation of the weights
- estimation of the consistency ratio

One of the advantages of this method is only two criteria have to be considered at a time. In addition it can be incorporated into GIS-based decision-making procedures (Eastman *et al.*, 1993; Jankowski, 1995). Whereas the disadvantages of using Pairwise Comparison method are as follows:

- The questions simply ask for the relative importance of evaluation criteria without reference to the scales on which the criteria are measured
- If many criteria are being compared the method may get very large (With  $n$  criteria, it involves  $n(n-1)/2$  comparisons)
- time consuming computations

Although the method involves time consuming computations, fortunately computer programs can perform all the necessary calculations. EXPERT CHOICE is one of the most popular software packages for the pairwise comparison procedure (Expert Choice, Inc., 1993). Also the method can easily be implemented in a spreadsheet environment (Kirkwood, 1997).

- *Trade-off Analysis Method*

This method makes use of direct assessments of trade-offs that the decision maker is willing to make between pairs of alternatives (Hobbs, 1980; Rowe and Pierce, 1982; Lai and Hopkins, 1989). 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. The approach requires the decision makers to compare two alternatives with respect to two criteria at a time and assess which alternative is preferred. It is assumed that the trade-offs the decision maker makes between any two criteria do not depend on the levels of other criteria.

The disadvantages of this method are:

- Difficult to use when the criteria are subjective ratings

- The decision maker is presumed to obey the axioms and can make fine grained in difference judgments

- *Comparing the Methods*

The comparison of the Ranking, Rating, Pairwise Comparison and Trade-off Analysis procedures are summarized in Table 2.1. according to Malczewski, 1999.

It can be noted that all techniques can be implemented within the spreadsheet environment (Kirkwood, 1997). The pairwise comparison method is one of the most effective techniques for spatial decision making including GIS based approaches (Eastman, 1993; Malczewski 1997). In addition, the pairwise comparison matrix is insignificantly different from the trade-off method in effectiveness. The pairwise comparison method is better than the trade-off approach with respect to time (Lai and Hopkins, 1995).

**Table 2.1.** Summary of methods for assessing criterion weights. (Malczewski, 1999)

<b>Methods/ Features</b>	<b>Ranking</b>	<b>Rating</b>	<b>Pairwise Comparison</b>	<b>Trade-off Analysis</b>
<b>Number of judgments</b>	n	n	$n(n-1)/2$	$<n$
<b>Response scale</b>	Ordinal	Interval	Ratio	Interval
<b>Hierarchical</b>	Possible	Possible	Yes	Yes
<b>Underlying theory</b>	None	None	Statistical / heuristic	Axiomatic / deductive
<b>Ease of use</b>	Very easy	Very easy	Easy	Difficult
<b>Trustworthiness</b>	Low	High	High	Medium
<b>Precision</b>	Approximations	Not precise	Quite precise	Quite precise

### Decision Rules

Decision rules help to decide which alternative is preferred to another. It integrates the data and information on alternatives and decision maker's preferences into an overall assessment of the alternatives.

As known, any spatial decision-making problem involves a set of objectives, a set of attributes, or both. Central to the distinction between spatial MADM and spatial MODM is the way in which the decision alternatives and the attribute-objective relations are specified. Accordingly, spatial multicriteria decision rules can be categorized into multiattribute and multiobjective decision rules. The aim of MADM analysis is to choose the best or the most preferred alternative, to sort out alternatives that seem 'good' and/or to rank the alternatives in descending order of preference. There are numerous number of decision rules that can be used for tackling the MADM problem. Additive decision rules are the best known and most widely used MADM methods in GIS-based decision making. Three additive MADM methods are the *simple additive weighting method*, *value/utility function approaches*, and *the analytic hierarchy process* (Malczewski, 1999). In Table 2.2, the properties of these 3 methods and in addition the Ideal Point Method, Concordance Method, and Ordered Weighted Averaging Method are summarized in a comparative manner.

In MADM methods the attributes serve as both decision variables and decision criteria, in the MODM approaches a distinction is made between decision criteria (objective functions) and decision variables. MODM decision rules define the set of alternatives in terms of a decision model consisting of a set of objective functions and a set of constraints imposed on the decision variables (Malczewski, 1999). In Table 2.3., the properties of the Value/Utility Models, Goal Programming, Interactive Programming, Compromise Programming, and Data Envelopment Analysis are summarized in a comparative manner.

**Table 2.2.** Multiattribute Decision Rules. (Modified from Malczewski, 1999)

<b>MADM Method</b>	<b>Scoring (SAW)</b>	<b>Multiattribute value / utility</b>
<b>Input</b>	Attribute scores, weights	Value / utility functions, weights
<b>Output</b>	Ordinal ranking	Cardinal ranking
<b>Decision Types</b>	Individual DM, deterministic	Individual and group DMs, deterministic, fuzzy
<b>DM Interaction</b>	Moderate	High
<b>Assumptions</b>	Nonrestrictive	Very restrictive
	1)linearity 2)additivity	1)preferential independence 2)utility independence
<b>Based on :</b>	concept of weighted average	multiattribute utility theory
<b>Advantages</b>	1)easy to use  2)quite widely applied in real world	decision maker focus initially on deriving utility function for one attribute at a time without worry about the other attributes
<b>Disadvantages</b>	little theoretical foundation unit measurement ignorance	1)impractical 2)time consuming 3)decision maker → considerable inf processing 4)utility and preferential independence will not be met in real life  5)neglects the existance of spatial relationships among spatial alternatives

**Table 2.2 (continued).** Multiattribute Decision Rules. (Modified from Malczewski, 1999)

<b>MADM Method</b>	<b>Analytic hierarchy process</b>	<b>Ideal point</b>
<b>Input</b>	Attribute scores, pairwise comparisons	Attribute scores, weights, ideal point
<b>Output</b>	Cardinal ranking (ratio scale)	Cardinal ranking
<b>Decision Types</b>	Individual and group DMs, deterministic, probabilistic, fuzzy	Individual and group DMs, deterministic, probabilistic, fuzzy
<b>DM Interaction</b>	High	Moderate
<b>Assumptions</b>	Moderately restrictive	Nonrestrictive
	reasonable judgment	quantitative information on attributes
<b>Based on :</b>	3 principles: decomposition, comparative judgment, synthesis of priorities	the separation from an ideal point
<b>Advantages</b>	1)flexible, 2)easy to use  3) incorporated in GIS environment 4) widespread use	alternative → inseparable bundle of attributes  Attractive approach when the dependency among attributes difficult to verify
<b>Disadvantages</b>	1) ambiguity in relative importance 2) the use of a 1 to 9 scale 3) inconsistent judgments of decision makers 4) meaningless questions during pairwise comparisons 5) large problems → too many pairwise comparisons	

**Table 2.2 (continued).** Multiattribute Decision Rules. (Modified from Malczewski, 1999)

<b>MADM Method</b>	<b>Concordance (outranking)</b>	<b>Ordered weighted averaging</b>
<b>Input</b>	Attribute scores, weights	Fuzzy attribute, weights, order weights
<b>Output</b>	Partial or ordinal ranking	Cardinal or ordinal ranking
<b>Decision Types</b>	Individual and group DMs, deterministic, probabilistic, fuzzy	Individual and group DMs, fuzzy
<b>DM Interaction</b>	Moderate	Moderate
<b>Assumptions</b>	Nonrestrictive	Moderately restrictive
<b>Based on :</b>	pairwise comparison	fuzzy set aggregation
<b>Advantages</b>	1)considers both objective and subjective criteria 2)least amount inf from decision maker	
<b>Disadvantages</b>	1)complete ranking may not be achieved 2)cannot be implemented by using cartographic modelling	implication for the interpretation of decision uncertainty



**Table 2.3.** Multiobjective Decision Rules. (Modified from Malczewski, 1999)

<b>MODM Method</b>	<b>Value/utility models</b>	<b>Goal programming</b>	<b>Interactive programming</b>
<b>Input</b>	Value/utility functions, weights	Aspiration levels, priorities, weights	Aspiration, reservation
<b>Output</b>	Best alternative	Best alternative	Satisfying alternative
<b>Types of Decisions</b>	Individual DM, deterministic, probabilistic	Individual DM, deterministic, fuzzy	Individual DM, deterministic, fuzzy
<b>DM Interaction</b>	Moderate/high	High	Moderate, increases with problem size
<b>Assumptions</b>	Very restrictive	Very restrictive	Moderately restrictive
	1) decision maker behaves according to the value/utility max decision rule; 2) existence of individual or value/utility function; 3) preferential independence; 4) utility dependence		existence of a utility / value function
<b>Based on :</b>	multiattribute utility theory	a form of linear programming	
<b>Advantages</b>	1) software and experience that currently exist for single objective optimization  2) can be applied directly to tackle MCDA	1) computational efficiency 2) incorporated into GIS procedures by integrating standard  3) mathematical programming software such as LINDO	1) do not require priori inf 2) aspiration/reservation method uses only well defined control parameters 3) whereas goal programming requires that one must also specify some weights 4) although fewer control parameters → always efficient solution unlike goal programming.
<b>Disadvantages</b>	difficult to construct value/utility function	1) detailed inf from decision maker 2) The cardinal weight and lexicographic methods → strong tendency to generate 3) inefficient solutions. Inefficiency problem seriously limits the utility 4) difficult when the goals are unrelated 5) poor controllability in the case of discrete problems	

**Table 2.3 (continued).** Multiobjective Decision Rules. (Modified from Malczewski, 1999)

<b>MODM Method</b>	<b>Compromise programming</b>	<b>Data envelopment analysis</b>
<b>Input</b>	Ideal point, weights	Set of evaluation inputs and outputs
<b>Output</b>	Compromise alternative, cardinal ranking	Cardinal ranking
<b>Types of Decisions</b>	Individual and group DMs, probabilistic, fuzzy	Individual and group DMs, deterministic, probabilistic, fuzzy
<b>DM Interaction</b>	Moderate	Low
<b>Assumptions</b>	Moderately restrictive	Moderately restrictive
	choice among alternatives depends on the point of reference	
<b>Based on :</b>	displaced ideal concept	hypothesis underlying → multiple incommensurate inputs in a given spatial unit generate multiple incommensurate outputs in that unit
<b>Advantages</b>	simple conceptual structure	can be performed spreadsheet based linear programming environment  Input data can be represented as a set of data layers in a GIS database  The results (efficiency measures) can be visualized in the form of a map.
<b>Disadvantages</b>	no clear interpretation of the various values of the parameter $p$ . Therefore, the selection of the best alternative within the reduced set of compromise alternatives must be made based on intuition	The information requirements are high

### Sensitivity Analysis

Analysis should be carried out to investigate whether preliminary conclusions are robust or if they are sensitive to changes in aspects of the model. Changes may be made to investigate the significance of missing information, to explore the effect of decision maker's uncertainty about their values or priorities or to offer a different perspective on the problem. Sensitivity analysis concerns with the way errors in a set of input data affect the final output (criterion outcomes). To be more specific, the analysis aims at identifying the effects of changes in the inputs (geographical data and the decision maker's preference) on the outputs (ranking of alternatives). If the changes do not significantly affect the outputs, the ranking is considered to be robust. If the current result is found to be unsatisfactory, the information about the output can be used to return to the problem formulation step (Belton and Stewart, 2002).

### Recommendation

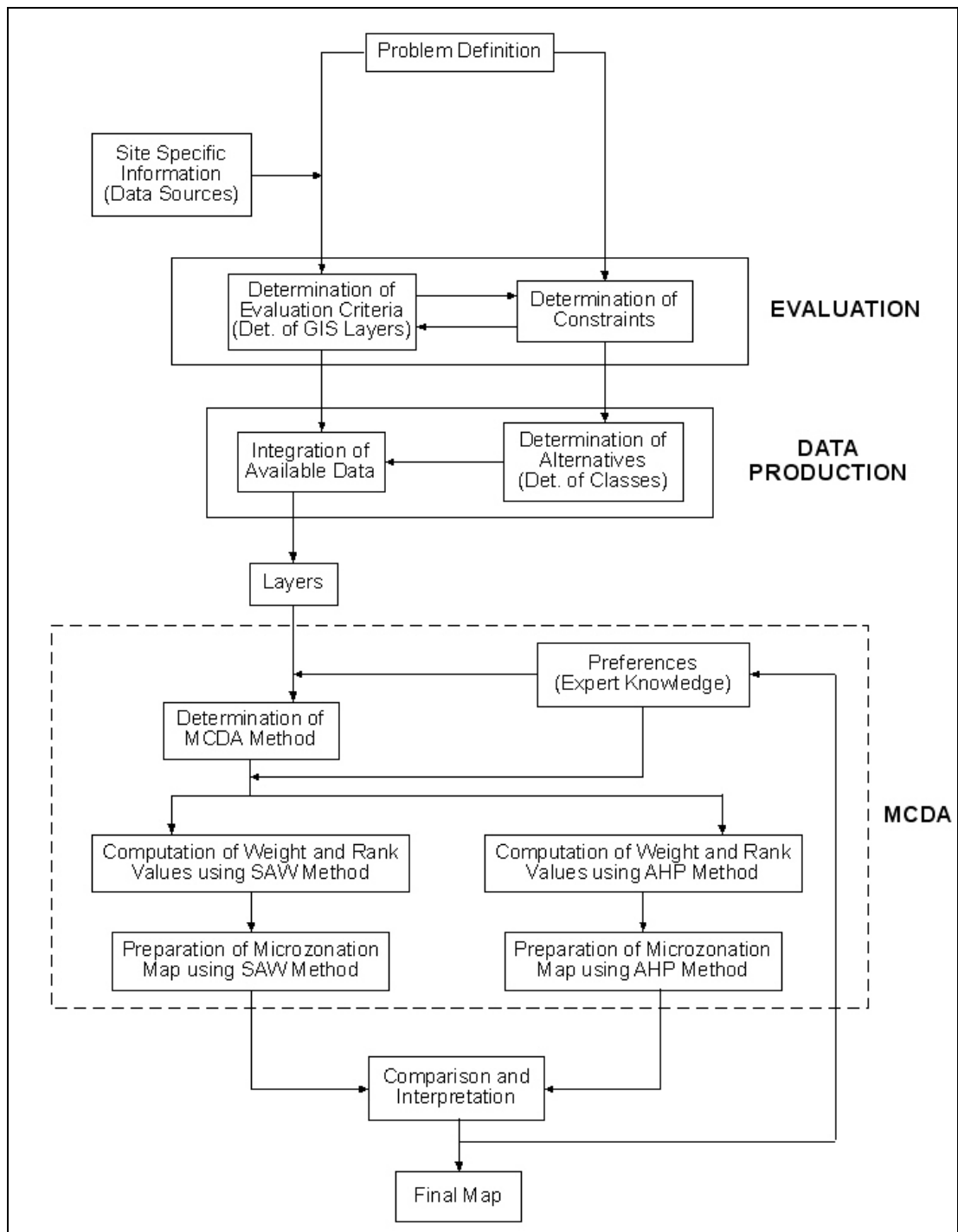
At the end of the decision making process, recommendation part is achieved. The recommendation should be based on the ranking of alternatives and the sensitivity analysis. It may include the description of the best alternative, or a group of alternatives.

## **CHAPTER 3**

### **METHODOLOGY**

#### **3.1. Implementation of Multicriteria Decision Analysis**

In this section, the application of Multicriteria Decision Analysis (MCDA) for the preparation of microzonation map of the study area is explained through the flowchart given in Figure 3.1. The main steps of the study are explained according to the flowchart diagram below:



**Figure 3.1.** Flowchart for the preparation for the microzonation map of study area using MCDA.

### **3.1.1. Problem Definition**

The problem in this study is defined as the preparation of the microzonation map regarding the suitability of the residential areas using GIS-based MCDA for Eskişehir downtown.

### **3.1.2. Site Specific Information**

In this step, the data sources of the study are revealed. The input data can be grouped in four main data sources (topographical maps, lithology map, borehole data and satellite images) as explained in detail in Chapter 4.

### **3.1.3. Evaluation**

This step involves the *determination of GIS layers* and the *determination of constraints* interactively. At the end of this step, the data that will be used for the preparation of the microzonation map are revealed. During this evaluation, the former step (site specific information) should also be reconsidered if necessary. The GIS layers are determined as slope, flood susceptibility, soil, depth to groundwater table, swelling potential and liquefaction potential, as explained in Chapter 4.

### **3.1.4. Data Production and Layers**

The *data production* step involves the *determination of the classes of each layer* and *integration of the available data* which is explained in detail in Chapter 4. At the end of the *data production* step, the *layers* are obtained in the form to be used in *multicriteria decision analysis* explained in the proceeding step of the study.

### 3.1.5. Multicriteria Decision Analysis (MCDA) and Results

The purpose of this step is to prepare the microzonation map by using the layers obtained, with Multicriteria Decision Analysis (MCDA). The *MCDA* step involves *preferences (expert knowledge), determination of MCDA methods, computation of weight and rank values and preparation of the microzonation maps* using the determined MCDA methods.

In this study, the Simple Additive Weighting (SAW) and Analytical Hierarchical Process (AHP) methods are used in the computation of the weight and rank values. According to these computed values, microzonation maps are prepared. This MCDA step is explained in detail in Chapter 5, but the theoretical explanation of the two MCDA methods that are used in the preparation of the microzonation maps are given in the following sections (section 3.1.5.1 and section 3.1.5.2).

The *results* step includes the comparison and interpretation of two microzonation maps obtained as a result of MCDA methods used. The comparison of the results is given in detail in Chapter 5, and the interpretation of the results is explained in the Discussion chapter.

#### 3.1.5.1. Simple Additive Weighting Method (SAW)

SAW method, also referred as weighted linear combination (WLC) or scoring methods is the most often used techniques for tackling spatial MADM. It is based on the concept of a weighted average. The decision maker directly assigns the weights of 'relative importance' to each thematic map layer. A total score is then obtained for each alternative by multiplying the importance weight assigned for each attribute by the scaled value given to the alternative of that attribute, and summing the products over the attributes. When the overall scores are calculated for all of the alternatives, the alternative with the highest score is chosen (Thill, 1999).

The decision rule evaluates each alternative,  $A_i$ , by the following formula (Malczewski, 1999):

$$A_i = \sum_j w_j x_{ij}$$

where  $x_{ij}$  is the score of the  $i^{\text{th}}$  alternative with respect to the  $j^{\text{th}}$  attribute, and the weight  $w_j$  is the normalized weight ( $w_j = 1$ ). The weights represent the relative importance of the

attributes. The most preferred alternative is selected by identifying the maximum value of  $A_i$  ( $i=1,2,\dots,m$ ).

The steps of GIS-based SAW method can be summarized as follows:

1. Define the layers and classes of these layers,
2. Assign rank values to the classes of the layers,
3. Standardize the rank values,
4. Assign weight values to each layer,
5. Normalize the weight values assigned,
6. Calculate the  $A_i$  score given in the mentioned formula,
7. Evaluate the alternatives according to the overall performance score.

The method can be operationalized using any GIS system having overlay capabilities. The overlay techniques allow the evaluation criterion map layers (input maps) to be aggregated in order to determine the composite map layer (output map).

It should be emphasized that, there are two strong assumptions implicit in the SAW method; the linearity and additivity of attributes. The linearity assumption means that the desirability of an additional unit of an attribute is constant for any level of that attribute. (Ex: 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). The additivity assumption means that, there is no interaction effect between attributes. This independence of attributes means that no correlation between two attributes can be found (Malczewski, 1999; Lai and Hopkins, 1989).

SAW method is found easy to apply and it is quite widely applied in real world, however, it is criticized for having little theoretical foundation and its ignorance of the definition of the units of measurement.

### **3.1.5.2 Analytical Hierarchical Process (AHP)**

AHP is a method developed to produce a ranking of decision alternatives with a mathematical structure. The essential idea is to find weights through pairwise comparisons of attributes and in addition to find rank values through pairwise comparisons of alternatives for each attribute (Marshall and Oliver, 1995).



The aim of this method is to derive quantitative weights from qualitative statements on the relative importance of criteria obtained from comparison of all pairs of criteria (Janssen, 1992).

It is essential that a credible decision theory yields unique answers for the alternatives of a decision, perhaps not only in terms of ranks, but also in terms of priorities. AHP is a theory of measurement concerned with deriving dominance priorities from paired comparisons of homogenous elements with respect to a common criterion or attribute (Saaty, 1994; Saaty and Hu, 1998).

This method, developed by Saaty in 1980, is based on 3 principles: Decomposition, Comparative Judgment, and Synthesis of Priorities. The decomposition principle requires that the decision problem be decomposed into a hierarchy that captures the essential elements of the problem. The principle of comparative judgment requires assessment of pairwise comparisons of the elements within a given level of the hierarchical structure, with respect to their parent in the next-higher level. The synthesis principle takes each of the derived ratio-scale local priorities in the various levels of the hierarchy and constructs a composite (global) set of priorities for the elements at the lowest level of the hierarchy (i.e. alternatives) (Malczewski, 1999).

The additive decision rules are appropriate for a single level of criteria. If the hierarchy of the criteria has more than one level, AHP should be used. In AHP method it is assumed that the decision maker is able to make reasonable judgments. The advantages and disadvantages of AHP method is given in Table 3.1 below (Thill, 1999; Malczewski, 1999; Siddiqui *et al.* 1996).

**Table 3.1.** Advantages and disadvantages of AHP method

Advantages	Disadvantages
flexibility	ambiguity in relative importance
easiness to use	the use of a 1 to 9 scale
availability of software	for problems having large number of criteria, too many pairwise comparisons must be performed
incorporation into GIS environment	
widespread use	

AHP procedure involves 3 major steps: Developing the AHP Hierarchy, Comparing the Decision Elements on a Pairwise Base, Construction an Overall Priority Rating.

- Developing the AHP Hierarchy: In developing a hierarchy, the top level is the ultimate goal of the decision at hand. The alternatives are represented in GIS databases. Each layer contains the attribute values assigned to the alternatives, and each alternative is related to the higher-level elements (attributes).
- Comparing the Decision Elements on a Pairwise Base: Pairwise comparisons are the basic measurement tools in the AHP procedure. This procedure involves 3 steps :
  - Development of a comparison matrix at each level of the hierarchy,
  - Computation of the weights for each element,
  - Estimation of the consistency ratio.

In the computation of the weights, the usage of eigenvector is strongly recommended. It is shown that the principal eigenvector is a necessary representation of the priorities derived from a positive reciprocal pairwise comparison judgment matrix (Saaty, 2003).

- Construction an Overall Priority Rating: The final step is to aggregate the relative weights of the levels obtained in the second 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. The overall score  $R_i$  of the  $i^{\text{th}}$  alternative is the total sum of its ratings at each of the levels and is thus computed in the following way :

$$R_i = \sum_k w_k r_{ik}$$

where  $w_k$  is the vector of priorities associated with the  $k^{\text{th}}$  element of the criterion hierarchical structure,  $\sum w_k = 1$  ; and  $r_{ik}$  is the vector of priorities derived from comparing alternatives on each criterion. The most preferred alternative is selected by identifying the maximum value of  $R_i$  (  $i = 1, 2, \dots, m$  )

## CHAPTER 4

### DATA EVALUATION

#### 4.1. Available Data and Parameter Selection

In this chapter, the input data sources, data production methods and steps to obtain the layers that will be used in the analysis are explained in detail. The data used in this study can be grouped in four main data sources:

1. Topographical maps
2. Lithology map
3. Borehole data
4. Satellite images

The slope, flood, soil, depth to groundwater table, swelling and liquefaction layers are determined to be used in the analysis for obtaining the microzonation map regarding the suitability of the residential areas.

By using the topographical maps, slope and flood layers of the study area are obtained, while the depth to groundwater table, swelling and liquefaction layers are prepared by using the borehole data. The soil layer of the study area is obtained through combination of lithology map and borehole data.

The properties of these aforementioned layers, sources of the data used and the data production processes are explained in the following section (Section 4.2).

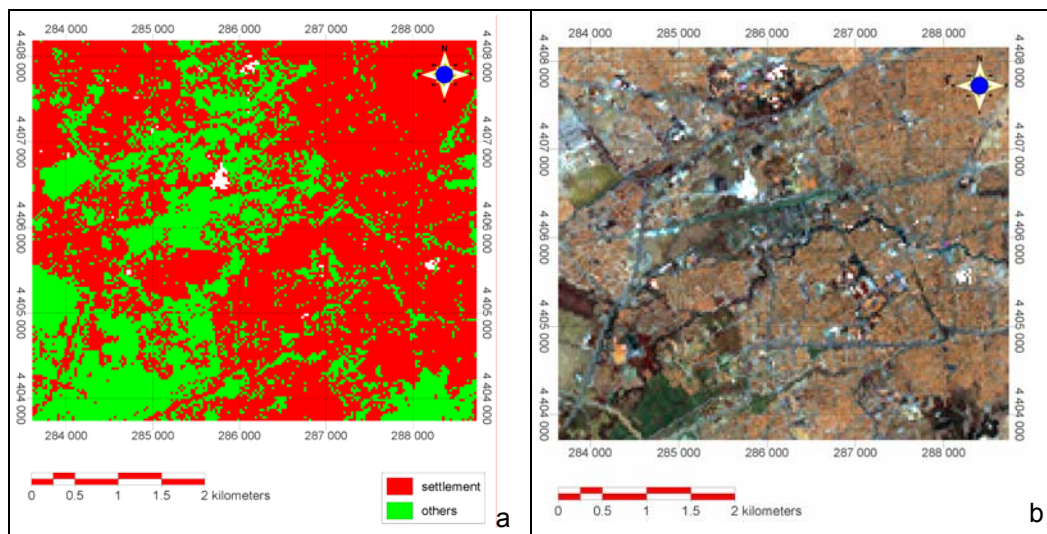
The fourth data source, Landsat ETM satellite images are analyzed to obtain the landcover map of the study area, because it is important to evaluate the suitability of the areas for the preparation of the microzonation map.

In order to identify the exact portion of the settlement areas, the evaluation of “settlement” and “others” classification is performed before preparation of the landcover

map. Therefore, a supervised classification method (Maximum Likelihood) is used to obtain the “settlement” and “others” classes.

The maximum likelihood method determines a class assignment for each cell on the basis of both the variance and correlation of the cell values in the training set classes that user provides. The Maximum Likelihood algorithm interprets the cell values in each training set class as having a Gaussian (normal) distribution. The distribution therefore can be described by the mean vector and the covariance matrix. The likelihood of a given cell value belonging to a particular training set class can be determined using these statistics. (TNTmips – Reference Manual)

In the result of this classification, very large portion of the study area is classified as settlement areas, as seen in Figure 4.1a. The settlement areas can also be observed from the original (RGB:531) satellite image, given in Figure 4.1b. Since the study area includes mainly the settlement areas, it is concluded that the use of landcover map as a layer in the analysis would not contribute to the microzonation map.



**Figure 4.1.** a) Result of classification, b) Special color composite (RGB:531)

## **4.2. Data Sources and Layers**

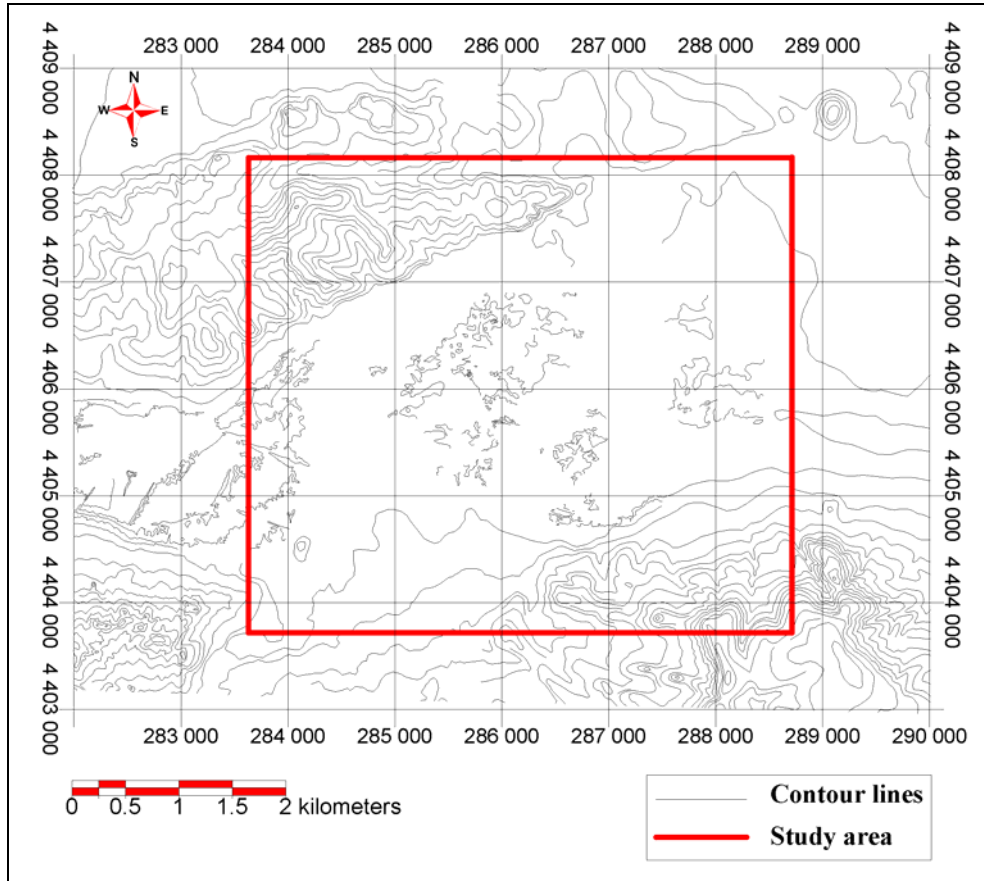
### **4.2.1. Topographical Map**

1:25000 scale topographical map is obtained from Ayday *et al.* (2001), and 1:5000 scale topographical maps are obtained from the İller Bankası (Bank of Provinces). These maps are registered according to the Universal Transverse Mercator (UTM) projection system (Zone: 36 & Datum: European 1950 – Mean), and used to obtain the Digital Elevation Model of the study area.

#### **4.2.1.1. Digital Elevation Model (DEM)**

Digital Elevation Model (DEM) is a representation of the topography of the Earth in digital format, that is, by coordinates and numerical descriptions of altitude. In the preparation of the DEM of the study area, firstly the contours on the 1:25000 scale topographic map have been digitized. Since the settlement areas are concentrated especially in the middle section of the study area, the contour lines could not be traced in this section. Thus the DEM of the study area could not be performed by using only the traced contours of the 1:25000 scale topographical map, since the information in the middle section is not satisfactory for the formation of the surface for the study area. The needed information is obtained from the 1:5000 scale topographic maps on which the contour lines for the middle section were available.

The map showing the digitized contour lines with the study area boundary is given in Figure 4.2. After assigning the values (from 1:25000 scale topographical maps – 10m contour interval (5m when needed) and from 1:5000 scale topographical maps – 1m contour interval) to the digitized contour lines, the cell size of the surface which will be created using the contours should be determined before the surface fitting process.



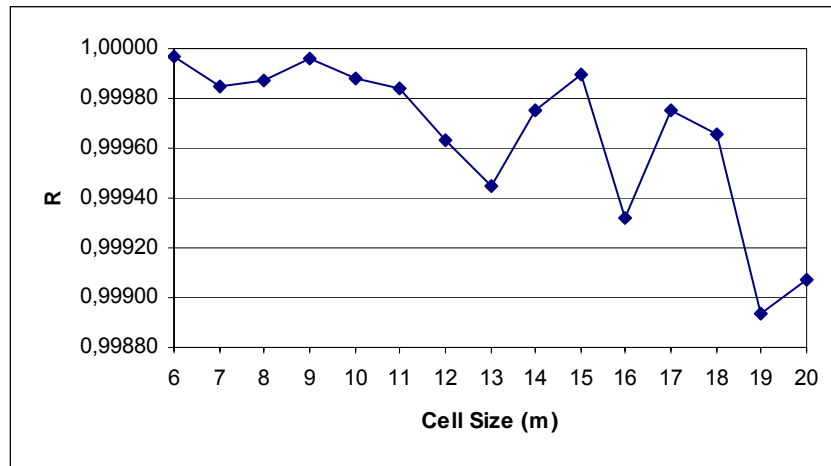
**Figure 4.2.** The digitized contour lines and the study area boundary.

The cell size of the DEM is determined by the method proposed by Florinsky and Kuryakova (2000). In this method, the following procedures must be carried out in order to define the adequate DTM (Digital Terrain Model) grid size ( $w$ ):

- Derive a set of DTMs using a series of  $w_i$ ,
- Perform a correlation analysis of data on a landscape property and a topographic variable estimated with various  $w_i$ ,
- Plot correlation coefficients between the landscape property and the topographic variable versus  $w_i$ ,
- Determine smoothed portions of the plot obtained which indicate intervals of adequate  $w_i$ .

The above method is applied to various cell sizes using triangulation surface fitting method. The Triangulation method creates an elevation raster object from vector point elements, database points, or TIN nodes. The Triangulation algorithm constructs an irregular triangular grid using the points or nodes as triangle vertices. Each triangle in the grid meets the Delaunay criterion, that is, a circle drawn through the vertices of a triangle encloses no other input points. This triangular grid thus has actual data points at the grid intersections (vertices), whereas the rectangular grid of other Surface Fitting methods usually does not. The method then fits a planar surface to each triangle so that the overall surface is modeled as a collection of triangular planar facets. The algorithm computes extrapolated points beyond the edges of those input objects with edges that are not well-defined. These external points are needed to ensure all cells within the specified raster dimensions are covered by the triangulation. (TNTmips - Reference Manual)

The triangulation surface fitting method is applied for the determination of the cell size, since the method does not allow the user to change the parameters, therefore the results are not user dependent. Cell sizes of 6 to 20 are used to determine the adequate cell size. The cell sizes smaller than or equal to 5 are not considered since the topographical contours are mainly digitized from the 1:25000 scale topographical map. This map has the accuracy of the 5 m intervalled contour lines, therefore the accuracy of the output could not be smaller than the input map. The correlation coefficients versus cell sizes graph is given in Figure 4.3. To determine the adequate cell size, smoothed portions of the graph should be used. According to the graph, since the smoothest portion of the graph is found to be around 10 m, the adequate cell size for the DEM of the study area is determined as 10 m.



**Figure 4.3.** The correlation coefficients versus cell sizes graph.

After the determination of the cell size, various surface fitting methods are applied to understand which method is the most appropriate in the preparation of the DEM of the study area. To be able to apply some of these methods, the line data is converted to point data. The applied surface fitting methods using the line data are; minimum curvature, inverse distance, and profiles. On the other hand the applied surface fitting methods using the point data are; minimum curvature, inverse distance, polynomial, triangulation and kriging. The triangulation operation with Delaunay method also applied to the both line and point data, and then the surface fitting operation with linear method is applied to the obtained data.

Inverse distance (using both line and point data) and polynomial methods are eliminated since these methods have some errors so that they could not represent the study area properly. The other performed methods are evaluated according to their accuracy in order to decide the most appropriate method that represents the data best. Consequently, the profiles and minimum curvature methods are chosen to be used.

The Profiles method uses a multi-directional linear interpolation algorithm for surface fitting. First the algorithm computes a raster grid using the input object extents and the specified cell size. Raster cells that are crossed by an input vector contour line are then assigned the associated surface value. From the lines that reach the edge of the raster, a value is computed for each remaining edge cell using linear interpolation parallel to the edge. The process then interpolates values for all remaining cells in the raster. For each of these cells, the algorithm searched in eight different directions for the closest cells



with assigned values (including edge cells within a specified search distance. From these it selects the pair of cells (on opposite sides of the output cell) that are closest to the output cell location, and uses linear interpolation to calculate the output cell values. The final step in the Profiles method is smoothing. The algorithm uses a 3-by-3 low pass kernel as a spatial smoothing filter. (TNTmips - Reference Manual)

The Minimum Curvature algorithm works in two stages, initialization and iteration. In the initialization stage, the Minimum Curvature method applies a 2D cubic spline function to the set of input elevation values and fits a smooth surface to the elevation values. Once initialization is completed, iterations of the algorithm adjust output raster cell values so that a smooth, uniformly representative surface is produced. (TNTmips - Reference Manual)

The accuracy evaluation for DEM is performed by the calculation of Root-Mean-Square Error (RMSE). For computing the RMSE, sample points are taken. The definition of RMSE and the clues for the determination of the sample points are given as follows in the USGS official web site (<http://rmmcweb.cr.usgs.gov/public/nmpstds/acrodcs/dem/2DEM0198.PDF>):

“The RMSE is defined as:

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

where  $Z_i$  = interpolated DEM elevation of a test point

$Z_i$  = true elevation of a test point

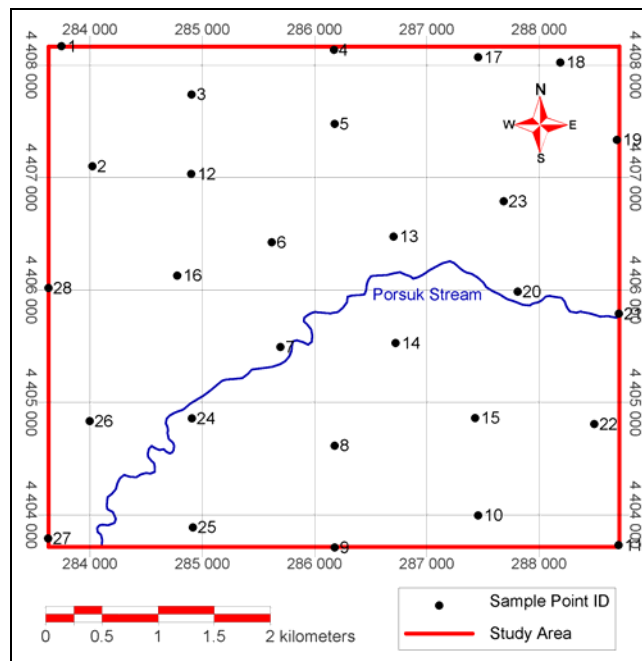
$n$  = number of test points

Test points should be well distributed, representative of the terrain, and have true elevations with accuracies well within the DEM accuracy criteria. Acceptable test points include, in order of preference: field control, aerotriangulated test points, spot elevations, or points on contours from existing source maps with appropriate contour interval. A minimum of 28 test points per DEM is required to compute the RMSE, which is composed of a single test using 20 interior points and 8 edge points. Edge points are those which are located along, at, or near the quadrangle neatlines and are deemed by the editor to be useful to evaluating the accuracy of the edge of the DEM.”

By taking into account the suggestions above, the 28 points (8 points in edges) on the contour lines are chosen to be the sample points, which are distributed in the study area as uniform as possible (Figure 4.4). The true and interpolated topographic values of the sample points are examined, and compared by calculating RMSE, to be able to decide

which interpolation method should be used. During the evaluation, it is decided that if the study area is divided into sections, and different methods are used for each section, then the accuracy of the DEM will increase. The differences between the topographical and the interpolated elevation values for profiles and minimum curvature surface fitting methods are given in Figure 4.5a and Figure 4.5b respectively. As can be observed from these two figures, the division of the study area into two sections will increase the accuracy of the DEM. The boundary of these two sections is given in Figure 4.6. The RMSE values are calculated, compared and evaluated separately for these two sections. The calculated RMSE values for different surface fitting methods for the section 1 and section 2 are given in Table 4.1 and Table 4.2 respectively. As a result, it is decided to use profiles surface fitting method for section 1 since the RMSE is minimum for profiles method in section 1. For section 2, although the minimum RMSE is in profiles method, the minimum curvature method, with second minimum RMSE value is preferred, because of the fact that profiles method has some errors within section 2. Examples for the mentioned error is shown in Figure 4.7.

Finally by integrating these two methods according to their sections, the DEM of the study area is formed (Figure 4.8). The RMSE value for the final DEM is calculated as 0,079209128 m.



**Figure 4.4.** The chosen sample points of the study area.

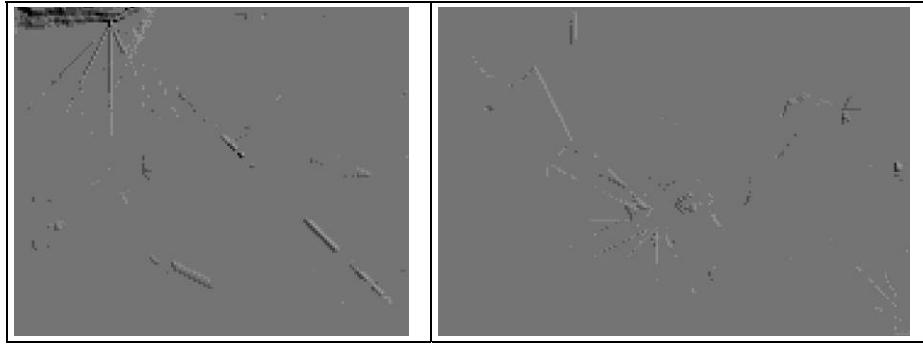


**Table 4.1.** The calculated RMSE values for different surface fitting methods for section 1.

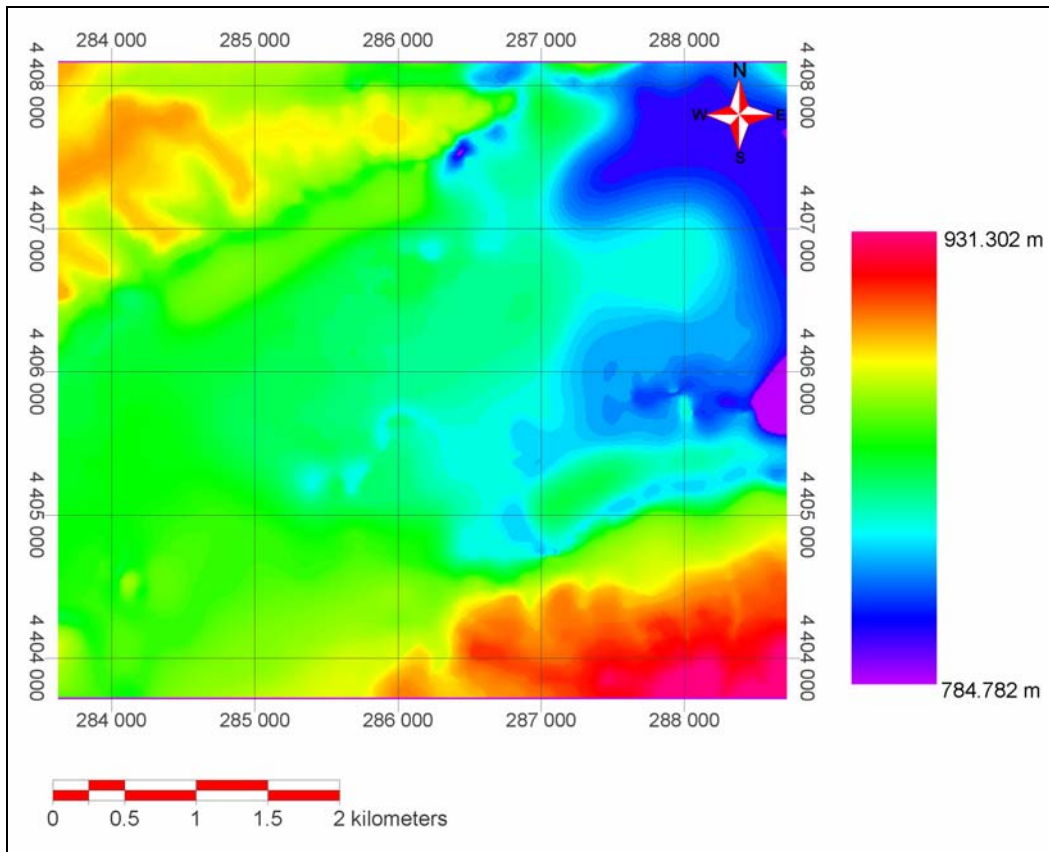
PointID	TOPO	mincurve_line	profiles	mincurve_point	triangle	kriging	TIN_line_linear	TIN_point_linear
1	820,00000000	820,00000000	820,00000000	820,19976807	820,00000000	820,19238281	820,00000000	820,00000000
2	810,00000000	810,00000000	810,00000000	810,00000000	810,49530029	810,40991211	810,49426270	810,49530029
3	810,00000000	810,00000000	810,00000000	810,18927002	809,86029053	810,03039551	809,86059570	809,86029053
9	825,00000000	825,74542236	825,72137451	826,05725098	825,79187012	825,91461182	825,79113770	825,79187012
10	860,00000000	860,00000000	860,00000000	859,57617188	859,35266113	858,75079346	859,35272217	859,35266113
11	930,00000000	930,00000000	930,00000000	930,12927246	929,42496779	929,16143799	929,42466572	929,42496779
12	800,00000000	800,00000000	800,00000000	800,75341797	800,52441406	800,77899170	800,52423096	800,52441406
22	810,00000000	810,00000000	810,00000000	810,70288086	809,82995605	809,37768555	809,82989502	809,82995605
<b>RMSE</b>		0,26354660	<b>0,25504440</b>	0,55357157	0,49314185	0,73316815	0,49283997	0,49314185

**Table 4.2.** The calculated RMSE values for different surface fitting methods for section 2.

PointID	TOPO	mincurve_line	profiles	mincurve_point	triangle	kriging	TIN_line_linear	TIN_point_linear
4	795,00000000	795,00000000	795,00000000	795,00000000	795,18597412	795,05487061	795,18585205	795,18597412
5	795,00000000	795,00000000	795,00000000	796,55065918	796,94274902	796,39282227	796,94104004	796,94274902
6	791,50000000	791,50000000	791,50000000	792,00000000	792,00000000	792,00000000	791,50000000	792,00000000
7	791,50000000	791,50000000	791,50000000	792,00000000	792,00000000	792,00000000	791,50531006	792,00000000
8	795,00000000	795,13543701	795,12054443	795,21441650	795,03332520	794,99151611	795,03332520	795,03332520
13	791,00000000	791,00000000	791,00000000	791,00000000	791,00000000	791,00000000	791,00000000	791,00000000
14	790,00000000	790,00000000	790,00000000	790,00000000	790,00000000	790,00000000	790,00000000	790,00000000
15	795,00000000	794,71502686	794,71661377	794,78430176	794,65649414	794,51947021	794,65655518	794,65649414
16	793,00000000	793,00000000	793,00000000	793,00000000	793,00000000	793,00000000	793,00000000	793,00000000
17	790,00000000	790,00000000	790,00000000	790,26666260	790,10980225	789,91107178	790,10949707	790,10980225
18	787,50000000	787,50000000	787,50000000	788,00000000	788,00885010	788,00000000	787,51110840	788,00885010
19	787,50000000	787,50054932	787,51696777	788,00091553	788,00067139	788,00000000	787,50079346	788,00067139
20	789,00000000	788,96374512	788,95428467	788,96289063	789,00000000	789,00000000	789,00000000	789,00000000
21	785,00000000	785,00000000	785,00000000	785,00000000	785,03027344	785,00000000	785,02528855	785,03027344
23	790,00000000	790,00097656	790,00000000	790,00146484	789,99774170	790,00000000	789,99719238	789,99774170
24	795,00000000	795,00000000	795,00000000	795,00292969	794,97613525	795,00000000	794,97613525	794,97613525
25	800,00000000	800,00000000	800,00000000	799,99432373	799,91815186	799,70782471	799,91815186	799,91815186
26	794,00000000	794,00000000	794,00000000	794,00000000	794,00000000	794,00000000	794,00000000	794,00000000
27	800,00000000	800,00000000	800,00000000	800,00000000	800,56286621	800,40924072	800,56311035	800,56286621
28	792,50000000	792,50000000	792,50000000	793,00000000	793,00000000	793,05908203	792,50000000	793,00000000
<b>RMSE</b>		<b>0,07101709</b>	0,06971962	0,43706346	0,52557741	0,43285510	0,46143214	0,52557741



**Figure 4.7.** Examples of the errors in profiles surface fitting method for section 2.



**Figure 4.8.** The digital elevation model (DEM) of the study area.

#### 4.2.1.2. Slope Layer

Slope is an important factor while considering the ease of engineering construction and susceptibility to landsliding (Dai *et al.*, 2001). Since there is not a slope stability problem in the study area (Koyuncu, 2001), the slope layer will not be used for susceptibility to landsliding, whereas it will contribute to the microzonation map in the aspect of the ease of engineering constructions, since high slopes cause excavation processes to become more difficult and also increases the cost of excavation.

The slope map is prepared in degrees using the DEM of the study area. The slope values are subdivided into three main classes according to the Guidelines for Urban Engineering Geological Investigations (South African Institute of Engineering Geologists). These classes are: Slopes between 2° and 6° will be in the most favorable class, slopes less than 2° and slopes between 6° and 12° will be in the intermediate class, and slopes greater than 12° will be in the least favorable class. The histogram of the slope map with the information of the distribution of the classes is given in Figure 4.9. The classified slope map of the study area is given in Figure 4.10.

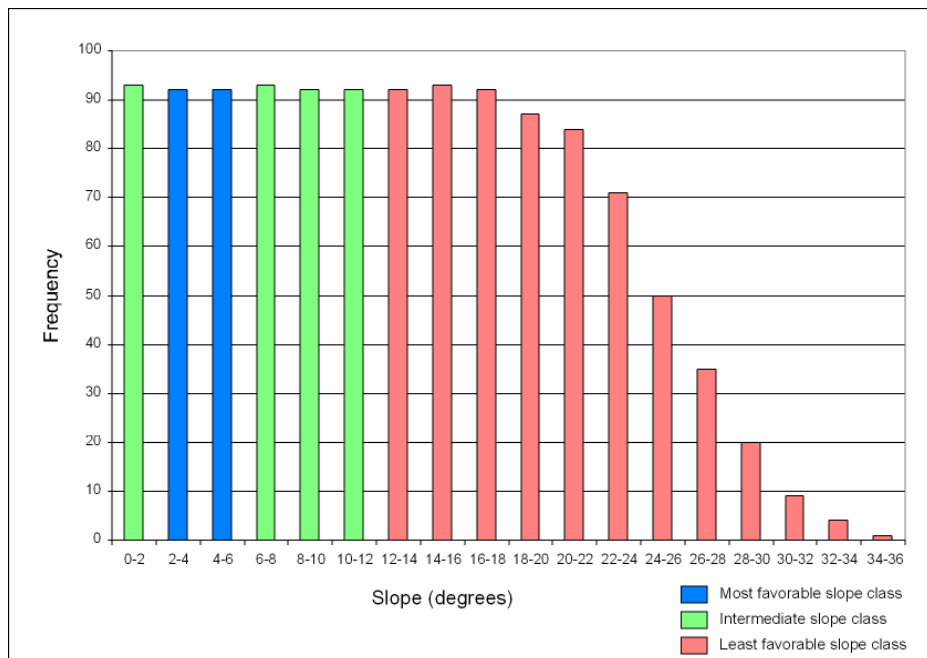
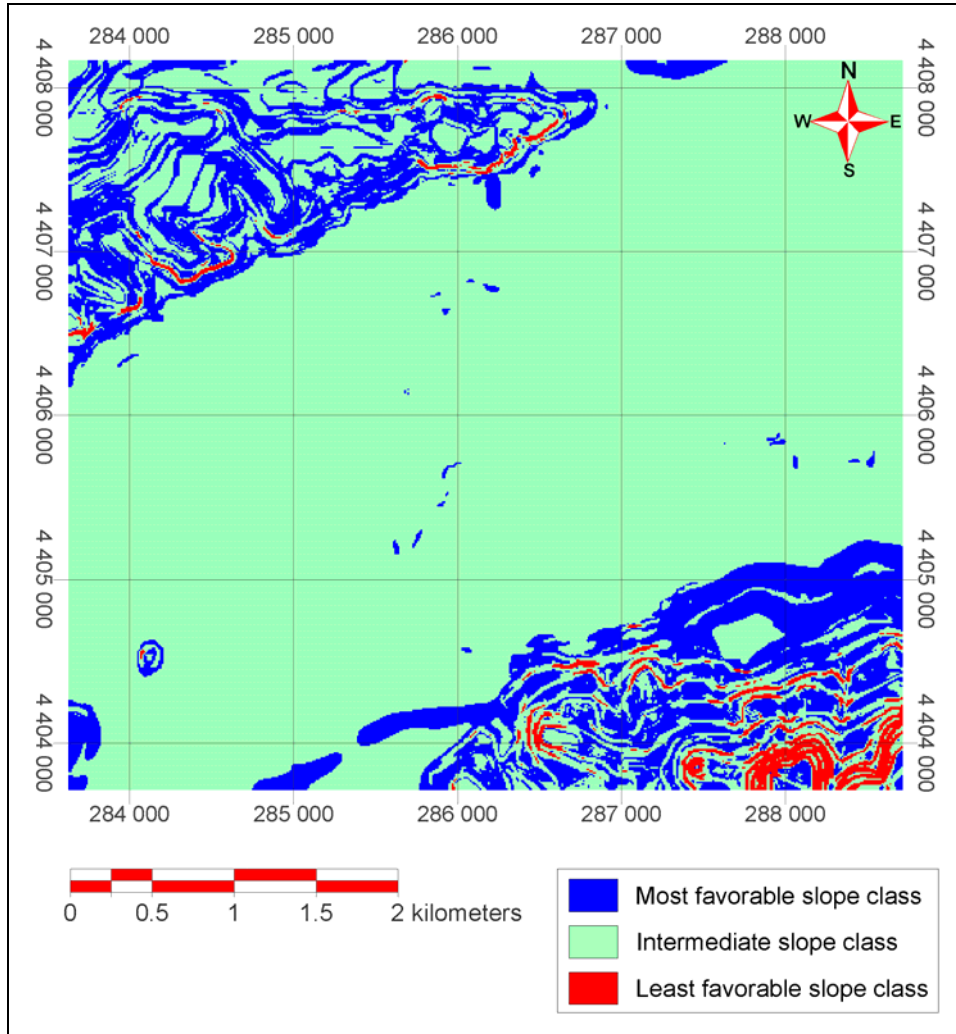


Figure 4.9. Histogram of the slope map.

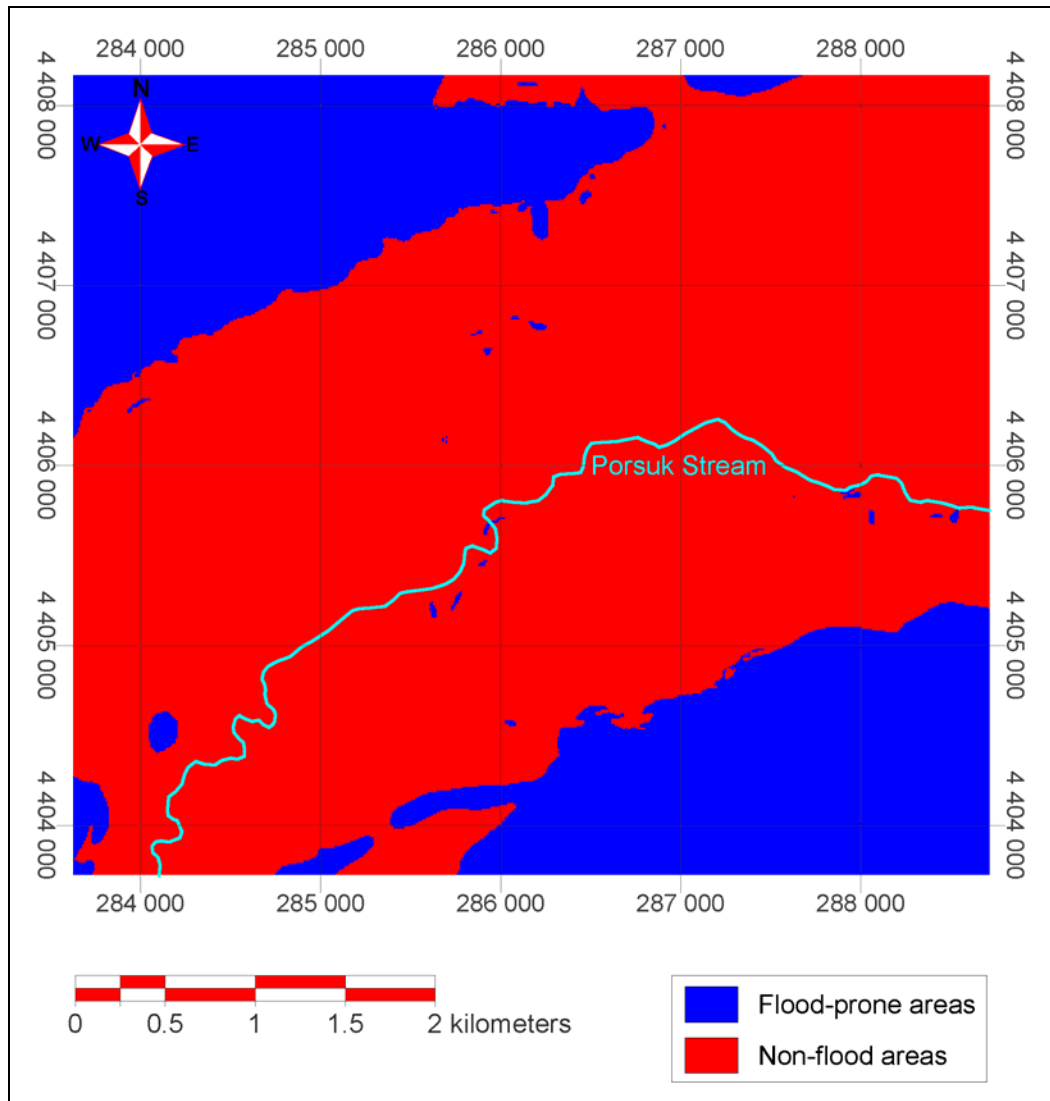


**Figure 4.10.** Slope layer of the study area.

#### 4.2.1.3. Flood Susceptibility Layer

The flood susceptibility of the study area is examined for the case of long duration thunderstorms. The areas having slope smaller than  $2^\circ$  within the Porsuk Stream floodplain, are determined as flood prone areas. It should be noted that in the preparation of the flood susceptibility map, it is assumed that the Porsuk Dam will not be failed even in the case of an earthquake.

The flood susceptibility map is prepared by using the slope map of the study area as an input. The areas having slope smaller than  $2^\circ$  and which have also connectivity with Porsuk Stream have been classified as flood prone areas. The flood susceptibility layer of the study area is given in Figure 4.11.



**Figure 4.11.** Flood susceptibility layer of the study area.



#### 4.2.2. Lithology Map

The lithology map of the study area is taken from Ayday *et al.* (2001). In this report, the authors have explained the steps used in the preparation of lithology map as follows:

“All 1:25000 scale geological maps available for Eskişehir region are collected. All lithological units and their boundary relationships have been checked by using aerial photos, satellite images and field observations. The geological data are then compiled on 1:2000 scale topographic map covering Eskişehir settlement area.”

In this study, six lithological units have been identified (Figure 4.12). These units are listed below:

- Mamuca Formation (Lower Eocene)
  - Conglomerate-sandstone Member
- Porsuk Formation (Upper Miocene)
  - Conglomerate-sandstone Member
  - Tuff – Marl – Clay Member
  - Limestone Member
- Old Alluvium (Quaternary)
- Young Alluvium (Quaternary)

The descriptions of these lithological units are based on the report prepared by Ayday *et al.* (2001) and the thesis prepared by Koyuncu (2001). The district map of the study area is given in Figure 4.13 in order to visualize the districts / geological unit correlation.

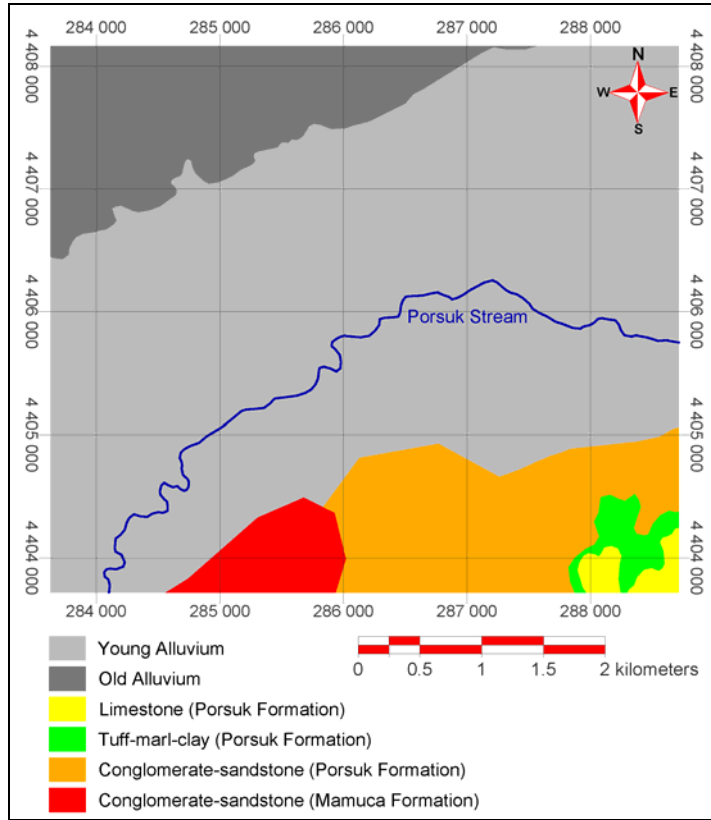


Figure 4.12. Lithology map of the study area (Ayday *et al.*, 2001)

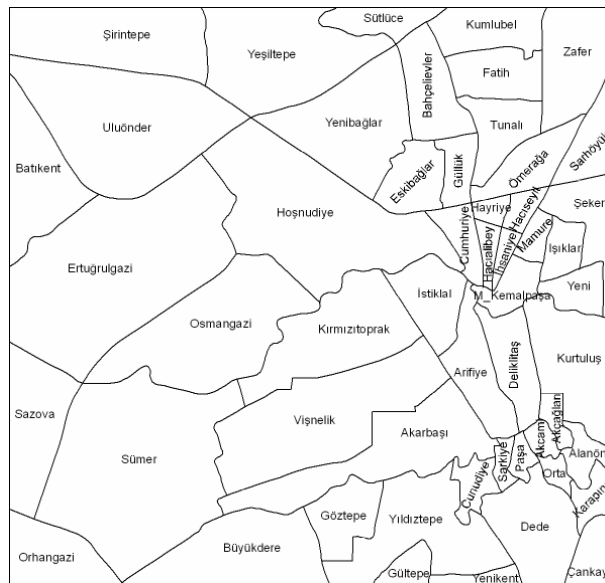


Figure 4.13. District map of the study area (Ayday *et al.*, 2001).

#### Mamuca Formation (Conglomerate-sandstone Member)

Conglomerate-sandstone member of Mamuca Formation is the oldest rock unit observed in the study area. This member crops out in the southern part of the study area at the districts Büyükdere and southwest of Akarbaşı. The sedimentary sequence starts with conglomerate comprising gravels of mainly ultra basic rocks and continues with the alternation of sand, gravel, clay and conglomerate. Conglomerate is red and dark red and does not show regular bedding at the lower levels. However, at the upper levels, the bedding is observed. The gravels in the conglomerate are rounded and generally contains gabbro and diabase. The sizes of individual gravels may be as large as cobbles. It is noted that the red / dark red clay is very well indurated and it is difficult to be crumbled by hand.

#### Porsuk Formation (Conglomerate-sandstone Member)

Conglomerate and sandstone member of the Porsuk formation crops out at the south-southeast part of the study area in Göztepe, Yıldıztepe, Gültepe, Cunuzdiye, Sarikiye, Paşa, Akcami, Alanönü districts and partially in Akarbaşı, Orta, Akçağlan, Kurtuluş, Dede and Karapınar districts. The sequence starts with coarse grained conglomerate at its lower part. The gravel of the conglomerate consists of limestone and granite. Towards the top of the sequence, the sizes of gravels get smaller and the unit grades into sandstone. At these levels the alternation of conglomerate and sandstone is observed.

#### Porsuk Formation (Tuff-Marl-Clay Member)

Tuff, marl clay member of Porsuk Formation crops out at the southeastern part of the study area, encircling Taşlı Hill in the districts of mainly the eastern part of Dede, southern parts of Karapınar and Orta, and northwest part of Çankaya. The color of tuff white, while the color of marl and clay is red. There are two kinds of tuff which are pink and white, and the white tuff is more resistant than the pink tuff.

#### Porsuk Formation (Limestone Member)

Limestone member forms the top of Porsuk Formation. This unit crops out at the southeastern part of the study area in the districts of southern part of Dede, and eastern and southern parts of Çankaya. It shows karstic features, such as solution cavities.

### Old Alluvium

Old alluvium, together with young alluvium, covers significant part of Eskişehir settlement area. This unit crops out at the northwest part of the study area, in the districts of Şirintepe, Batıkent, Uluönder, Yeşiltepe, and Sütlüce. The top level of the old alluvium comprises thin and hard layer consisting of clay and carbonate depositions. The color of this layer is white and it can be distinguished easily with this property. Underneath, there is fine-grained sand and silt, coarse-grained sand and gravel levels. Under these levels, sandstone, siltstone and claystone layers are alternating. The sandstone levels are rather loose and can be crumbled easily by hand, however, the carbonaceous level on top is hard and can be hardly crumbled.

### Young Alluvium

Young alluvium is the youngest unit of Eskişehir vicinity. It has widespread outcrops in the Eskişehir settlement. This unit crops out in the districts adjacent to Porsuk Stream. Young alluvium is formed from the deposits of Porsuk Stream, Sarısu Brook and their tributaries. It consists of loose gravel, sand, silt and clay levels and their combinations. Below the organic soil formed at top, light yellow silty sand is observed. At some places, the thick clay level is observed under this level. At the lower parts sand and silty sand levels are seen. Towards bottom, the percentage of sand increases and gravelly sand levels begin.

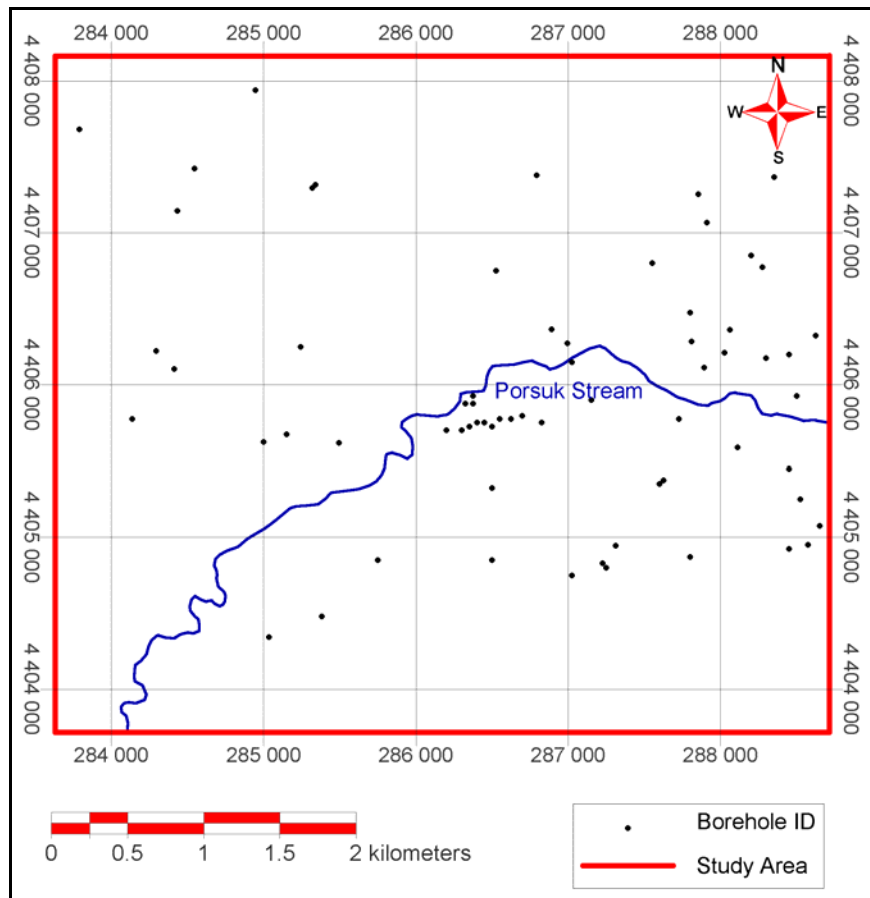
#### **4.2.2.1. Soil Layer**

The soil layer of the study area is based on the lithology map and the report prepared by Ayday *et al.* (2001). The data of 66 boreholes are investigated and evaluated. The locations of the boreholes are shown in Figure 4.14.

The borehole data are compiled for the depth range of 2.5 – 3.5 m, and the data are plotted into the plasticity chart (Figure 4.15). According to this plasticity chart, the data are evaluated for their soil behavior. The units classified as bedrock (Mamuca and Porsuk formations), are not taken into consideration. The soil map of the study area is prepared according to the unified soil classification system (USCS). The groups of the classification are given in Table 4.3. The Table 4.3 is obtained from Cernica (1995) in which the source of this table is given as ASTM D-2487-69.

**Table 4.3.** Unified Soil Classification System (Cernica, 1995)

Major Divisions			Group Symbols	Typical Names
Coarse-Grained Soils More than 50% retained on No. 200 sieve	Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean gravels -200 < 5%	GW	Well-graded gravels and gravel-sand mixtures, little or no fines
			GP	Poorly graded gravels and gravel-sand mixtures, little or no fines
		Gravels with fines -200 > 12%	GM	Silty gravels, gravel-sand-silt mixtures
			GC	Clayey gravels, gravel-sand-clay mixtures
	Sands more than 50% of coarse fraction passes No. 4 sieve	Clean sands -200 < 5%	SW	Well-graded sands and gravelly sands, little or no fines
			SP	Poorly graded sands and gravelly sands, little or no fines
		Sands with fines -200 > 12%	SM	Silty sands, sand-silt mixtures
			SC	Clayey sands, sand-clay mixtures
Fine-Grained Soils 50% or more passes No. 200 sieve	Silts and Clays Liquid limit 50% or less	ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays	
		OL	Organic silts and organic silty clays of low plasticity	
	Silts and Clays Liquid limit greater than 50%	MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts	
		CH	Inorganic clays of high plasticity, fat clays	
		OH	Organic clays of medium to high plasticity, fat clays	
Highly Organic Soils			PT	Peat, muck and other highly organic soils



**Figure 4.14.** Location of the boreholes used in the preparation of soil layer

Based on USCS, the classes of the soil map are found to be bedrock, SC, MH / ML, CH and CL. The soil layer of the study area is given in Figure 4.16.

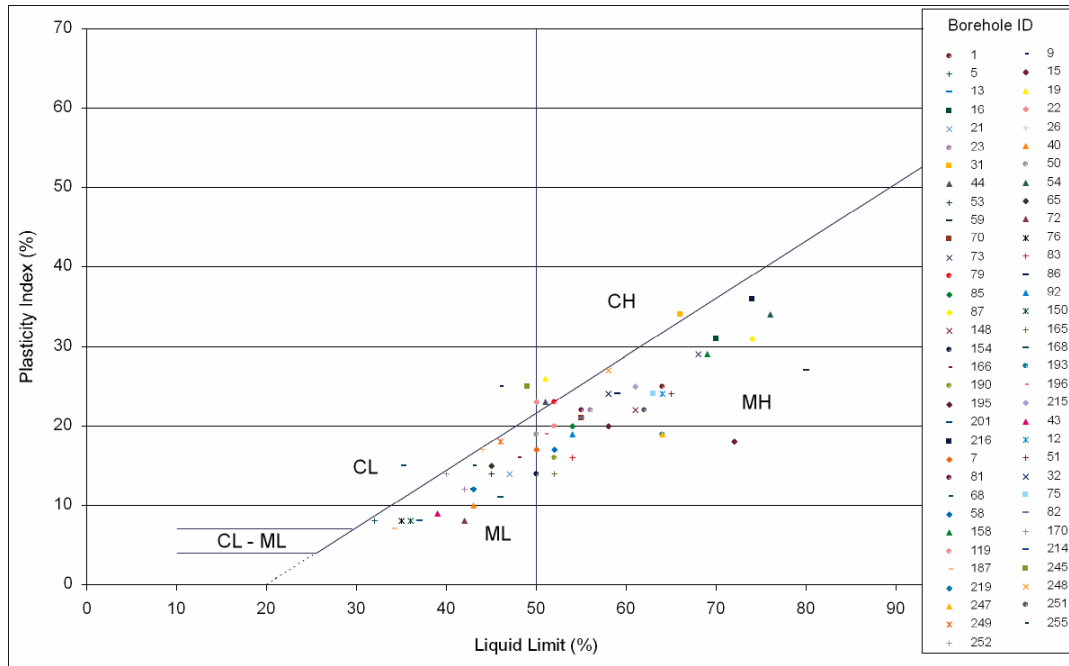


Figure 4.15. Plasticity chart used in the preparation of soil layer.

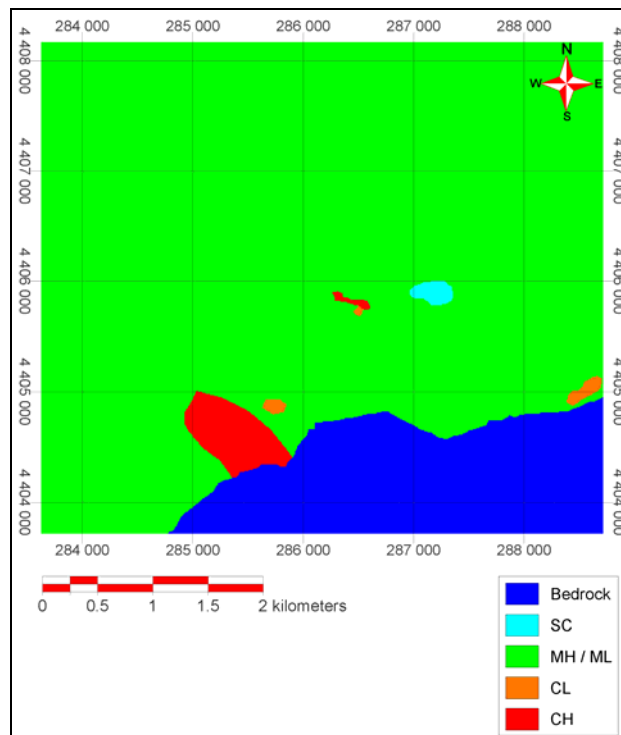


Figure 4.16. Soil layer of the study area. Legend details are given in Table 4.3.

### **4.2.3. Borehole Data**

The borehole data used in this study are obtained from Ayday *et al.* (2001). The borehole data are analyzed and evaluated in order to obtain the depth to groundwater table, swelling potential of the soil and the soil layers.

#### **4.2.3.1. Depth to Groundwater Table Layer**

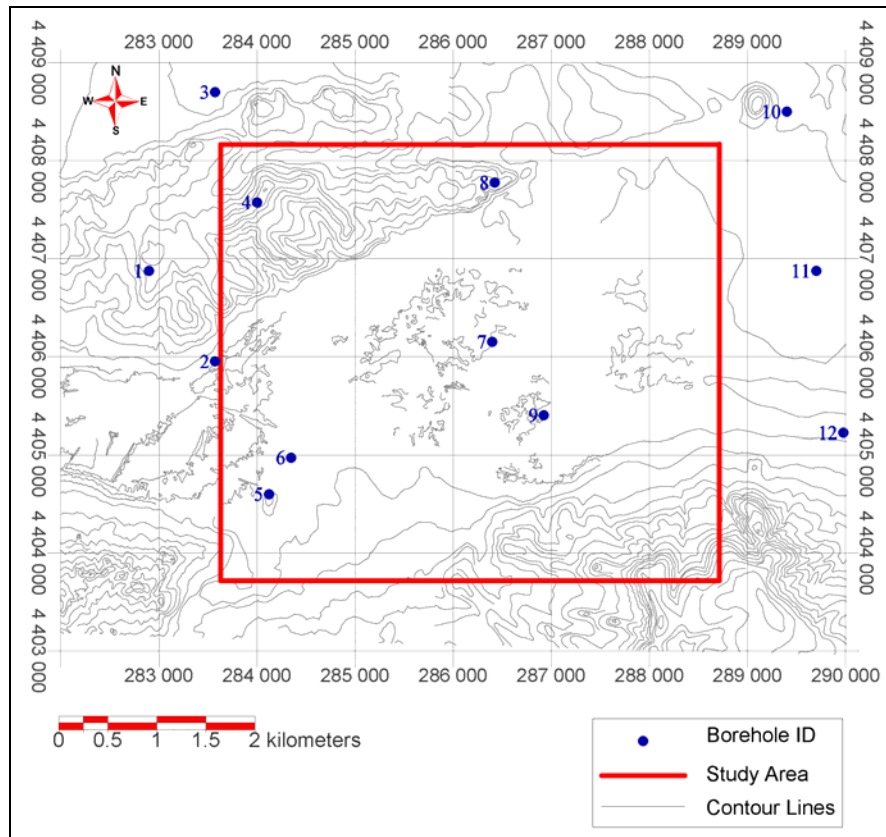
Depth to groundwater table layer is prepared due to its significance on the performance of the foundation stability and excavation works. At the study area most precipitation occurs during April – May period (Ayday *et al.*, 2001). Therefore, during the preparation of the depth to groundwater table, the groundwater levels of May are considered. The groundwater levels used are given in Table 4.4. Six of the boreholes are located inside the study area and the other six are located in the close vicinity. The locations of these boreholes are given in Figure 4.17.

Depth to groundwater table values are calculated by subtracting the groundwater table elevations from the topographical elevations that are obtained from the DEM of the study area. After preparing the depth to groundwater table map using Rockworks software, the map is edited, evaluated and divided into three classes. Depth range of 0 – 5 m is classified as least favorable class, 5 – 10 m as intermediate class, and greater than 10 m as most favorable class. The depth to groundwater table layer of the study area is given in Figure 4.18.

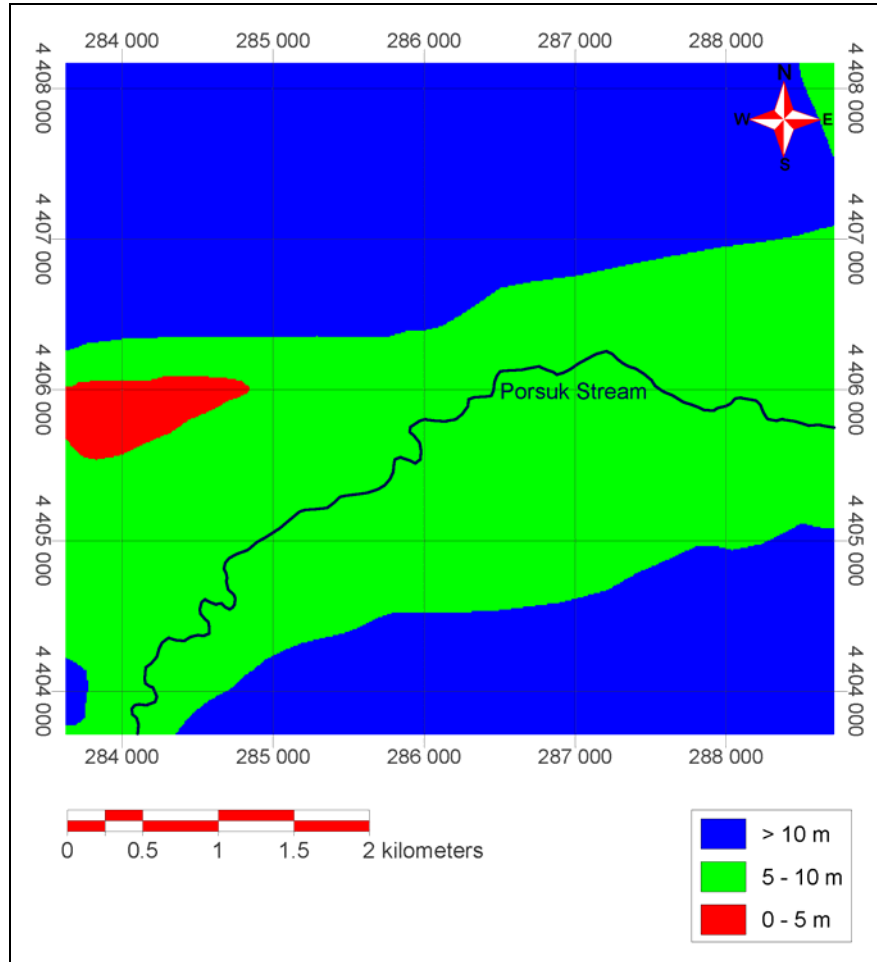


**Table 4.4.** Groundwater table elevation values.

Borehole ID	Easting	Northing	z - value	Gwt Elevation	Depth to Gwt
1	282900	4406875	828,0434783	792,7	35,34347826
2	283575	4405950	792,5	789	3,5
3	283575	4408700	796,2059801	793,6	2,605980066
4	284000	4407575	823,9799805	792,35	31,62998047
5	284125	4404600	796,5696411	788,85	7,71964111
6	284350	4404975	794,6394043	787,7	6,9394043
7	286400	4406150	791	784,5	6,5
8	286425	4407775	807,5	789,15	18,35
9	286925	4405400	789,465332	783,4	6,06533203
10	289400	4408500	786,8441558	782,8	4,044155844
11	289700	4406875	788,3541927	781,1	7,254192741
12	289975	4405225	788,5424354	780,74	7,802435424



**Figure 4.17.** Location of boreholes used in the preparation of depth to groundwater table layer.



**Figure 4.18.** Depth to groundwater table layer of the study area

#### 4.2.3.2. Swelling Potential Layer

The swelling potential of the study area is examined for the first 2.5 m because below this depth, the soil moisture remains constant. The locations of selected 13 boreholes are given in Figure 4.19. The units that are classified as bedrock are not taken into consideration. After compiling the Clay Content (%) and Plasticity Index (%) from the borehole data within 0 – 2.5 m depth interval, these values are evaluated by using the activity chart. As can be observed from this graph (Figure 4.20), the values are found to be within the low and medium expansion classes. Therefore, the classes of the swelling potential of the study area are determined as; low expansion, medium expansion, and bedrock. The swelling potential layer is given in Figure 4.21.

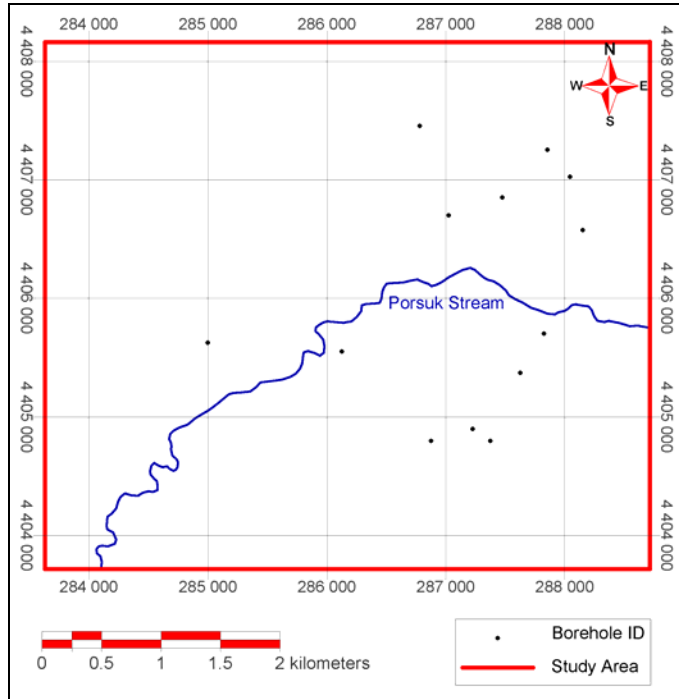


Figure 4.19. Location of boreholes used in the preparation of swelling potential layer.

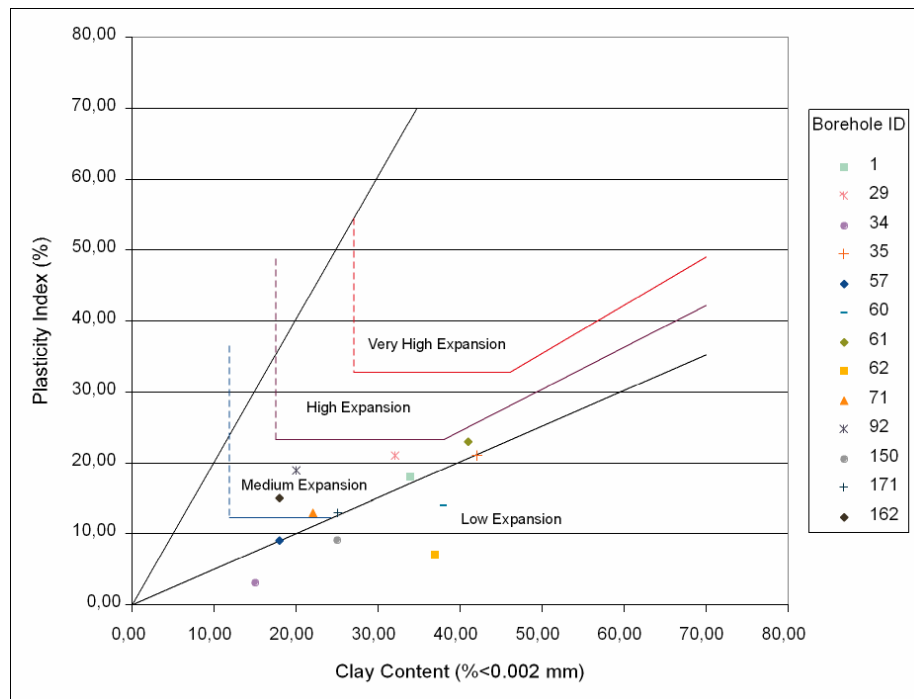
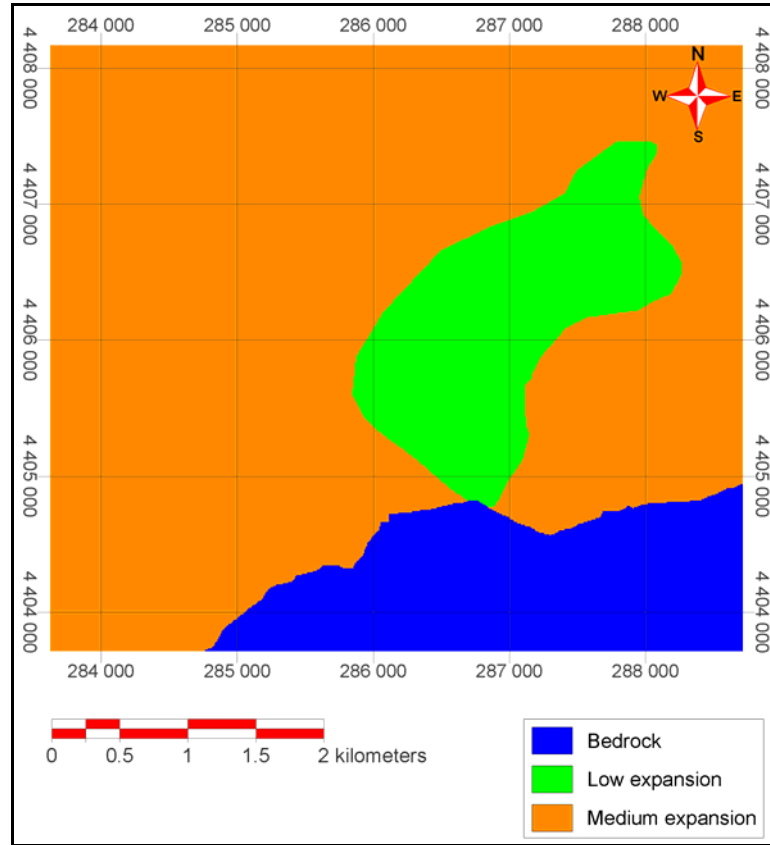


Figure 4.20. Activity chart used in the preparation of swelling potential layer.



**Figure 4.21.** Swelling potential layer of the study area.

#### 4.2.3.3. Liquefaction potential layer

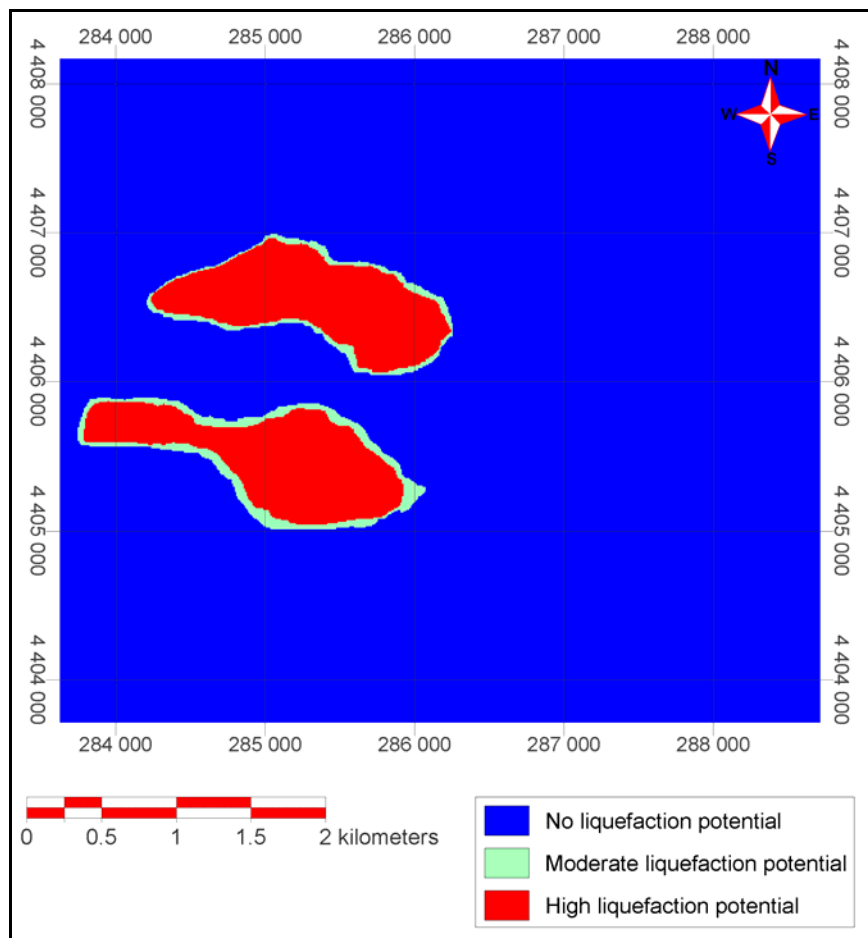
The liquefaction potential layer of the study area is taken from Ayday *et al.*, (2001). The map is based on Seed and Alba (1986) approach. In the calculations, 0.4g is taken as peak horizontal acceleration (pha) and the grain size data for a depth of 5 m are used. The factor of safety values are calculated using the formula below, for liquefaction potential.

Liquefaction can be expected at depths where the loading exceeds the resistance or when the factor of safety against liquefaction, expressed as

$$FS_L = \frac{\text{cyclic shear stress required to cause liquefaction}}{\text{equivalent cyclic shear stress induced by earthquake}} = \frac{\tau_{cyc,L}}{\tau_{cyc}} = \frac{CSR_L}{CSR}$$

is less than 1 (Kramer, 1996).

The liquefaction potential map is reclassified to obtain the liquefaction potential layer of the study area. The classes of "bedrock" and "groundwater level deeper than 10m" are assigned to the class of "no liquefaction". As a result, the liquefaction potential layer of the study area has three classes: high liquefaction potential ( $FS_L < 1.0$ ), liquefaction potential ( $1.0 < FS_L < 1.2$ ) and no liquefaction ( $FS_L > 1.2$ ). The liquefaction potential layer of the study area is shown in Figure 4.22.



**Figure 4.22.** Liquefaction potential layer of the study area (modified from Ayday et al, 2001).

## CHAPTER 5

### ANALYSIS

#### 5.1. Common Steps of Multicriteria Analysis Applications

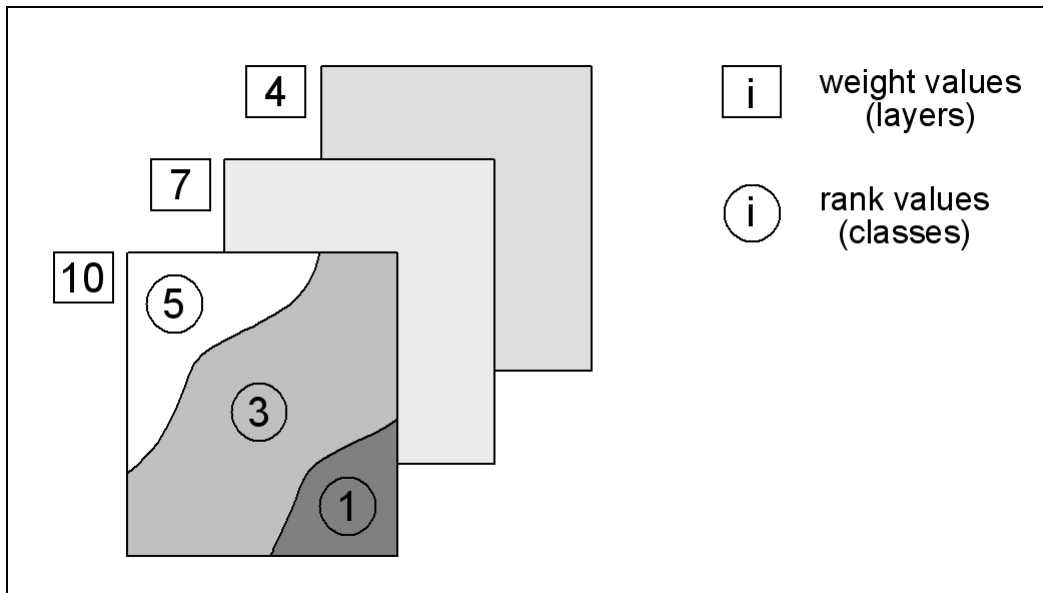
In order to obtain geotechnical microzonation map of the study area regarding the foundation suitability of the residential areas, two methods are applied: Simple Additive weighting (SAW) and Analytical Hierarchical Process (AHP). In this chapter, after summarizing the general steps for obtaining the microzonation maps, these two methods will be explained in detail. In the analysis, assigning weight values to the layers and rank values to the classes of each layer are performed. Slope, flood, soil, depth to groundwater table, swelling and liquefaction are the layers prepared to be used in the analysis.

In Figure 5.1, the schematic diagram of layers, classes, assigned weight and rank values are shown. The simplified flowchart for assigning weight and rank values to obtain microzonation map is given in Figure 5.2.

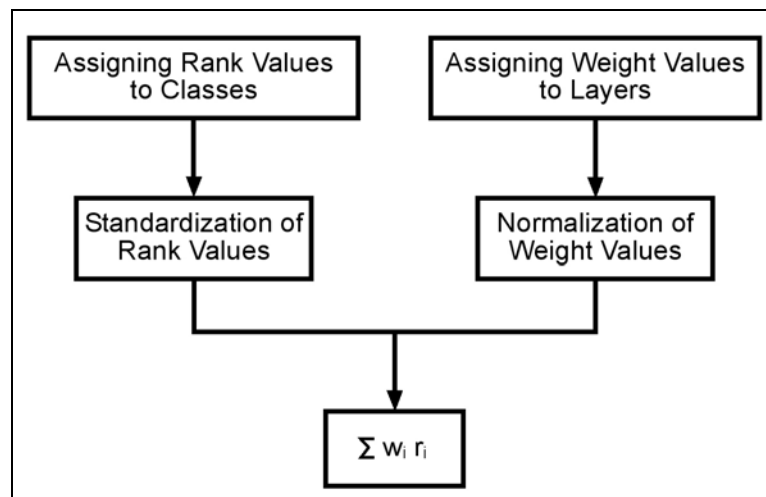
In order to prevent the conceptual confusion, the prepared "layers" will be referred to as "thematic maps" until the ranking values are assigned to them. Thus the term "layers" implies "thematic maps with the assigned rank values".

The first step is to give "rankings" to the classes of each thematic map, and the layers that will be used for the analysis are formed. For each class of the thematic map, rankings are given according to their significance in foundation performance. In the ranking process only the classes of that thematic map are considered, contribution of the layers or the other classes to the microzonation map are not considered. After rankings are given to each class, the thematic maps are considered as layers to perform the final evaluation.

After the rankings are assigned to the classes of each layer, the weights are assigned to layers according to their importance. The influence between the layers is not considered since the layers are assumed to be independent from each other.



**Figure 5.1.** Schematic diagram of layers, classes, assigned weight and rank values.



**Figure 5.2.** Simplified flowchart for assigning weight and rank values.

The weight and rank values of the layers and classes of each layer are standardized in order to obtain a common dimensionless unit. Afterwards, the output (microzonation map) is created by multiplying the weight value assigned for each layer by the rank value given to the classes of that layer and finally by summing up the products. The obtained microzonation map of Eskişehir downtown area regarding the foundation suitability of residential areas, is grouped into different zones. The General Directorate of Disaster Affairs of Turkey (GDDA, 2000) recommended the following subdivisions:

Zone I: Areas suitable for settlement – normal residential developments can be planned without any further precautions.

Zone II: Provisional settlement areas – development can take place provided certain precautionary measures against heave, excessive settlements, shallow water table, etc. are taken.

Zone III: Areas requiring detailed geotechnical investigations – conditions are such that individual investigations are required and prescribed standard precautions to be taken against very high heave, very high settlement, very shallow water table, liquefaction, flood, etc.

Zone IV: Areas not suitable for settlement – no settlement of any kind is allowed in areas where seismicity, landslides, floods, water table at the surface, steep slopes, etc. pose serious risks to residential development. Such areas may be used for recreational purposes.

Two different methods are applied in assigning the weighting values to the layers and ranking values to the classes of the layers: *Simple Additive Weighting (SAW) and Analytical Hierarchical Process (AHP) methods.*

SAW method directly gives the weight and rank values based on the common sense of engineering judgment, hence totally based on expert opinion. In this method, all of the layers are concurrently considered in assigning weight values, and all classes of each layer are also concurrently considered to assign rank values. As a result, six weight values are assigned to six layers.

In the AHP method, pairwise comparisons form the backbone of the methodology. In assigning the weights of the layers, only two layers are considered at a time. Totally 15 different weights are given, since in assigning each weight, two layers are considered. In other words, the total number of pairing that every layer matches with each other is 15. In similar, the ranking values to the classes of each layer are also assigned considering only two classes at a time.



The explanations of the assigned weight and rank values are given separately for each method in the sections 5.2 and 5.3, respectively. Furthermore, the comparison of the results due to these two methods is given in section 5.4.

## **5.2. Simple Additive Weighting (SAW)**

In the Simple Additive Weighting (SAW) method, the weight and rank values are assigned to the layers and the classes of each layer, according to the relative importance of that layer/class to the microzonation map, taken as evaluation criteria. In the assigning of weight and rank values, inverse weighting and ranking criteria is used as given below:

- Weight Values: Least important = 1, next least important = 2, .. , most important = 10.
- Rank Values: Least important = 1, next least important = 2, .. , most important = 5.

### **5.2.1. Assigning Weight and Rank Values**

The assigned weight and rank values for the layers/classes of the study area based on the engineering judgment are given in Table 5.1. As can be observed from the table that the most important layer is defined as the liquefaction layer, followed by the flood, soil, depth to groundwater table, swelling and slope layers in decreasing amount of importance. In the determination of the weight values, the liquefaction layer has been given the greatest value because of the fact that the study area is located in the second degree earthquake zone. The flood layer takes the second important role since there is a large floodplain in the study area, and for the case of thunderstorms of long duration, there is a possible risk of flood (In 1963, the overflow of Porsuk Stream resulted in serious flood hazard). Soil layer is also important since the behavior of the soil should be taken into account during construction. In the aspect of contribution to the microzonation map, the depth to groundwater table, swelling and slope layers carry relatively low importance, since the possible problems can be vanquished relatively more easily and practically. The weight assigning order of these three layers is given according to the easiness of the precautions needed, as depth to groundwater table, swelling and slope. The determination criteria for assigned rank values in Table 5.1 are explained below for each layer:

- The ranking values for the classes of the liquefaction layer are '1' and '5' for *high liquefaction potential* ( $FS_L < 1.0$ ), and *no liquefaction potential* ( $FS_L > 1.2$ ) classes respectively. Therefore the most critical class is ranked as far as possible from the safe class. The ranking for the *moderate liquefaction potential* ( $1.0 < FS_L < 1.2$ ) class is assigned as '2', since there is still a danger of liquefaction, but not as the *high liquefaction potential* class.
- The rank values for the classes of the flood layer are assigned as '1' to the flood prone areas and '5' to the safe areas, so that the most favorable class is ranked far from the unsafe class.
- In the soil layer the classes are sorted according to their soil behavior as *bedrock*, *SC*, *MH/ML*, *CL* and *CH*. The rankings are given as 5, 4, 3, 2 and 1 respectively.
- The ranking values for the classes of the depth to groundwater table layer are '1' for  $0 - 5$  m and '5' for  $> 10$  m classes, so that the most critical class is ranked as far as possible from the safe class. In addition, the rank value for  $5 - 10$  m class is assigned as '3', since it is in the intermediate critical zone.
- In the swelling potential layer, the classes are ranked as '3', '4' and '5' for *medium expansion*, *low expansion* and *bedrock* classes, respectively. The range of the rank values of this layer is within 3 – 5, since there is no high or very high expansion in the study area.
- The ranking values for the classes of slope layer are given as '5' and '1' for the most and the least favorable slope classes respectively. The ranking of the intermediate slope class is assigned as '4', since, with simple additional precautions, this class can also be suitable for residential areas.

**Table 5.1.** Assigned weight and rank values for the layers/classes of the study area.

LAYERS	WEIGHTING	CLASSES	RANKING
Liquefaction potential layer	10	No liquefaction potential	5
		Moderate liquefaction potential	2
		High liquefaction potential	1
Flood susceptibility layer	8	Non-flood areas	5
		Flood-prone areas	1
Soil layer	7	Bedrock	5
		SC	4
		MH / ML	3
		CL	2
		CH	1
Depth to groundwater table layer	5	>10 m	5
		5-10 m	3
		0-5 m	1
Swelling potential layer	4	Bedrock	5
		Low expansion	4
		Medium expansion	3
Slope layer	3	Most favorable slope class	5
		Intermediate slope class	4
		Least favorable slope class	1

### 5.2.2. Standardization of Rank and Weight Values

The rank values of the classes are standardized according to the relative distance between the origin and the maximum rank value, using the following formula:

$$X'_{ij} = X_{ij} / X_j^{\max}$$

where  $X'_{ij}$  is the standardized rank value for the  $i^{\text{th}}$  class for the  $j^{\text{th}}$  layer.  $X_{ij}$  is the raw rank value, and  $X_j^{\max}$  is the maximum rank value for the  $j^{\text{th}}$  layer. The weight values are normalized by dividing each weight by the summation of the weights. Thus the summation of the normalized weight values equals to 1. The standardized rank values and normalized weight values are given in Table 5.2.

**Table 5.2.** Standardized rank values and normalized weight values.

LAYERS	Weighting (normalized)	CLASSES	Ranking (standardized)
Liquefaction potential layer	0,2703	No liquefaction potential	1
		Moderate liquefaction potential	0,4
		High liquefaction potential	0,2
Flood susceptibility layer	0,2162	Non-flood areas	1
		Flood-prone areas	0,2
Soil layer	0,1892	Bedrock	1
		SC	0,8
		MH / ML	0,6
		CL	0,4
		CH	0,2
Depth to groundwater table layer	0,1351	>10 m	1
		5-10 m	0,6
		0-5 m	0,2
Swelling potential layer	0,1081	Bedrock	1
		Low expansion	0,8
		Medium expansion	0,6
Slope layer	0,0811	Most favorable slope class	1
		Intermediate slope class	0,8
		Least favorable slope class	0,2

### 5.2.3. Result Map of SAW

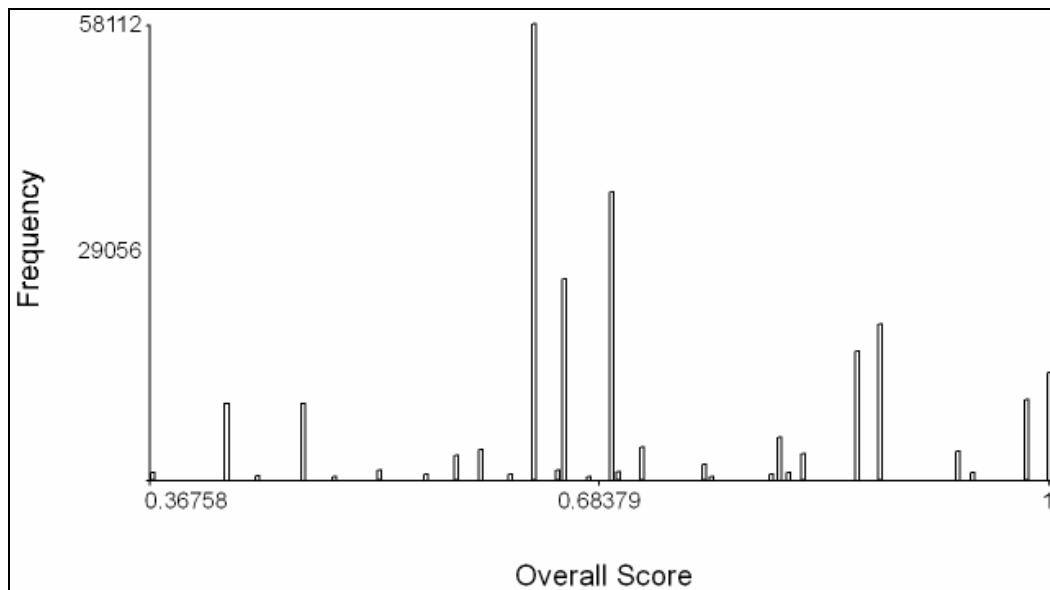
For the preparation of the microzonation map of the study area, the overlay operations of the layers are used. Each pixel of the output microzonation map ( $M_i$ ) is calculated by using the following summation:

$$M_i = \sum_j w_j x_{ij}$$

where,  $x_{ij}$  = rank value of the  $i^{\text{th}}$  class with respect to the  $j^{\text{th}}$  layer

$w_j$  = normalized weight of the  $j^{\text{th}}$  layer

Thus the normalized weight value assigned for each layer is multiplied by the standardized rank value given to the classes of that layer. Finally the summation of the products is calculated. The histogram of the microzonation map is given in Figure 5.3.

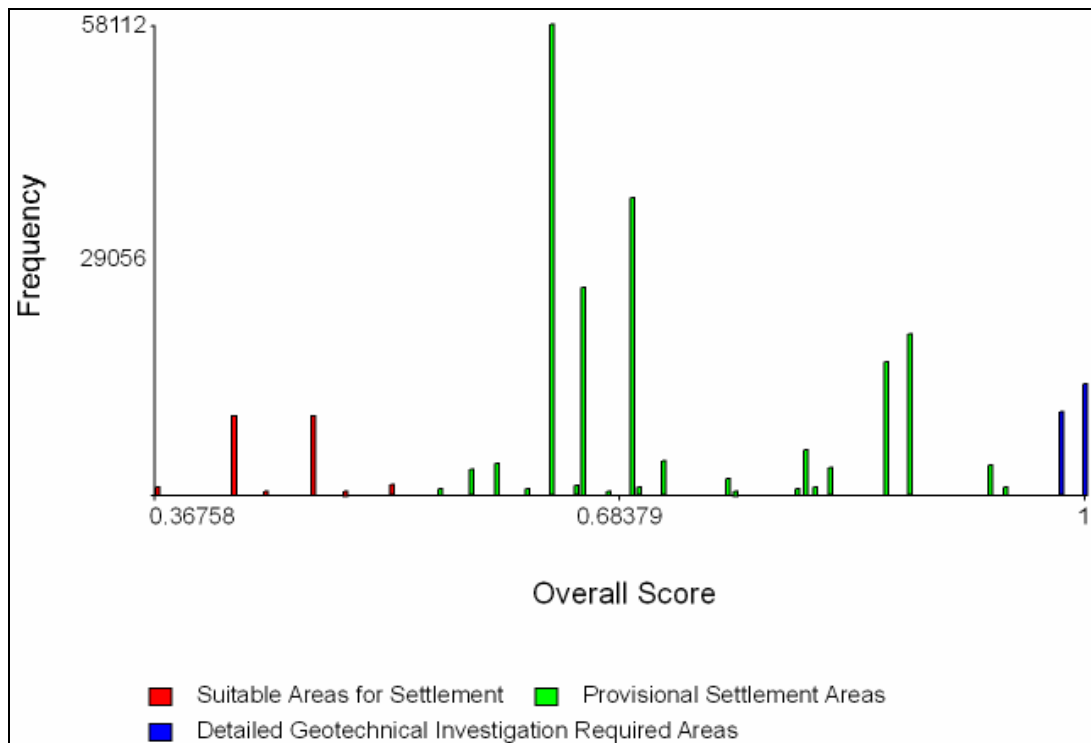


**Figure 5.3.** The histogram of the microzonation map obtained from the weight and rank values assigned by using SAW method.

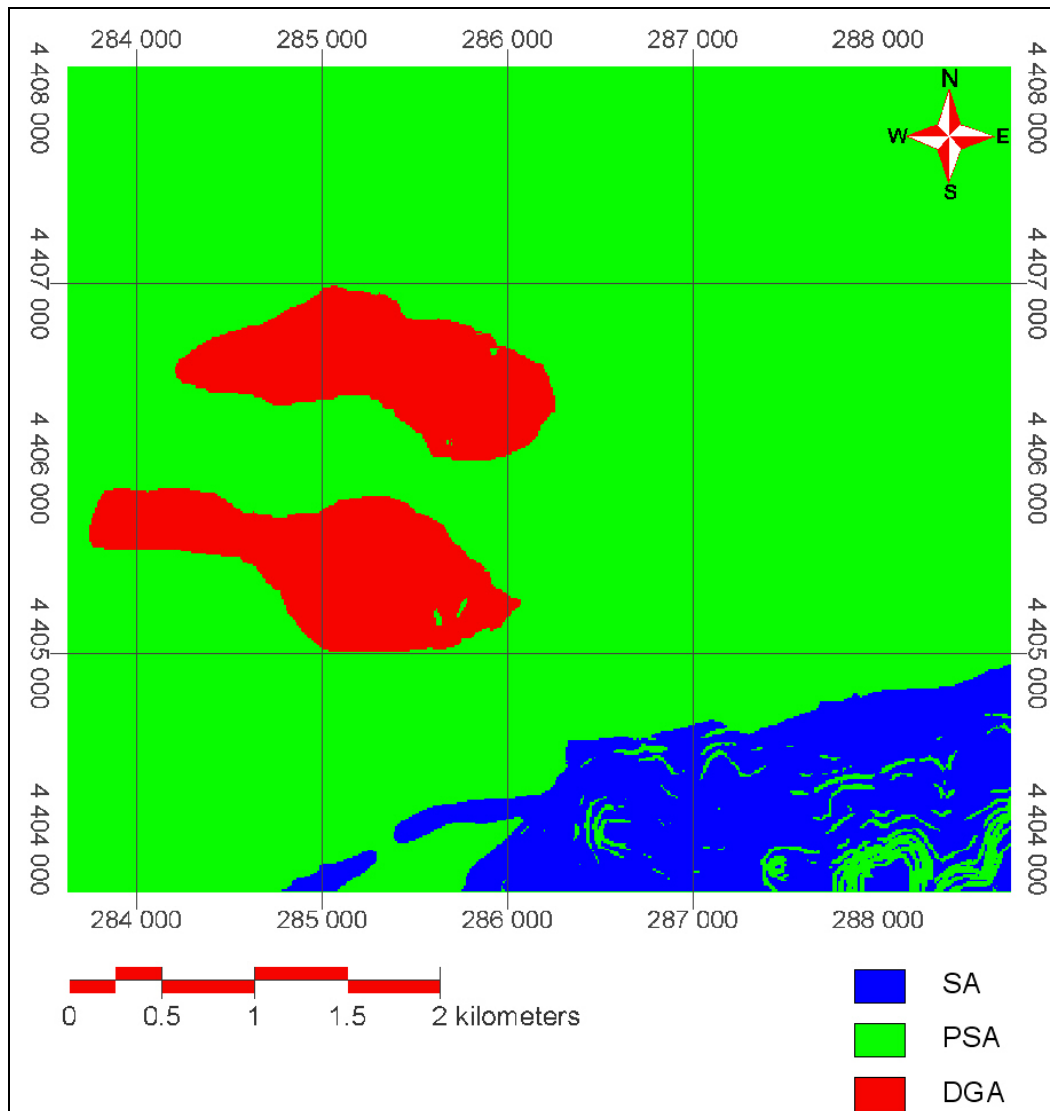
The microzonation map of the study area is categorized as:

- SA: Suitable Areas for Settlement
- PSA: Provisional Settlement Areas
- DGA: Detailed Geotechnical Investigation Required Areas

The microzonation map prepared by using the SAW method is divided into these three zones by using the histogram of the microzonation map. The boundaries of these zones are shown on the histogram of the microzonation map in Figure 5.4. The microzonation map prepared by using the SAW method is given in Figure 5.5.



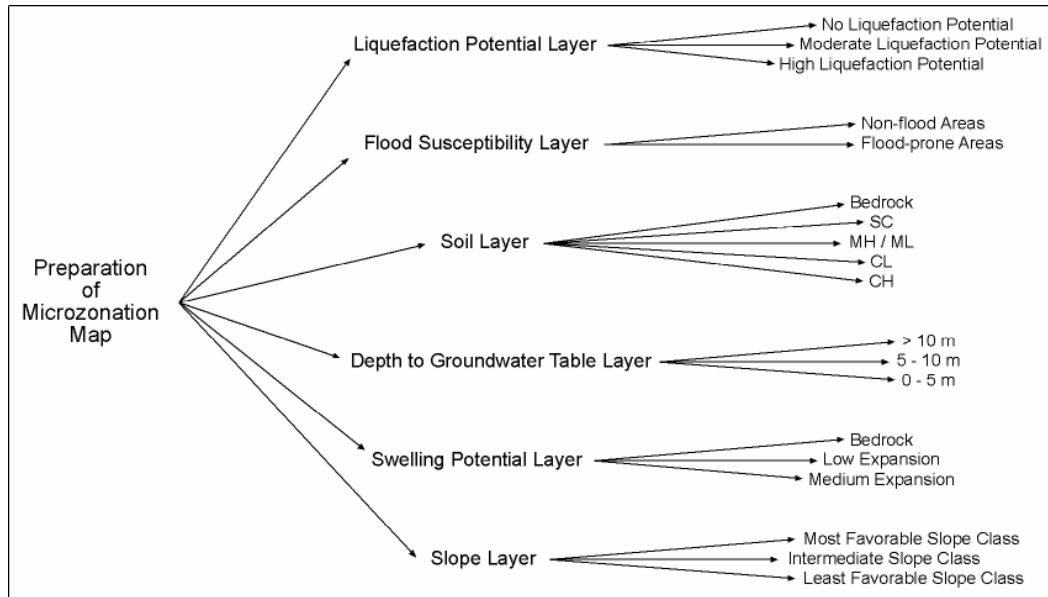
**Figure 5.4.** Histogram showing the boundaries of the three zones of microzonation map.



**Figure 5.5.** The microzonation map prepared by using the SAW method. (SA: Suitable areas for settlement, PSA: Provisional settlement areas, DGA: Detailed geotechnical investigation required areas)

### 5.3. Analytical Hierarchical Process (AHP)

The hierarchical structure used in the preparation of the microzonation map is given in Figure 5.6.



**Figure 5.6.** The hierarchical structure used in the preparation of the microzonation map

To assign the weight and rank values to the layers and classes of each thematic map in the Analytical Hierarchical Process (AHP) method, the principle of comparative judgment is used. To apply this principle, *in assigning weights*, pairwise comparisons of each layer with other layers are assessed, while *in assigning rank values*, pairwise comparisons of each class with other classes of the same thematic map are assessed.

For assignment of weight and rank values, used comparison judgments scale is taken from Saaty (2004), as given in Table 5.3 with their corresponding meanings.



**Table 5.3.** Comparison judgments from a fundamental scale of absolute numbers for assigning weight / rank values (Saaty, 2004)

Weight/Rank	Intensities
1	Equal
3	Moderately dominant
5	Strongly dominant
7	Very strongly dominant
9	Extremely dominant
2,4,6,8	Intermediate values
Reciprocals	For inverse judgments

### 5.3.1. Assigning Weight Values

The pairwise comparison matrix for assigning the weight values for the layers is given in Table 5.4.

**Table 5.4.** The pairwise comparison table for assigning weight values

	Liquefaction	Swelling	Soil	Depth to gwt	Slope	Flood
Liquefaction	1	5	3	4	6	1
Swelling	1/5	1	1/3	1/2	1	1/4
Soil	1/3	3	1	2	4	1
Depth to gwt	1/4	2	1/2	1	3	1/3
Slope	1/6	1	1/4	1/3	1	1/5
Flood	1	4	1	3	5	1

The logic behind assigning values in the pairwise comparison matrix is follows:

- The liquefaction layer has equal importance with the flood layer and moderate prevalence to soil layer, whereas it has moderate-strong, strong, and strong-very strong prevalence against depth to groundwater table, swelling and slope layers, respectively.
- The flood layer has equal importance with the soil layer, whereas it has moderate, moderate-strong, and strong prevalence against depth to groundwater table, swelling and slope layers, respectively.
- The soil layer has equal-moderate, moderate, and moderate-strong prevalence against depth to groundwater table, swelling and slope layers, respectively.
- The depth to groundwater table has equal-moderate prevalence to swelling layer and it has moderate prevalence against slope layer, whereas the swelling and slope layers have equal importance with each other, since the precautions needed to overcome the possible problems due to these three layers resemble each other in the aspect of easiness and are more practical than the precautions needed for the other layers.

### **5.3.2. Assigning Rank Values**

The AHP method cannot only be used to assess weights but can also be used to assess the performance of alternatives by pairwise comparison of the alternatives (Janssen, 1992).

In order to assign the rank values to the classes of each thematic map, the pairwise comparison matrix is prepared separately for the thematic maps, in the scope of Table 5.3. The pairwise comparison matrix preparation criteria and the related tables for each thematic map are given below:

- The pairwise comparison matrix for liquefaction thematic map is given in Table 5.5. The 'no liquefaction' class has extremely high prevalence to the 'high liquefaction potential ( $f_s < 1.0$ )' class, whereas it has very strong prevalence against 'moderate liquefaction potential' class. On the other hand the 'liquefaction potential' class has only moderate prevalence to the 'high liquefaction potential' class, since in that class there is still a danger of liquefaction.

**Table 5.5.** Pairwise comparison matrix for liquefaction thematic map.

	No liquefaction potential	Moderate liquefaction potential	High liquefaction potential
No liquefaction potential	1	7	9
Moderate liquefaction potential	1/7	1	2
High liquefaction potential	1/9	1/2	1

- The pairwise comparison matrix for flood thematic map is given in Table 5.6. The 'non-flood areas' class has strong prevalence against the 'flood-prone areas' class.

**Table 5.6.** Pairwise comparison matrix for flood thematic map.

	Non-flood areas	Flood-prone areas
Non-flood areas'	1	1/5
Flood-prone areas	5	1

- The pairwise comparison matrix for soil thematic map is given in Table 5.7. Due to the soil behavior the 'bedrock' class has moderate prevalence against 'SC', while it has strong, strong-very strong, and very strong prevalence to the 'MH-ML', 'CL' and 'CH' classes respectively.

The 'SC' class has moderate, strong and strong-very strong prevalence against 'ML-MH', 'CL' and 'CH' classes respectively.

The 'ML-MH' class has moderate and moderate-strong prevalence against 'CL' and 'CH' classes respectively, whereas 'CL' class has moderate prevalence against 'CH' class.

**Table 5.7.** Pairwise comparison matrix for soil thematic map.

	Bedrock	SC	MH / ML	CL	CH
Bedrock	1	3	5	6	7
SC	1/3	1	3	5	6
MH / ML	1/5	1/3	1	3	4
CL	1/6	1/5	1/3	1	3
CH	1/7	1/6	1/4	1/3	1

- The pairwise comparison matrix for depth to groundwater table thematic map is given in Table 5.8. The '>10m' class has very strong prevalence against '0-5m' class and equal-moderate prevalence to the '5-10m' class. Since the possible problems caused by the presence of water during construction decreases significantly when depth to groundwater table exceeds 5m. The '5-10m' class has moderate-strong prevalence against '0-5m'.

**Table 5.8.** Pairwise comparison matrix for depth to groundwater table thematic map.

	> 10 m	5 – 10 m	0 – 5 m
> 10 m	1	2	7
5 – 10 m	1/2	1	4
0 – 5 m	1/7	1/4	1

- The pairwise comparison matrix for swelling thematic map is given in Table 5.9. The 'bedrock' class has strong and moderate prevalence to the 'medium expansion' and 'low expansion' classes respectively, whereas the 'low expansion' class has moderate prevalence against medium expansion.

**Table 5.9.** Pairwise comparison matrix for swelling thematic map.

	Bedrock	Low expansion	Medium expansion
Bedrock	1	3	5
Low expansion	1/3	1	3
Medium expansion	1/5	1/3	1

- The pairwise comparison matrix for slope thematic map is given in Table 5.10. The '2-6' class has moderate and strong-very strong prevalence against '<2 & 6-12' and '>12' classes respectively, while '<2 & 6-12' class has strong prevalence against '>12' class, since with simple adding precautions the '2 & 6-12' class can also be suitable for residential areas.

**Table 5.10.** Pairwise comparison matrix for slope thematic map.

	Most favorable slope class	Intermediate slope class	Least favorable slope class
Most favorable slope class	1	3	6
Intermediate slope class	1/3	1	5
Least favorable slope class	1/6	1/5	1

### 5.3.3. Obtaining Overall Weight and Rank Values

In order to obtain the overall weighting/ranking values, Expert Choice Inc. suggests that the eigenvector solution is the best approach, which has been demonstrated mathematically by Saaty (1990). The solution for the eigenvector is explained in the following steps:

1. A short computational way to obtain this weighting/ranking is to raise the pairwise matrix to powers that are successively squared each time.
2. The row sums are then calculated and normalized.

3. The computer is instructed to stop when the difference between these sums in two consecutive calculations is smaller than a prescribed value.

Applying the above method, the overall weight values of the layers and the overall rank values of the classes of each layer is obtained.

The pairwise comparison matrix is squared; row sums are calculated and normalized, following this the obtained result matrix is squared; row sums are calculated and normalized. This process is repeated until the difference between the normalized values becomes exactly zero. When the difference value is zero, then the normalized values are taken as weight/rank values for the classes/layers. The computed weight and rank values are given in Table 5.11.

**Table 5.11.** The computed weight and rank values.

LAYERS	WEIGHTING	CLASSES	RANKING
Liquefaction potential layer	0,350722	No liquefaction potential	0,792757
		Moderate liquefaction potential	0,131221
		High liquefaction potential	0,076022
Flood susceptibility layer	0,256510	Non-flood areas	0,833333
		Flood-prone areas	0,166667
Soil layer	0,184303	Bedrock	0,496900
		SC	0,264927
		MH / ML	0,129109
		CL	0,069362
		CH	0,039702
Depth to groundwater table layer	0,102535	>10 m	0,602629
		5-10 m	0,315029
		0-5 m	0,082342
Swelling potential layer	0,057615	Bedrock	0,636986
		Low expansion	0,258285
		Medium expansion	0,104729
Slope layer	0,048315	Most favorable slope class	0,634838
		Intermediate slope class	0,287203
		Least favorable slope class	0,077959

### 5.3.4. Consistency Ratio

The consistency ratio is calculated in order to determine the pairwise comparisons are consistent or not. The consistency ratio (CR) is designed in such a way that if  $CR < 0.10$ , the ratio indicates a reasonable level of consistency in the pairwise comparisons; if however  $CR \geq 0.10$ , the values of the ratio are indicative of inconsistent judgments (Malczewski, 1999).

In order to calculate the consistency ratio; weighted sum vector, consistency vector, lambda ( $\lambda$ ), consistency index (CI) and random inconsistency index (RI) is needed. The schematic diagram for the calculation of the consistency ratio is given in Figure 5.7. The calculations of the parameters mentioned are explained below according to Malczewski (1999):

- Weighted sum vector is calculated by multiplying the weight for the 1<sup>st</sup> criterion with the 1<sup>st</sup> column of the original pairwise comparison matrix, the weight for the 2<sup>nd</sup> criterion with the 2<sup>nd</sup> column of the original pairwise comparison matrix, ... , then the weight for the n<sup>th</sup> criterion with the n<sup>th</sup> column of the original pairwise comparison matrix; finally, summing these values over the rows.
- Consistency vector is calculated by dividing the weighted sum vector by the criterion weights determined previously.
- Lambda ( $\lambda$ ) is simply the average value of the consistency vector.
- The calculation of consistency index (CI) is based on the observation that  $\lambda$  is always greater than or equal to the number of criteria under consideration (n) for positive, reciprocal matrixes, and  $\lambda = n$  if the pairwise comparison matrix is a consistent matrix. Accordingly,  $\lambda - n$  can be considered as a measure of the degree of inconsistency. The CI term provides a measure of departure from consistency, and it can be normalized as:

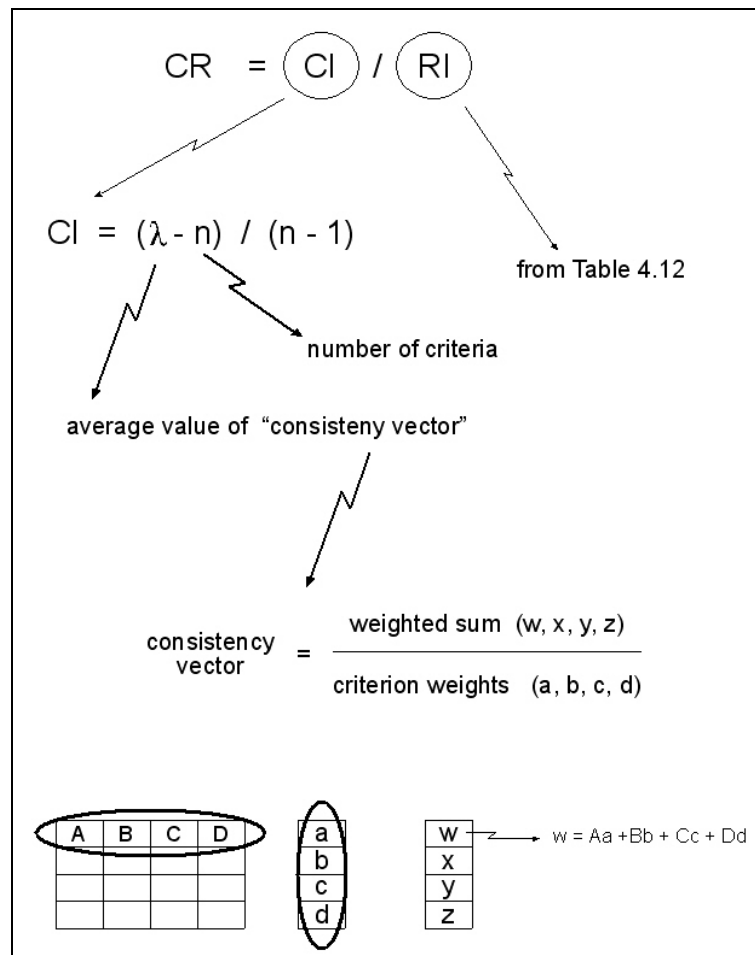
$$CI = (\lambda - n) / (n - 1)$$

- Random inconsistency index (RI) is taken from the Table 5.12 by Malczewski (1999). This table is explained as being adapted from Saaty (1980).
- Consistency ratio (CR) is defined as:

$$CR = CI / RI$$

**Table 5.12.** 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 5.7.** Schematic diagram of consistency ratio calculation.



The calculation of the consistency ratio for the assigned *weight values* of layers and the assigned rank values for the classes of each layer for this study is explained below.

The weighted sum vector and the consistency vector of the weight values assigned to layers are calculated and given in Table 5.13.

**Table 5.13.** The weighted sum vector and the consistency vector of the weight values assigned to layers

	Weighted Sum Vector	Consistency Vector
Liquefaction potential	2,148246	6,125204
Swelling potential	0,352904	6,125204
Soil	1,128895	6,125204
Depth_to_groundwater table	0,628045	6,125204
Slope	0,295940	6,125204
Flood susceptibility	1,571175	6,125204

$$\lambda = 36.751225 / 6 = 6.125204175$$

$$CI = (6.125204175 - 6)/(6 - 1) = 0.025040835$$

$$RI = 1.24 \text{ (from Table 5.12 )}$$

$$CR = 0.025040835 / 1.24 = 0.020194222$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

The consistency ratio for the *rank values* assigned to the classes of each layer is given below separately for each layer:

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *liquefaction layer* is calculated and given in Table 5.14.

**Table 5.14.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of liquefaction layer.

	Weighted Sum Vector	Consistency Vector
<b>No liquefaction potential</b>	2,395499	3,021730
<b>Moderate liquefaction potential</b>	0,396515	3,021730
<b>High liquefaction potential</b>	0,229716	3,021730

$$\lambda = 9.065190 / 3 = 3.021729922$$

$$CI = ( 3.021729922 - 3 ) / ( 3 - 1 ) = 0.010864961$$

$$RI = 0.58 \text{ (from Table 5.12 )}$$

$$CR = 0.010864961 / 0.58 = 0.018732692$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *flood layer* is calculated and given in Table 5.15.

**Table 5.15.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of flood layer.

	Weighted Sum Vector	Consistency Vector
<b>Flood-prone areas</b>	0,333333	2,000000
<b>Non-flood areas</b>	1,666667	2,000000

$$\lambda = 4.000000 / 2 = 2.000000$$

Since  $\lambda = n$ , the pairwise comparison matrix is a consistent matrix.

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *soil layer* is calculated and given in Table 5.16.

**Table 5.16.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of soil layer.

	Weighted Sum Vector	Consistency Vector
<b>Bedrock</b>	2,631314	5,295466
<b>SC</b>	1,402911	5,295466
<b>MH - ML</b>	0,683693	5,295466
<b>CL</b>	0,367307	5,295466
<b>CH</b>	0,210240	5,295466

$$\lambda = 26.477329 / 5 = 5.295465778$$

$$CI = ( 5.295465778 - 3 ) / ( 3 - 1 ) = 0.073866445$$

$$RI = 1.12 \text{ (from Table 5.12 )}$$

$$CR = 0.073866445 / 1.12 = 0.065952183$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *depth to groundwater table layer* is calculated and given in Table 5.17.

**Table 5.17.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of depth to groundwater table layer.

	Weighted Sum Vector	Consistency Vector
> 10 m	1,809081	3,001982
5 – 10 m	0,945711	3,001982
0 – 5 m	0,247189	3,001982

$$\lambda = 9.005945 / 3 = 3.001981509$$

$$CI = ( 3.001981509 - 3 ) / ( 3 - 1 ) = 0.000990754$$

$$RI = 0.58 \text{ (from Table 5.12 )}$$

$$CR = 0.000990754 / 0.58 = 0.001708197$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *swelling layer* is calculated and given in Table 5.18.

**Table 5.18.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of swelling layer.

	Weighted Sum Vector	Consistency Vector
<b>Bedrock</b>	1,935488	3,038511
<b>Low expansion</b>	0,784802	3,038511
<b>Medium expansion</b>	0,318222	3,038511

$$\lambda = 9.115533 / 3 = 3.038511091$$

$$CI = ( 3.038511091 - 3 ) / ( 3 - 1 ) = 0.019255545$$

$$RI = 0.58 \text{ (from Table 5.12 )}$$

$$CR = 0.019255545 / 0.58 = 0.033199216$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

The weighted sum vector and the consistency vector of the rank values assigned to the classes of *slope layer* is calculated and given in Table 5.19.

**Table 5.19.** The weighted sum vector and the consistency vector of the rank values assigned to the classes of slope layer.

	Weighted Sum Vector	Consistency Vector
<b>Most favorable slope class</b>	1,964200	3,094015
<b>Intermediate slope class</b>	0,888610	3,094015
<b>Least favorable slope class</b>	0,241206	3,094015

$$\lambda = 9.282045 / 3 = 3.094015108$$

$$CI = ( 3.094015108 - 3 ) / ( 3 - 1 ) = 0.047007554$$

$$RI = 0.58 \text{ (from Table 5.12 )}$$

$$CR = 0.047007554 / 0.58 = 0.081047507$$

Since  $CR < 0.10$ , the pairwise comparisons are consistent.

As can be observed from the calculated consistency ratios, all of the pairwise comparisons applied in order to obtain the microzonation map are found to be consistent.

### 5.3.5. Result Map of AHP

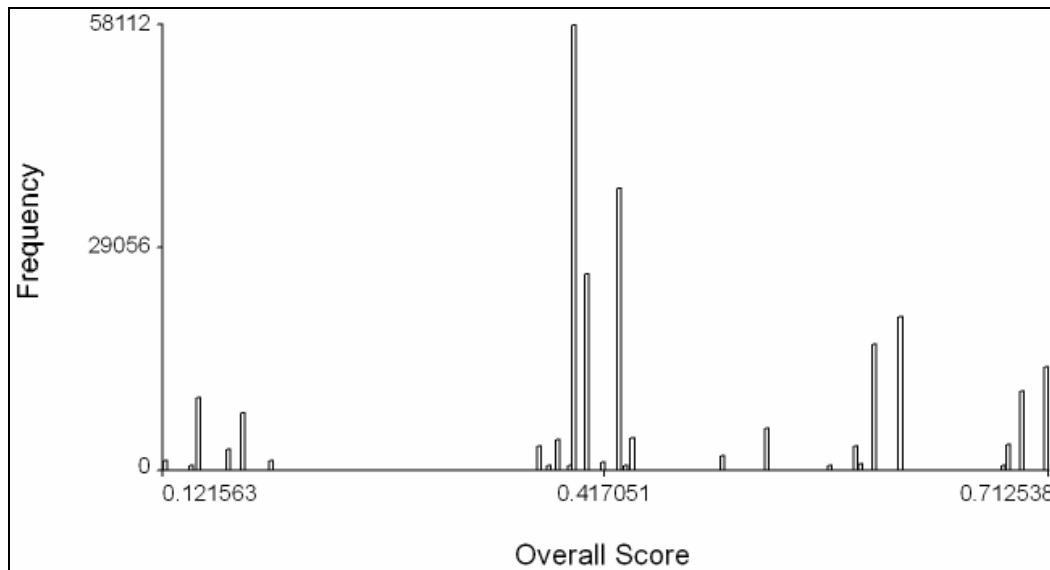
The geotechnical microzonation map of the study area using results of AHP method, is prepared in a similar manner with that of SAW method. Each pixel of the output microzonation map ( $M_i$ ) is also calculated by using the following summation:

$$M_i = \sum_j w_j x_{ij}$$

where,  $x_{ij}$  = rank value of the  $i^{\text{th}}$  class with respect to the  $j^{\text{th}}$  layer

$w_j$  = normalized weight of the  $j^{\text{th}}$  layer

Thus, the normalized weight value assigned for each layer is multiplied by the standardized rank value given to the classes of that layer. Finally the summation of the products is calculated. The histogram of the microzonation map is given in Figure 5.8.

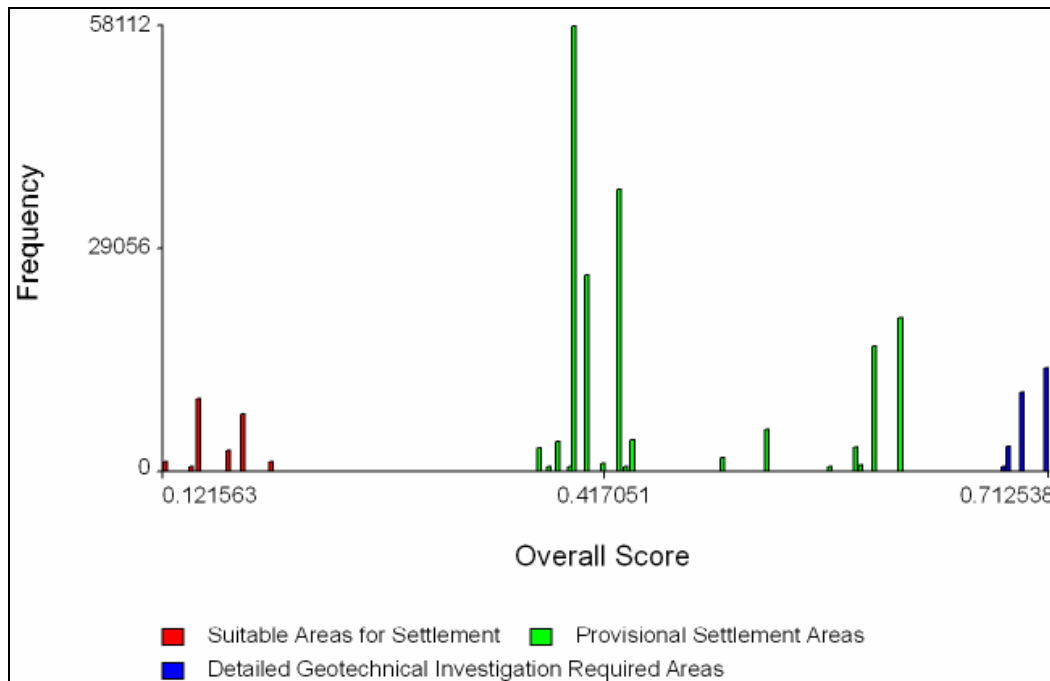


**Figure 5.8.** Histogram of the microzonation map obtained from the weight and rank values assigned by using AHP method.

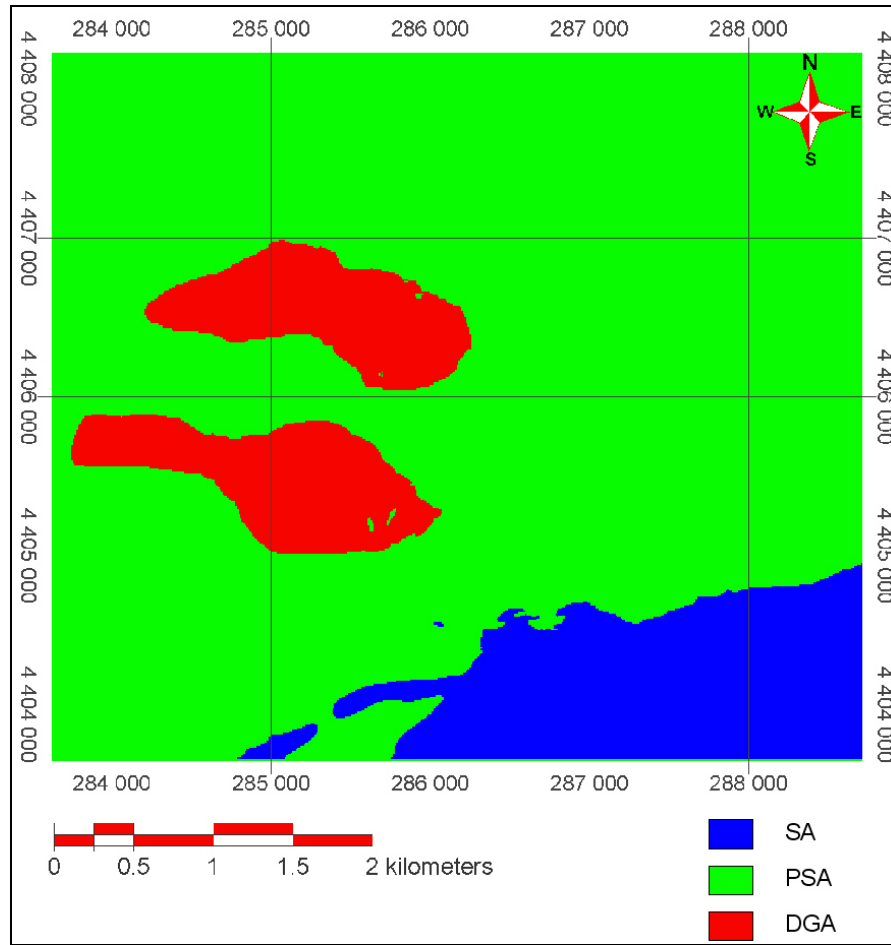
The microzonation map of the study area is categorized as:

- SA: Suitable Areas for Settlement
- PSA: Provisional Settlement Areas
- DGA: Detailed Geotechnical Investigation Required Areas

The microzonation map prepared by using the AHP method is divided into these three zones by using the histogram of the microzonation map. The boundaries of these zones are shown on the histogram of the microzonation map in Figure 5.9. The microzonation map prepared by using the AHP method is given in Figure 5.10.



**Figure 5.9.** Histogram showing the boundaries of the three zones of the microzonation map.



**Figure 5.10.** The microzonation map prepared by using the AHP method. (SA: Suitable areas for settlement, PSA: Provisional settlement areas, DGA: Detailed geotechnical investigation required areas)

#### 5.4. Comparison of Microzonation Maps

In order to compare the microzonation maps which are prepared using SAW and AHP methods, the common areas and non common areas are revealed. During this process, firstly the classes of the microzonation maps are transferred from the ordinal scale to the interval scale. The numbers are assigned to the classes of both microzonation maps, in such a way that, in the addition of these two microzonation maps, the results can be easily interpreted. The assigned numbers to the classes of both microzonation maps are shown in Table 5.20.



**Table 5.20.** The numbers assigned to the classes of both microzonation maps.

	Methods	SAW	AHP
Classes			
DGA		1	10
PSA		2	20
SA		3	30

Afterwards, these two microzonation maps are added to be able to find out the common and non common areas. The possible result numbers of the addition process are shown in Table 5.21 with the corresponding percentages obtained from the addition process.

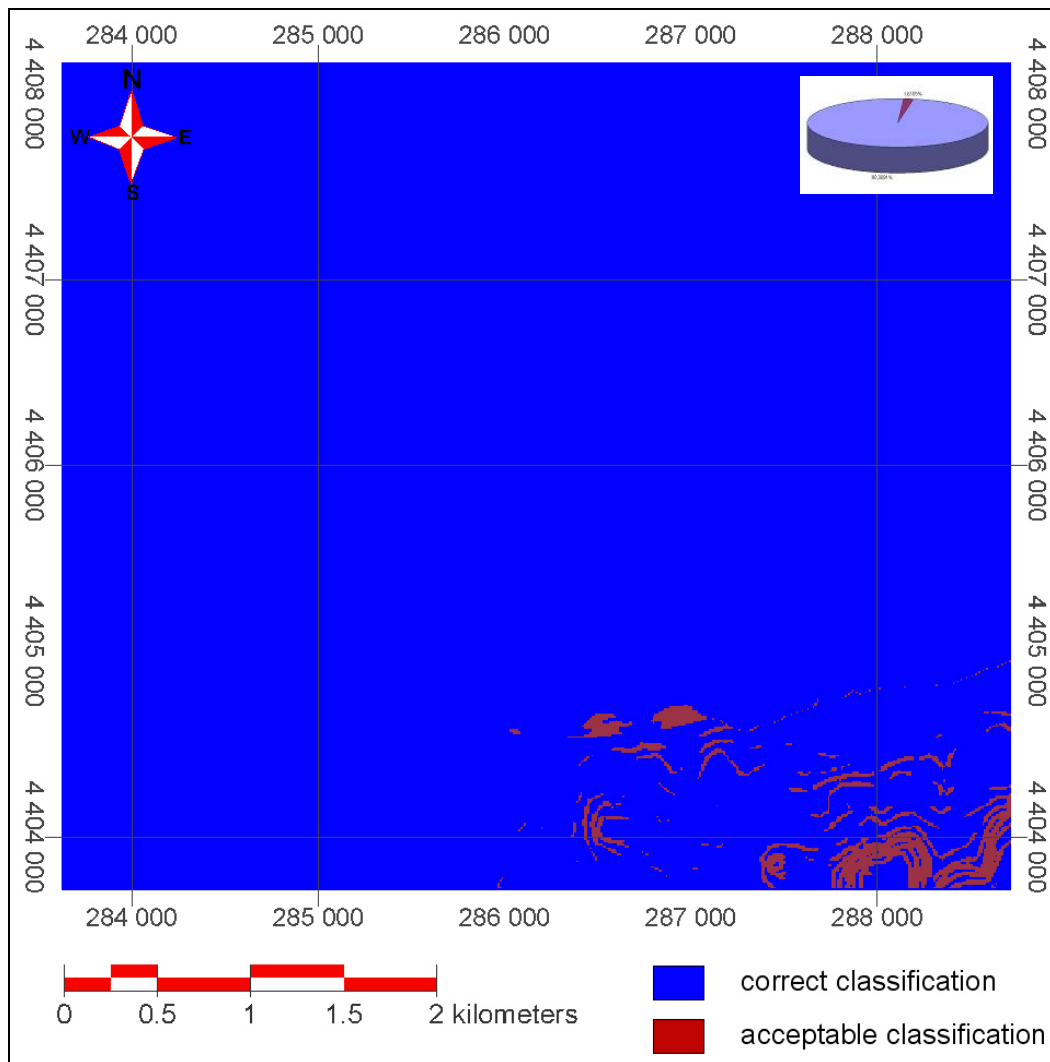
**Table 5.21.** Possible result numbers of the addition process with the corresponding percentages.

	1	2	3	
10 20 30	11 9.50 %	12 0%	13 0%	<div style="display: flex; flex-direction: column; gap: 5px;"> <div><span style="color: blue;">■</span> correct classification</div> <div><span style="color: lightgreen;">■</span> acceptable classification</div> <div><span style="color: red;">■</span> not acceptable classification</div> </div>
	21 0%	22 78.59 %	23 0%	
	31 0%	32 1,61 %	33 10.29 %	

As a result of the comparison analysis of the study area, the two microzonation maps are found to give similar outputs. In the comparison output map; only the classes of 11, 22, 33, and 32 are found. The absence of classes 13 and 31 shows that there is no conflict between the microzonation maps. The locations corresponding to the classes in the study area is given in Figure 5.11, and the meanings of the class numbers are given below:

- Class 11 means that the “DGA” classes are found in both of the microzonation maps prepared with the SAW and AHP methods.
- Class 22 means that the “PSA” classes are found in both of the microzonation maps prepared with the SAW and AHP methods.
- Class 33 means that the “SA” classes are found in both of the microzonation maps prepared with the SAW and AHP methods.
- Class 32 means that the “PSA” class found in the microzonation map prepared with SAW method is found as “SA” class in the microzonation map prepared with AHP method.

As a result, the quotient of the correct classification category (Classes 11, 22 and 33) in the comparison of two microzonation maps is found to be 98.39 % of the total study area.



**Figure 5.11.** The locations of the comparison classes. Inset shows portion of correct classification to misclassification

## CHAPTER 5

### DISCUSSION

Multicriteria Decision Analysis Methods assume implicitly that complete information is available so that the decision maker knows precisely the criterion outcomes. However, in real world situations, the information available to the decision maker is subject to errors.

The GIS data and data production errors can be investigated in two categorizes. First one is the errors associated with imprecision in the measurement of criterion values, and the second one is the errors due to the process of translating real-world entities into map layers.

In this study, the original geological, hydrogeological, and geotechnical data are considered to be quite satisfactory. However, the number of boreholes (especially for the groundwater level observations) could be increased to obtain more information for better geotechnical characterization of the study area. For the preparation of the data layers, the continuous surfaces are formed from the interpolation of this raw point/line data. During this interpolation process, some errors have occurred due to lack of information between the consecutive points/lines. These errors are tried to be minimized in the preparation of DEM of the study area by applying several surface fitting methods and choosing the method with least RMSE value. For the maps prepared using the borehole data, the point data is interpolated manually as accurate as possible.

In addition to the GIS dataset errors, there is uncertainty involved in the specification of decision-maker preferences. In fact, the criterion map errors and decision maker preference errors are interrelated. The information derived from criterion maps is an essential element for specifying the decision maker's preferences. For reliable results, the decision maker is expected to be an expert to make preferences since the importance of each criterion can be overestimated or underestimated according to these preferences.

The subjectivity of the preferences comes mainly from the assignment of weight and rank values. In the scope of this study, the weight and rank values which are used both in SAW and AHP methods, are assigned according to the engineering judgment.

The microzonation maps which are obtained as results of these two methods, and found to be consistent with each other. Although the two resultant microzonation maps are almost the same, the microzonation map prepared using AHP method is chosen to be the final map of this study. The reason for this choice is due to its less subjectivity according to its strategy as a method.

Decision analysis is a set of systematic procedures for analyzing complex decision problems. The basic strategy is to divide the decision problem into small, understandable parts; analyze each part; and integrate the parts in a logical manner to produce a meaningful solution. (Malczewski, 1999)

In the AHP method, this strategy is applied in assigning rank and weight values since only two layers/classes are considered and compared at a time.

## CHAPTER 6

### CONCLUSION AND RECOMMENDATIONS

The aim of the study is to prepare geotechnical microzonation map regarding the suitability of the residential areas for the chosen section in Eskişehir downtown area. During the preparation of the microzonation map, a large amount of data is needed to be spatially related; therefore the use of GIS was essential. Since MCDA methods provide the tools for aggregating the geographical data and the decision maker's preferences, GIS-based MCDA methods are used for the preparation of the microzonation map.

The main steps of the study are summarized at the following:

- Preparation of slope, flood, soil, depth to groundwater table, swelling and liquefaction layers,
- Assignment of the weight and rank values to the layers and the classes of each layer respectively using SAW method,
- Preparation of the microzonation map using SAW method,
- Assignment of the weight and rank values to the layers and the classes of each layer respectively using AHP method,
- Preparation of the microzonation map using AHP method,
- Comparison of the two microzonation maps.

As a result of the comparison of the two microzonation maps, the results are found to be consistent with each other. The microzonation map prepared by using AHP method is determined to be the final map of the study.

According to this final map; the majority of the study area is found to be in the "Suitable Areas for Settlement" (Zone I) and "Provisional Settlement Areas" (Zone II) zones. The minority quotient of the study area is found to be in Zone III, in which detailed geotechnical investigations are required. For the already settled areas which are not found in the first zone, the necessity of the precautions should be considered.

On the other hand, in a particular decision problem, the combination of different MCDA methods such as AHP and goal programming can be considered. The usage of AHP method for structuring the problem and assigning the weight/rank values to the layers/classes, and subsequently the usage of goal programming for the determination of the optimal solution to the problem is recommended.

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