# EVALUATION OF SETTLEMENT SITES BEYOND THE SCOPE OF NATURAL CONDITIONS AND HAZARDS BY MEANS OF GIS BASED MCDA: YEŞILIRMAK CATCHMENT

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

BY

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IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
GEODETIC AND GEOGRAPHIC INFORMATION TECHNOLOGIES

MAY 2010

Approval of the thesis:

**EVALUATION OF SETTLEMENT SITES BEYOND THE SCOPE OF NATURAL CONDITIONS AND HAZARDS BY MEANS OF GIS BASED MCDA: YEŞİLIRMAK CATCHMENT**

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# ABSTRACT

EVALUATION OF SETTLEMENT SITES BEYOND THE SCOPE OF NATURAL CONDITIONS AND HAZARDS BY MEANS OF GIS BASED MCDA: YEŞILIRMAK CATCHMENT

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June 2010, 70 Pages

Our country is a risky position in terms of natural disasters. In the long run, preferentially settlement areas were selected to ensure maximum benefits in terms of both economic and security aspects, other criteria is not taken account when selection of sites.

The main purpose of this study is to examine and compare the properties of settlement location based on natural hazard and environmental constraints to be able to understand the interaction between the settlements and natural conditions at the regional scale of Yeşilırmak Basin.

A MCDA was set up with 10 different data layers in two data domains (environmental and natural hazards domains), are evaluated. The results of the

MCDA scores are then transferred to settlement databases in order to evaluate the number of existing settlements in different environmental and natural hazard related suitability classes.

It is found that almost 29% of Yeşilırmak catchment is environmentally favorable for settlement, and in coherence with that 41% of all existing settlements are located in this zone, indicating a clear preference among the perception of environmentally better places to be settled in.

On the other hand with respect to the natural hazards dataset, the locations of the settlements fail to create any preference, as 73,32% of the area is used by 73,50% of existing settlements, which indicates that the perception of natural hazards are low and do not effect settlement criteria, while the acceptable risk of community is high.

Keywords : Multi Criteria Decision Analysis (MCDA), Geographic Information Systems (GIS), Analytical Hierarchy Process (AHP), Settlement site selection, Yeşilırmak Basin, Planning

# ÖZ

CBS TABANLI MCDA YARDIMIYLA DOĞAL ŞARTLAR VE AFETLER GÖZ ÖNÜNE ALINARAK YERLEŞİM YERLERİNİN DEĞERLENDİRİLMESİ: YEŞILIRMAK HAVZASI

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Mayıs 2010, 70 Sayfa

Ülkemiz doğal afetler açısından riskli bir konumda bulunmaktadır. Tarih içerisinde gerek güvenlik gerekse ekonomik açıdan maksimum fayda sağlanabilecek bölgeler öncelikli yerleşim alanları olarak seçilmiş ve buralara yerleşilmiştir.

Bu çalışmanın temel amacı, Yeşilırmak havzasını bölgesel ölçekte, yerleşimler ve çevresel şartlar arasındaki ilişkiyi anlamak için yerleşim yerlerinin özelliklerini doğal afetlere ve çevresel kısıtlara dayandırarak incelemek ve karşılaştırmaktır.

MCDA, 2 temel alanda (çevresel ve doğal afetler alanlarında) 10 farklı veri katmanına göre değerlendirilmiştir. Çevresel ve doğal afetler açısından uygunluk sınıflarında bulunan mevcut yerleşimlerin sayısının çıkarılabilmesi için MCDA skorları yerleşim yerleri veritabanına aktarılmıştır.

Yeşilırmak su toplama havzasının hemen hemen %29 u yerleşim yerleri için çevresel özellikler açısından uygun olduğu ve bu bölgelerde mevcut yerleşimlerin %41'nin bulunduğu, buda çevresel olarak daha iyi yerlerde yerleşim yapma isteği açık bir şekilde çalışma sonucunda tespit edilmiştir.

Diğer taraftan doğal afet veri seti açısından, yerleşim yeri seçimi için bir tercihin bulunmadığını, çalışma bölgesinin risksiz olan %73,32'lik bölümünde yerleşimlerin %73,50 bulunduğundan anlaşılmakta, buda halkın risk kabul edebilme toleransı içerisinde olduğu sürece afete duyarlı yerleşim yerleri seçimi için herhangi bir tercihinin olmadığı ve seçimi etkilemediğini göstermektedir.

Anahtar Kelimeler : Çoklu ölçütlü Karar Analizleri (MCDA), Coğrafi bilgi Sistemleri (CBS), Analitik Hiyerarşi Yöntemi (AHY), Yerleşim alanı yer seçimi, Yeşilırmak Havzası, Planlama

# ACKNOWLEDGMENTS

I would like to express my deep gratitude for Assoc. Prof. Dr. M. Lütfi Süzen regarding his constant support, major contributions, unlimited patience and the valuable guidance he has provided. His crucial and effective interventions during the whole study have provided me great ease at handling the problems.

I am grateful to Inst. Gözde Biricik Özacar for her constant support and enlightening vision that helped me out many times throughout every stage of the study. The friendly attitude combined with the practical knowledge she shared, had a major influence on me.

I would like to thank to all my colleagues who helped me to solve the problems and motivational supports and especially thank to my managers, for their patience and supports in the Proline.

I am very thankful for the planners, who work in the Ministry of Environmental and Forestry, General Directorate of Environmental Impact Assessment (EIA) and Planning, Planning and Strategic EIA department, Planning of Marmara and Black Sea Regions Divisions, for their contribution of technical support of field experience during the study period, while sharing their practical experiences.

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# CHAPTER 1

# 1. INTRODUCTION

The decision on “where to settle” has long been a debate throughout the history. There have been many reasons changing from military threats to political governance, from cultural advancement to presence of higher crop yields. This variation could be seen both in spatial clusters as well as for a single site. Hence for any settlement site that is observed governs the cumulated decisions throughout time. Even though the settlement site meets the best suitable environmental conditions, the site still might be prone to natural hazards, which in turn describes the acceptable risk of the community present at that time period.

First settlement areas are believed to be selected according to only general rights, proximity of natural resource, security, economy etc.. These priorities are very basic level criteria of the selection. Human community’s life style and the priorities have been changed (for example environmental impacts, natural hazards, needs of industrialization, etc.) and also keeps changing. Based on all these issues, process of finding appropriate settlement areas, had became more and more complex regardless of time.

## 1.1. Purpose and Scope

Large part of the Turkey is under risk of natural hazards. But in time especially ancient cities, people settle regions without considering natural hazards and protecting themselves from the hazards damages. Even some disasters had believed to be sent by god(s) to punish the society. However the rationale logic behind this, is that from ancient times to recent, the priorities of people is based on economical, agricultural and security benefits, resulting in a conscious acceptable risk by the society.

In contemporaneous planning discipline one of the main complex topics is finding suitable areas for settling and working. There are so many criteria affecting the selection of these suitable areas. Because of the scarcity of unique solving methods, the complexity of the selection criteria and selection can be changed according to the location of the application areas, besides in different times planners apply different kind of planning approaches. Besides all this complexity, the application scale is also a challenging issue for the site selection problems.

The main purpose of this study is to examine and compare the properties of settlement location based on natural hazard and environmental constraints to be able to understand the interaction between the settlements and natural conditions at the regional scale of Yeşilırmak Basin. In order to approach the problem a Geographical Information Systems (GIS) based Multi Criteria Decision Analysis (MCDA) is set up to define a conceptual framework with contemporaneous planning experience, to be compared with the existing settlement locations.

## 1.2. Study Area

In order not to add a certain area limited bias, natural boundaries are selected throughout the study. Turkey is composed of 26 river basins and project area is chosen to be one of the important and relatively large one of these basins. Yeşilırmak basin is covering approximately 5% of surface area of the whole Turkey. There are 2862 settlements (counties and villages) and 11 provinces spread all over the basin.

Yeşilırmak basin is selected as the project site because of its prospective nature about natural disasters and wide variety of environmental conditions. The presence of active faults, the broad elevation range from sea level to 3300 meters, different amounts of rainfall, extensive drainage network and very dense settlement are the main parameters that lead to the selection of this basin.

Study area located at the north part of the Turkey (Figure 1.1). The extent of the area is $41^{o}$.39' north, $39^{o}$.48' south, $39^{o}$.81' west and $34^{o}$.49' east with WGS 1984 Datum. The basin area is about 4.000.000 hectares.

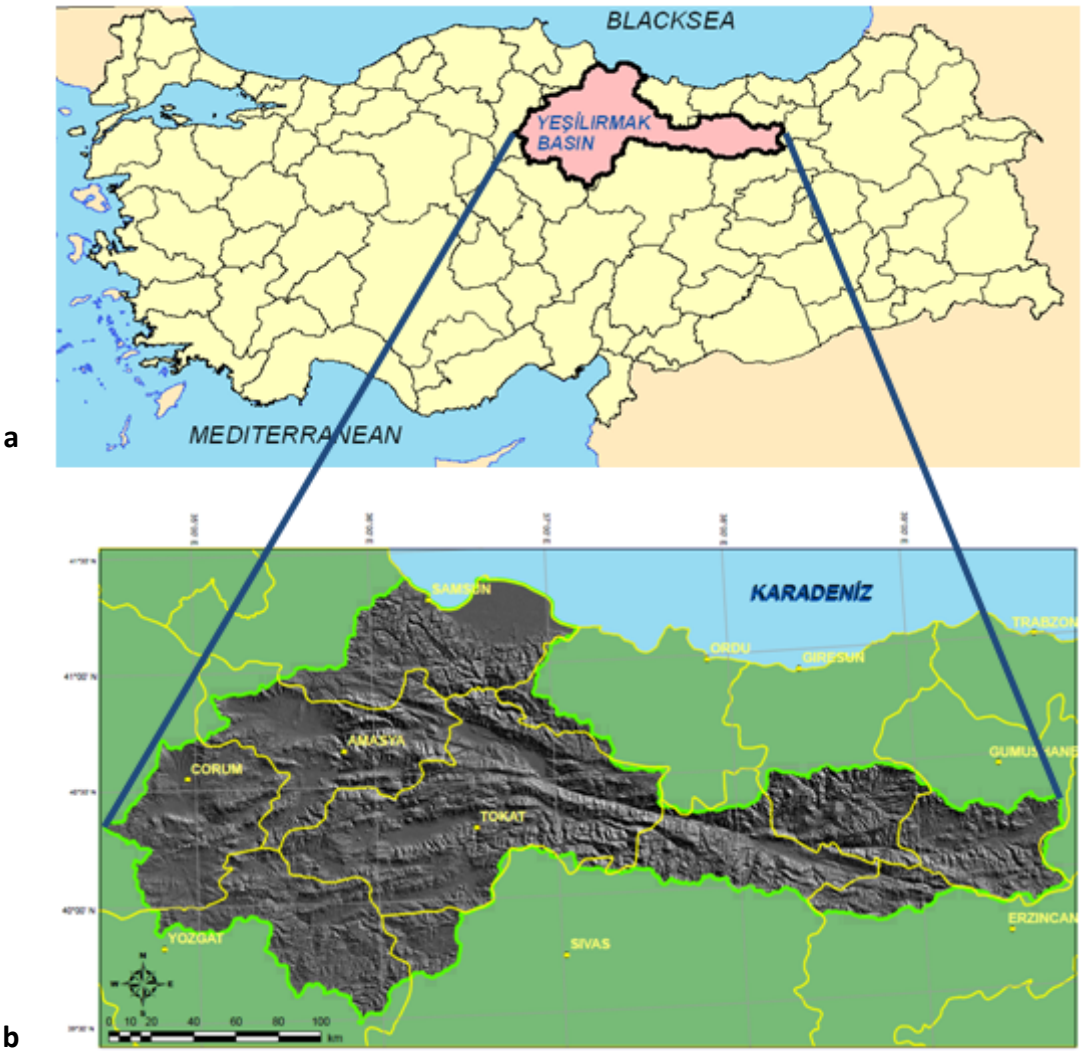



**Figure 1.1** - (a) General view of Project Area at the country level and (b) Yeşilırmak Basin

# CHAPTER 2

# 2. BACKGROUND INFORMATION

Scholars interested in settlement pattern research, mainly divided in three groups in favor of 3 different sets of settlement site factors. First group favors of the environmental features such as hydrology (Craig, 1986; Lockwood, 1988) and soil features (Bitterman, 1988; McNabb, 1988; Hornsby, 1990). For some scholars social influences are the determinants on settlement patterns/locations. According to Craig 1986, Elliot 1988 and Lockwood 1988 ethnic ties plays an important role in where to settle. And the third group of scholars insists on the power of the local economic factors such as the road networks, powerful landlords, wealth of the settlers (Gaffielo, 1987; Clarke and Brown 1987). This point of view reminds the complexity of this phenomenon. Although there have been certain researchers emphasize on ethnic attraction most geographers believe that settlement patterns develop as favoring the occupation of the best lands (Lehr, 1985; Lockwood, 1988). Roy and others (2002), tried to understand the settlement of Quebec's Upper St Lawrence regions with respect to the geomorphologic deposits, soil features, combined with other social factors such as the ethnic background of immigrants and the road network.

Archaeologists have long regarded the main characteristic of human settlement site selection patterns to be multi-factorial and very complex (Trigger, 1968). The environmental factors are also the determinants of the distributions of human settlements such as water availability, soil fertility, and natural food and other

resources (Kirch and Weisler, 1985). In addition to the environmental factors settlement patterns are also influenced by level of technology, security measures, sociopolitical and economic factors, and even ritual practices and ideological beliefs (Kirch and Weisler, 1985). Such complex, hierarchically nested determinants influenced the location of habitations (Chadwick *et al*., 2004). In that situation Multi-criteria Decision Analysis (MCDA) is used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information (Malczewski, 1996).

The spatial relationships between the human activities and the environmental features give us the settlement patterns that can explain the organization of human societies and their interactions with the natural environment (Kantner, 2010). In 1930s Julian Steward investigated the relationship between settlement patterns, population size and the environment. G.R. Willey used aerial photography and topographic maps to understand the organization of settlements in Vinu Valley (Willey, 1953). The next step was the usage of analytical techniques such as formal sampling methods, correlation of settlement configurations with different types of social organizations. Statistical techniques were employed to identify the patterns of settlements (Parsons, 1972). As the accessibility to powerful computers is increased more complex tools for analysis for larger areas with larger data sets were utilize with the help of GIS.

As part of a master degree this thesis attempts to understand the role played by the natural hazards in settlement patterns, along with fault lines, epicenters, flood zones, erosion areas, other factors such as soil, hydrology, precipitation, slope, elevation, aspect will also be examined in a GIS environment strengthened with MCDA.

## 2.1. Selection of Sites with GIS Based MCDA

Planning activities, by its nature require analysis of different data and approaches of together in one process. In order to solve a complex problem for certain purposes planers generally analyze and examine different types of input data with different kinds of approaches. Evaluation of these data and approaches with respect to the information regarding spatial positions are called “Suitable Site Selection Activities” (Olcan and Şeker, 2007).

One of the basic approaches for suitable site selection is Multi-criteria Decision Analysis (MCDA). It is an approach that it provides the decision-makers the information requested by emphasizing them among the huge data clusters. This method is the completion of the analysis activities enabling usage and evaluation of multi data layers that have different orders of priority basically together and in an integrated way. (Arcia, 2003)

In planning discipline to solve the problem, too many data are handled at the same time; which generate new problems resulting in complexity. MCDA is used to deal with the difficulties that decision-makers encounter in handling large amounts of complex information (Malczewski, 1996). The principle of the method is to divide the decision problems into smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner (Malczewski, 1996). So creation of decision tree is a main underlying part of MCDA. As it seen in Figure 2.1, criteria of suitable land fill sites are grouped into natural / environmental and artificial factors at first level of decision tree. As the level is lovered in the tree, evaluation of criteria is becoming less complex (Şener *et al.,* 2006).

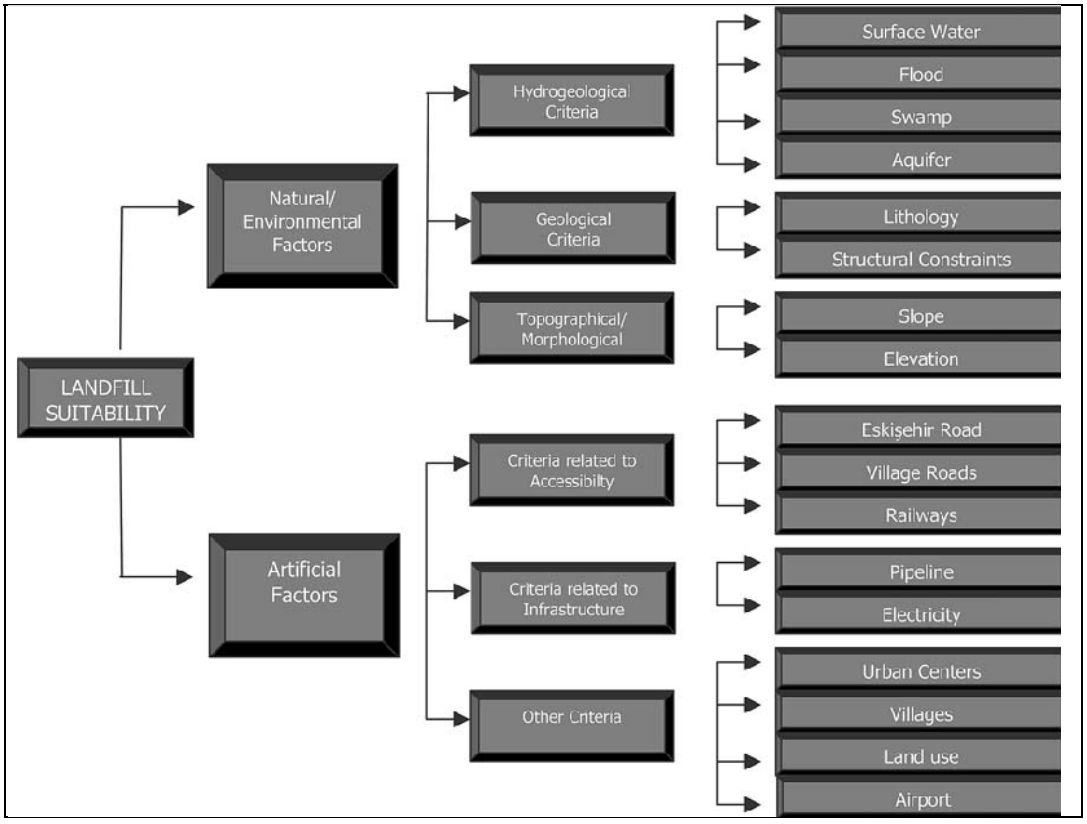



**Figure 2.1** - The decision tree developed for the landfill site selection problem River Network (Şener et al., 2006)

The integration of GIS and MCDA is a powerful tool to solve the suitable settlement site selection problem, because GIS provides efficient manipulation and presentation of the data and MCDA supplies consistent ranking of the potential landfill areas based on a variety of criteria (Malczewski, 1999).

### 2.1.1. Implementation of MCDA

MCDA activities are basically composed of 5 stages;

1. **Specifying the problem –** Definition of the problem needed to be solved is the initiative step of the activities to be carried out. The problems such as; where the appropriate areas to be located or where the industrial areas

should be placed are defined. According to each defined problematic issue, the steps to be followed will be shaped; data, thresholds and base maps will be varied.

2. **Specifying the criteria –** Determining correctly the data layers necessary for the solution of the specified problem is critically important for the outcome of the activity. Simply erroneously specified layers will conclude in erroneous outcomes. The layers specified here are the whole of the necessary components for the solution of the problem. Also any legislative component or constraint should be implemented here in this stage.

3. **Specifying the priority of the criteria according to each other –** To solve the defined problem the significance of each criterion is expected to be different. For example if the necessity is to find out the best site for agricultural development, the significance of the distance to the road and to the water resources of this region should be different. There are many different methods described below for this activity. Among these methods Analytic Hierarchy Process (AHP) that evaluates the impact of each criterion to other criterion by the users will be used in this study.

4. **Normalizing the data –** To process the data together, the attributes of the layers should be of same kind. As the obtained data will vary in terms of the attributes (such as the number, digital or text attributes), maximum and minimum values (like 0-1 or 0-100) digitally for the attributes to be used in all of the analysis activities should be defined and these values should be allocated according to the order of priority in solving the problems of attributes.

5. **Specifying the appropriate sites –** The normalized data are analyzed together and the outcome is attained. The final map is analyzed and if it is not found as successful, the criteria weights are changed and final map is recalculated.

### 2.1.2. Decision Rules

To integrate the criterion map layers and their weights, we can use some decision rules. It is very important to select appropriate rules for accomplishing the process of MCDA (Chankong and Haimes, 1983).

#### 2.1.2.1. Simple Additive Weighting (SAW)

Simple additive weighting also known as weighted linear combination or scoring methods; is a simple and frequently used multiattribute decision technique (Janssen, 1992; Eastman et.al, 1993; Malczewski, 1997). In this method, first the criteria is defined and criterion data is collected then the priority (weight) of each layers are defined and finally all criteria are summed out to yield in a result map.

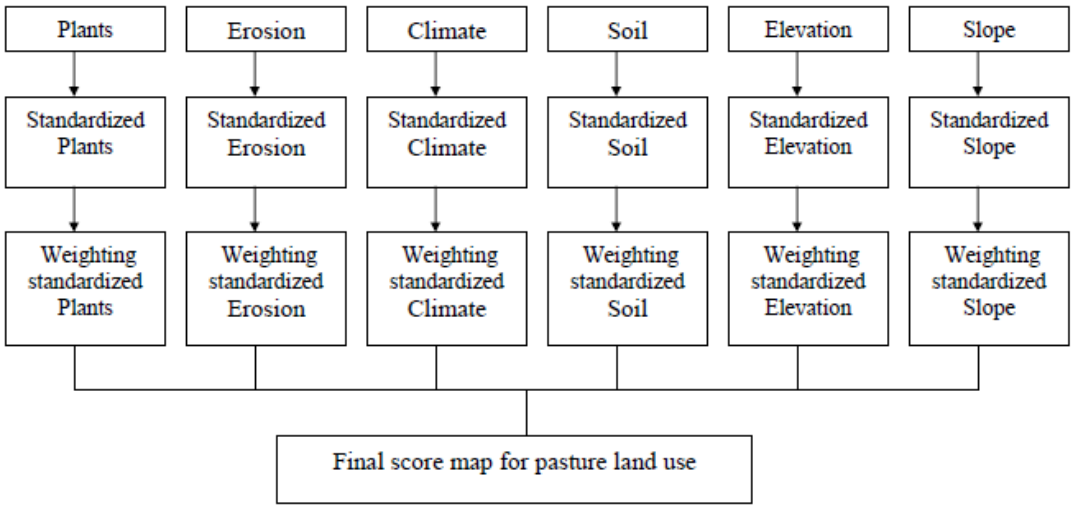



**Figure 2.2** - An example of SAW processing scheme (Bakhtiarifar et al., 2009)

#### 2.1.2.2. The Ideal Point Methods

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

#### 2.1.2.3. Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS)

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

According to this method, best option is the option that simultaneously is the nearest unit to ideal point and the hindmost minus ideal unit. The ideal unit is a hypothetical option that is the most desirable standardized weight level from each criterion between considered options and similarly minus ideal point includes worst standardized weight level between options TOPSIS involves either uniform increscent of desirability. (Bakhtiarifar et al., 2009)

#### 2.1.2.1. Ordered Weighted Average (OWA)

Provide a parameterized class of mean type aggregation operators. Many notable mean operators such as the max, arithmetic average, median and min, are members of this class. (Yager, 1988) They have been widely used in computational intelligence because of their ability to model linguistically expressed aggregation instructions.

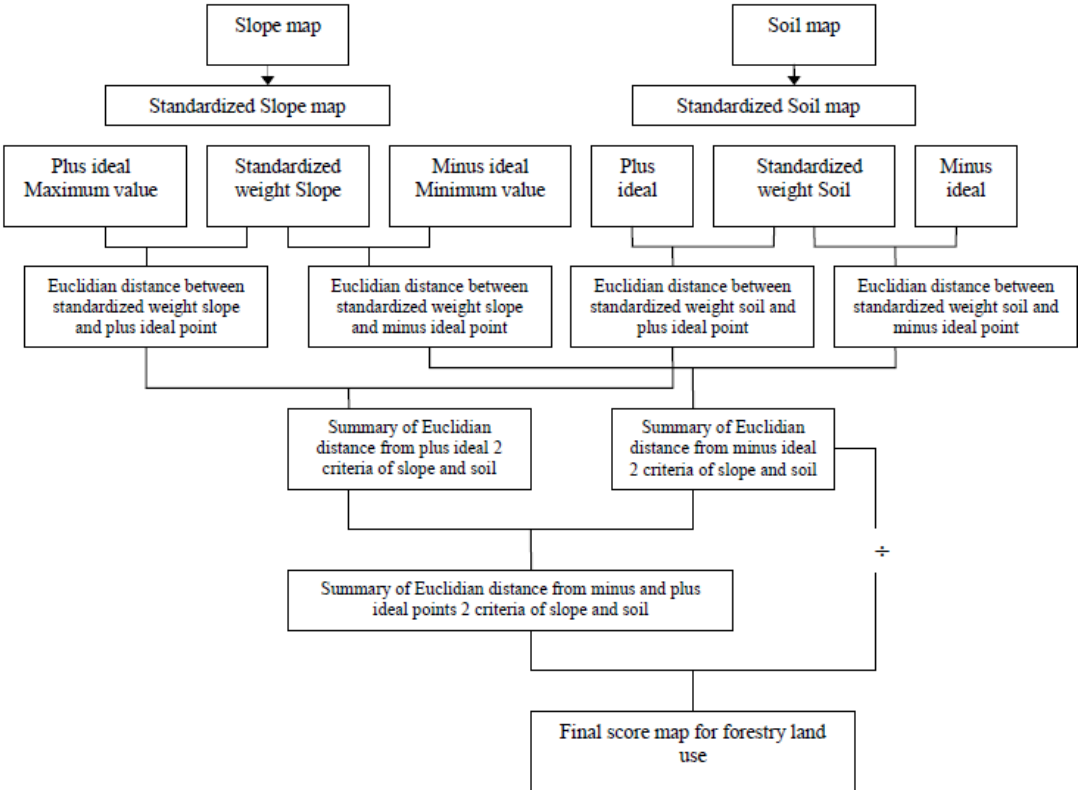



**Figure 2.3** - Sample of TOPSIS, (Bakhtiarifar et al., 2009)

### 2.1.2.2. Analytical Hierarchy Process (AHP)

In the Analytic Hierarchy Process (AHP) developed by Saaty (1980), a complex decision problem is decomposed into simpler decision problems to form a decision hierarchy. When developing the hierarchy; the top level is the ultimate goal which in this case is site selection (Şener, 2004).

In the AHP process, firstly problem is decomposed into simpler decision problems to form a decision hierarchy. At the top of the decision hierarchy there is a main goal, when decrease the hierarchy from the general to more specific until a level of attributes are reached and also each level must be linked to the next higher level (Duc, 2006).

After the decomposition stage is completed, cardinal rankings for criteria are determined, which is done by pairwise comparisons. In the AHP method, pairwise comparisons form the backbone of the methodology (Saaty, 1990). The complexity of the problem is reduced with pairwise comparison by each time comparing two criteria (Şener *et.al.,* 2006). Two alternatives and the importance in relation between them are considered at a time which provides easier ranking. In order to fill comparison matrix (Table 2.1), comparison judgment scale should be used as presented in Table 2.2. (Şener *et al.,* 2006).

As a result of evaluation of different MCDA decision rules (SAW, TOPSIS, AHP, The Ideal Point Methods, OWA) in planning perspective, AHP is decided to be the most appropriate one. The reasons behind this selection is the robust theoretical principles, numerous applications on different problems and disintegrating a complex problem into cognitive meaningful pairwise comparisons without losing the meaning of the criteria beyond the scope of the original problem.

**Table 2.1** - Sample comparison matrix (Atasoy et.al., 2008).

| | ***Slope*** | ***Landslide*** | ***Geology*** | ***Soil*** | ***Aspect*** | ***River*** | ***Land Cover*** |
|---|---|---|---|---|---|---|---|
| ***Slope*** | 1 | 1 | 3 | 3 | 7 | 3 | 5 |
| ***Landslide*** | 1 | 1 | 3 | 3 | 7 | 3 | 5 |
| ***Geology*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 |
| ***Soil*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 |
| ***Aspect*** | 1\7 | 1\7 | 1\6 | 1\6 | 1 | 1\6 | 1\4 |
| ***River*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 |
| ***Landcover*** | 1\5 | 1\5 | 1\4 | 1\4 | 4 | 1\4 | 1 |

**Table 2.2** - AHP Comparison Judgment Scale (Saaty, 1980).

| 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 |

## 2.2. Application Reviews of GIS Based MCDA

In real world people should always take decisions. Some of these decisions are very complex, because of too many inputs. Some of them are related to the geography or have criteria of spatial data. Therefore when it is came to the need of taking spatial decision; GIS based MCDA is used in literature. In this part of the thesis, 3 types of application samples from 3 application groups which are related to the topic of thesis are reviewed. One of them is suitable site selection of waste disposal site, the other one is related to the planning discipline, study of determining sustainable built-up areas and last one is the application in agriculture as land suitability evaluation using GIS for vegetable crops in Kathmandu Valley / Nepal. Waste disposal site selection is one of the serious main potential problem for most of the growing cities. Appropriate landfill site should be selected carefully by considering both regulations and constraints on other sources (Şener *et. al.,* 2006). In that case, the selection of site of land fill is a very complex MCDA structure, it has not only environmental constraints but also legislative ones.

Firstly, the input map layers are defined. There are sixteen layers including topography, settlements, roads, railways, airport, wetlands, infrastructures, slope, geology, land use, floodplains, aquifers and surface water (Şener et al., 2006).

Analysis are done by two different MCDA methods (Simple Additive Weighting and Analytic Hierarchy Process) in GIS environment, than comparison of the maps produced by these two different methods show that both methods yield conformable results (Şener et al., 2006).

The ranking of sixteen criteria is defined in Table 2.3. In GIS-based SAW method evaluation criteria scores should be standardized before processing of all criteria together (Malczewski, 1999). The scores are calculated by dividing the difference between the maximum raw score and a given raw score by the score range in Table 2.3 (Şener et al., 2006)

**Table 2.3** - The criterion weights defined for simple additive weighting (SAW) method (Şener *et al.,* 2006)

| Data layer | Weight | Normalized weights |
|---|---|---|
| Urban centers | 10 | 0.1136 |
| Villages | 9 | 0.1023 |
| Surface Water | 8 | 0.0909 |
| Flood | 8 | 0.0909 |
| Swamp | 8 | 0.0909 |
| Geology | 7 | 0.0795 |
| Aquifer | 7 | 0.0795 |
| Land use | 6 | 0.0682 |
| Slope | 5 | 0.0568 |
| Pipeline | 5 | 0.0568 |
| Electricity | 3 | 0.0341 |
| Elevation | 3 | 0.0341 |
| Highway E90 | 3 | 0.0341 |
| Airport | 3 | 0.0341 |
| Village Road | 2 | 0.0227 |
| Railway | 1 | 0.0114 |

Main objective of the AHP method is to decompose of complex decision problems into smaller one. So a decision tree is created before analysis processes began as it is shown in Figure 2.1. Than pairwise comparison matrix is evaluated for the AHP process (Table 2.4).

**Table 2.4** - The comparison matrix developed for the landfill site selection problem (Şener *et al.*, 2006)

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

Another application type of GIS based MCDA is planning discipline applications. Planning activities, by its nature require analysis of different data and approaches of together in one process. In order to solve a complex problem for certain purposes planers generally analyze and examine different types of input data with different kinds of approaches.

In Rize Province it has been studied for determining sustainable built-up areas. To solve this problem the researchers used the combination of analysis and synthesis of GIS taking the spatial data into account (Atasoy *et al.,* 2008). In this study the inputs of the planning activity are defined as road network, rivers, soil map, geology, landslide areas, stone pits, slope aspect for Rize province (Atasoy *et al.,* 2008). AHP method is used for evaluation of all criteria. Firstly comparison matrix is defined for each criteria's internal attributes (Table 2.5) and then overall comparison matrix is calculated (Table 2.6) At the end of the study, the pixel-based maps have been produced for sustainable settlement areas belonging to Rize province (Figure 2.4).

**Table 2.5** - Comparison matrix of each attributes and their weight (Atasoy et al., 2008)

| **Geology** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **Weights** |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 Alv alüvyon | 1 | | | | | | | | | **0,022** |
| 2 Pl-pleistosen | 9 | 1 | | | | | | | | **0,288** |
| 3 Gr-granit | 7 | 1\4 | 1 | | | | | | | **0,117** |
| 4 An-Andezit | 2 | 1\7 | 1\5 | 1 | | | | | | **0,032** |
| 5 Da-Dasit | 7 | 1\5 | 1\3 | 7 | 1 | | | | | **0,093** |
| 6 Kn | 6 | 1\2 | 2 | 5 | 3 | 1 | | | | **0,16** |
| 7 Dy | 9 | 1 | 4 | 7 | 5 | 2 | 1 | | | **0,288** |
| **Consistency Ratio** | | **0.073** | | | | | | | | |
| **Slope (%)** | | | | | | | | | | |
| (1) <10 | 1 | | | | | | | | | **0,377** |
| (2) 10-20 | 1\3 | 1 | | | | | | | | **0,235** |
| (3) 20-30 | 1\4 | 1\3 | 1 | | | | | | | **0,152** |
| (4) 30-50 | 1\5 | 1\4 | 1\3 | 1 | | | | | | **0,106** |
| (5) 50-60 | 1\6 | 1\5 | 1\4 | 1\3 | 1 | | | | | **0,064** |
| (6) 60-70 | 1\7 | 1\6 | 1\5 | 1\4 | 1\3 | 1 | | | | **0,047** |
| (7) >70 | 1\9 | 1\8 | 1\7 | 1\8 | 1\5 | 1/6 | 1 | | | **0,02** |
| **Consistency Ratio** | | **0.010** | | | | | | | | |
| **Aspect** | | | | | | | | | | |
| Flat | 1 | | | | | | | | | **0,08** |
| North | 1\5 | 1 | | | | | | | | **0,024** |
| Northwest | 1\4 | 3 | 1 | | | | | | | **0,058** |
| West | 5 | 7 | 4 | 1 | | | | | | **0,23** |
| Southwest | 4 | 5 | 1 | 1\2 | 1 | | | | | **0,126** |
| South | 5 | 7 | 4 | 1 | 2 | 1 | | | | **0,23** |
| Southeast | 2 | 4 | 3 | 1\2 | 3 | 1\2 | 1 | | | **0,148** |
| East | 1 | 3 | 2 | 1\4 | 1\3 | 1\4 | 1\2 | 1 | | **0,067** |
| West - East | 1\2 | 2 | 1\2 | 1\5 | 1\4 | 1\5 | 1\4 | 1\2 | 1 | **0,037** |
| **Consistency Ratio** | | **0,058** | | | | | | | | |
| **Land Cover** | | | | | | | | | | |
| Tea | 1 | | | | | | | | | **0,144** |
| Broad-leaved | 1\5 | 1 | | | | | | | | **0,034** |
| Coniferous | 1\5 | 1 | 1 | | | | | | | **0,034** |
| Rocky | 5 | 9 | 9 | 1 | | | | | | **0,466** |
| Grassland | 1\5 | 1 | 1 | 1\9 | 1 | | | | | **0,034** |
| Agriculture | 1 | 5 | 5 | 1\5 | 5 | 1 | | | | **0,144** |
| Settlement | 1 | 5 | 5 | 1\5 | 5 | 1 | 1 | | | **0,144** |
| **Consistency Ratio** | | **0,024** | | | | | | | | |
| **Land Use Capability Class** | | | | | | | | | | |
| Class 1 | 1 | | | | | | | | | **0,023** |
| Class 2 | 2 | 1 | | | | | | | | **0,032** |
| Class 3 | 3 | 2 | 1 | | | | | | | **0,047** |
| Class 4 | 4 | 3 | 2 | 1 | | | | | | **0,069** |
| Class 5 | 5 | 4 | 3 | 2 | 1 | | | | | **0,101** |
| Class 6 | 6 | 5 | 4 | 3 | 2 | 1 | | | | **0,145** |
| Class 7 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | | | **0,206** |
| Class 8 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 1 | | **0,377** |
| **Consistency Ratio** | | **0,035** | | | | | | | | |
| **Landslide** | | | | | | | | | | |
| Very Low | 1 | | | | | | | | | **0,422** |
| Low | 1\2 | 1 | | | | | | | | **0,275** |
| Medium | 1\4 | 1\3 | 1 | | | | | | | **0,169** |
| High | 1\5 | 1\4 | 1\4 | 1 | | | | | | **0,09** |
| Very High | 1\6 | 1\5 | 1\5 | 1\4 | 1 | | | | | **0,044** |
| **Consistency Ratio** | | **0,026** | | | | | | | | |
| **Distance to River (m)** | | | | | | | | | | |
| 0-25 | 1 | | | | | | | | | **0,069** |
| 25-50 | 3 | 1 | | | | | | | | **0,155** |
| >75 | 9 | 7 | 1 | | | | | | | **0,777** |
| **Consistency Ratio** | | **0,03** | | | | | | | | |

**Table 2.6** - Comparison matrix of each criteria's and their weight (Atasoy et al., 2008)

| | | | | | | | | ***Weight ( %)*** |
|---|---|---|---|---|---|---|---|---|
| ***Slope*** | 1 | 1 | 3 | 3 | 7 | 3 | 5 | **28** |
| ***Landslide*** | 1 | 1 | 3 | 3 | 7 | 3 | 5 | **28** |
| ***Geology*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 | **12** |
| ***Soil*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 | **12** |
| ***Aspect*** | 1\7 | 1\7 | 1\6 | 1\6 | 1 | 1\6 | 1\4 | **3** |
| ***Distance to River*** | 1\3 | 1\3 | 1 | 1 | 6 | 1 | 4 | **12** |
| ***Land Cover*** | 1\5 | 1\5 | 1\4 | 1\4 | 4 | 1\4 | 1 | **5** |

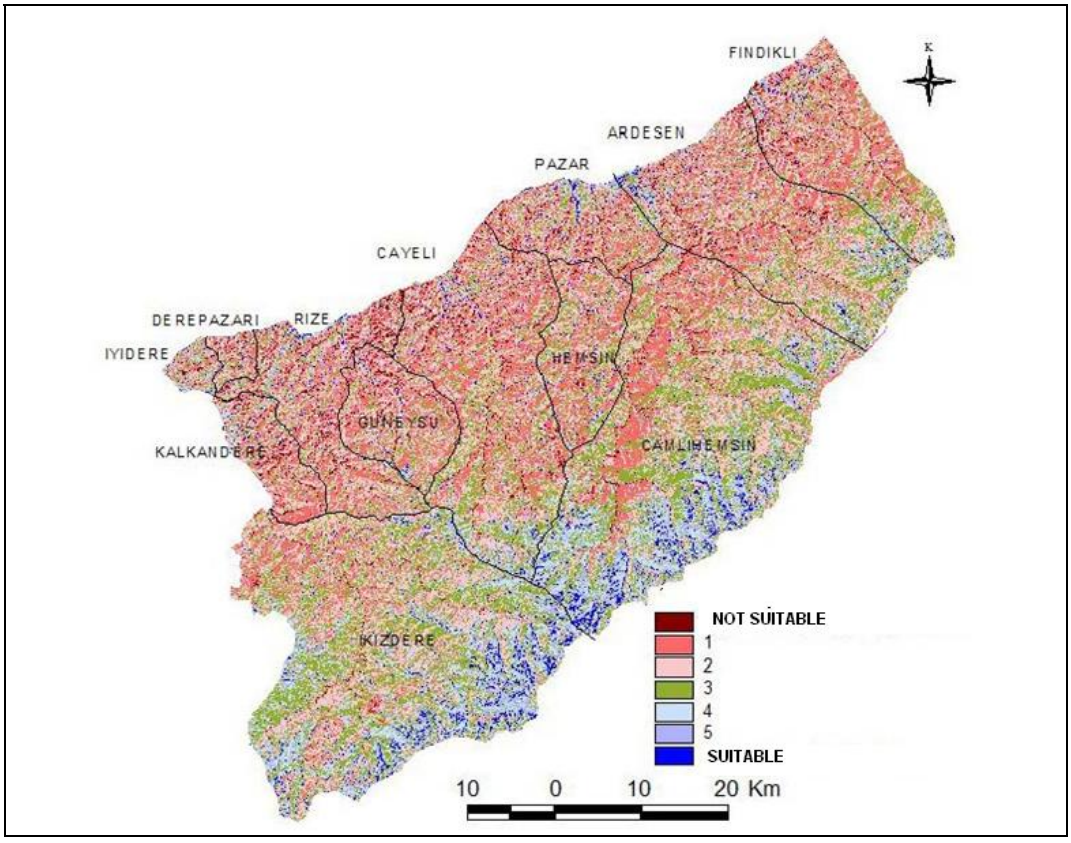



**Figure 2.4** - Suitable settlement sites map of Rize province (Atasoy et al., 2008)

The other application area of GIS based MCDA is in agriculture. Nepal has highly populated settlements and the need for food is increasing (Baniya, 2008). The main problem the area is that land capabilities and cultivation potential is low and the existing areas are diminishing. It is necessary that a MCDA should be set up to evaluate the land suitability of Kathmandu valley for vegetable crops (Baniya, 2008).

General concept of the study is presented in the Figure 2.5. Before starting the study, built up areas and non-agriculture landuses were omitted from the analysis. In this work firstly criteria are defined with the help of field work, literature review, expert opinions, interviews of local farmers, professional agencies and other information from the local authorities (Baniya, 2008). Criteria are grouped into 3 groups of physical, social parameters and economic indicators and then sub criteria are defined to form a decision tree as presented in Figure 2.6.

After definition of criteria value, classifications for each criterion of each attribute is ranked (Table 2.7) according to AHP comparison judgment scale.

*"Final result of the MCDA land suitability evaluation of Kathmandu valley show that more than 90 percent land area can hold good vegetable cultivation. Together they can meet little above 70 percent demand of the Kathmandu valley. So, result of this study has to communicate to farmers to make full use of land potential for the development of vegetable cultivation."* (Baniya, 2008).

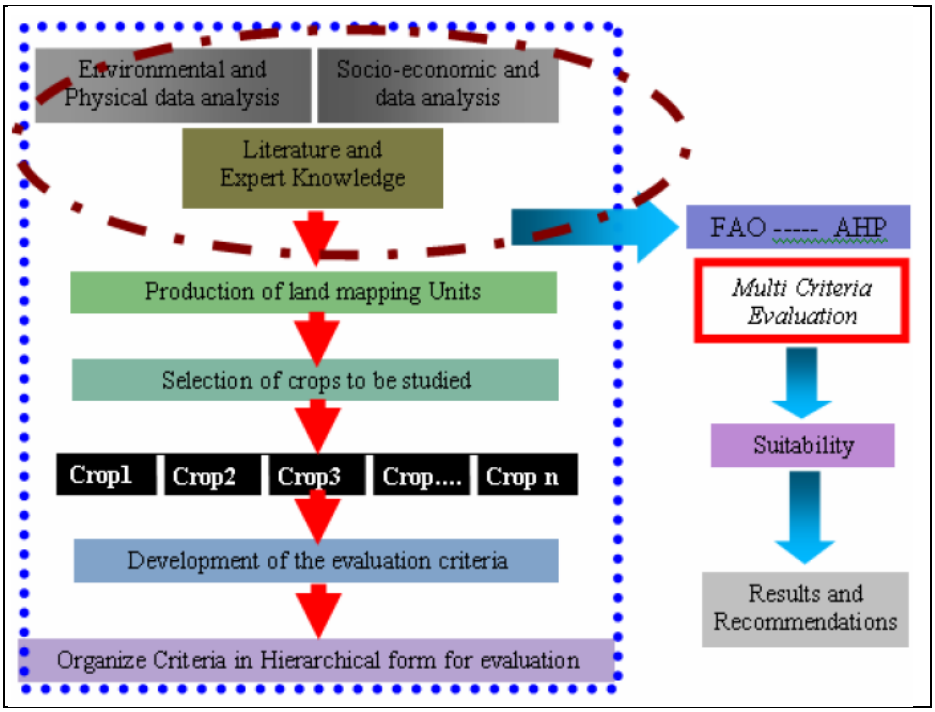



**Figure 2.5** - Conceptual flow of the research approach (Baniya, 2008)

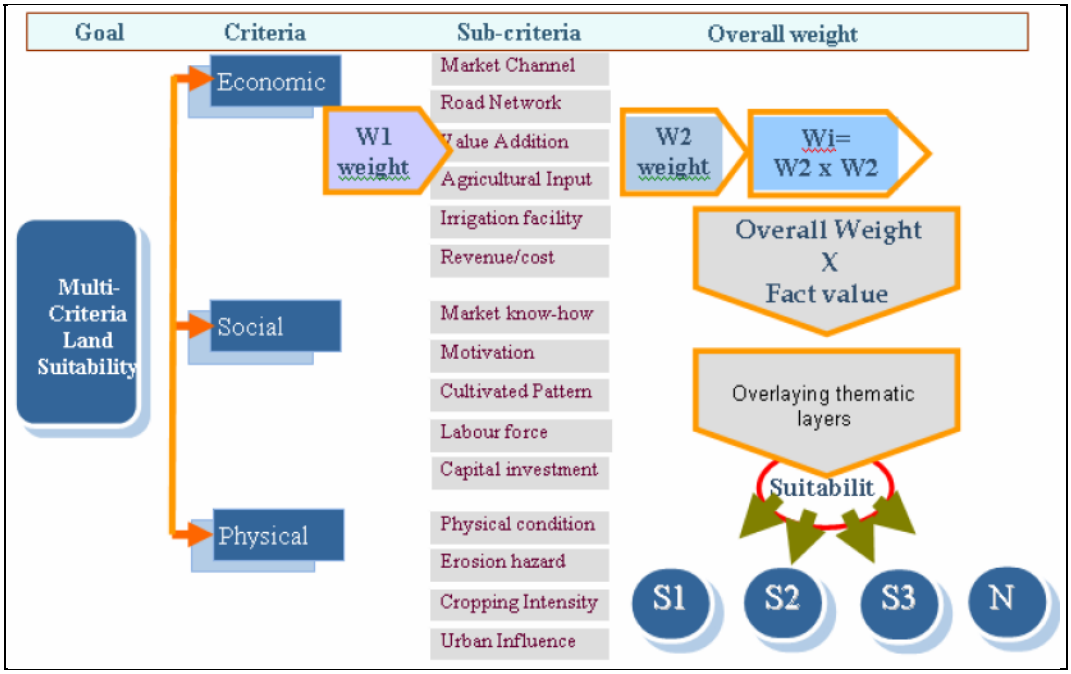



**Figure 2.6** - Flow chart of the suitability analysis methodology (Baniya, 2008)

**Table 2.7** - Fact value classifications for each criterion for each attribute (Baniya, 2008)

| Sub-criteria | Attribute values of criteria | Score |
|---|---|---|
| **Criteria 1 : Infrastructural Parameters** | | |
| Irrigation facilities availability | Perennial irrigation sources | 9 |
| | Seasonal irrigation availability | 7 |
| | No irrigation except rein fed | 5 |
| Road Network and condition | Good condition motorable road | 9 |
| | Far from road head | 7 |
| | Far and bad road condition | 5 |
| Value addition process | Available processing know-how | 9 |
| | Lack of processing facilities | 7 |
| Market channel | Good institutionalized regular market | 9 |
| | Lack of proper market system to sell product | 7 |
| Agricultural input availability | Available all the time | 9 |
| | Seasonal unavailability | 7 |
| | Unavailable | 5 |
| Revenue Cost ratio | Above 1,2 | 9 |
| | Below 1,2 | 7 |
| **Criteria 2 : Social Parameters** | | |
| Marketing know how | Good market accessibility and marketing information | 9 |
| | Lack of marketing information | 7 |
| | Inaccessible markets | 5 |
| Motivation of Farmers | Motivated and trained | 9 |
| | Trained | 7 |
| | Unskilled | 5 |
| Cultivation Pattern | Market oriented | 9 |
| | Household consumption | 7 |
| | Utilization of farmland only | 5 |
| Labour force | Easy and round the year available | 9 |
| | Easy and seasonal availability | 7 |
| | Scarce labour force | 5 |
| | Scarce and expensive | 3 |
| Investment capacity | Minor capitol resource needed | 9 |
| | High capitol requirement | 7 |
| | Very high capital resource requirement | 6 |
| **Criteria 3 : Physical Parameters** | | |
| Physical condition | Highly suitable (S1) | 9 |
| | Medium suitability (S2) | 7 |
| | Low suitability (S3) | 5 |
| Erosion Potential | Stable | 9 |
| | Susceptible to Erosion | 7 |
| | Highly Vulnerable to erosion | 5 |
| Crop Intensity | Intensive | 9 |
| | Moderate | 7 |
| | Extensive | 5 |
| Risk of urban sprawl | Low | 9 |
| | High | 5 |

# CHAPTER 3

# 3. DATA

After the definition of problems, another important stage of analysis is that definition of criteria to figure out the evaluation of settlement sites beyond the scope of natural conditions and hazards.

In decision making processes experts were used whom were defining which data are to be used and provided their level of importance with necessary literature reviews, similar works and their practical experiences. One of the group of discussed experts are planners who are working in the Ministry of Environmental and Forestry, General Directorate of Environmental Impact Assessment (EIA) and Planning, Planning and Strategic EIA department, Planning of Marmara and Black Sea Regions Divisions. They were specialized on making Regional Plans, and they represent the legal authorities that are responsible of regional plans. The other group of experts work at METU in Geological Engineering and City and Regional Planning Departments. The result of evaluation of criteria lead into 3 main clusters regarding their genetic natures.

1. Environmental Data – elevation, aspect, slope, distance to rivers, rainfall, and temperature
2. Hazard Data – earthquake zone, earthquake activity, flood and erosion
3. Settlement Data – location of settlements

## 3.1. Data Definition

### 3.1.1. Environmental Data

When the selection of environmental data, criteria used are generally not changeable or affected by other factors over time. For example recent land use and landcover information are omitted because there was no such knowledge regarding past thousands of years. Same way forest, agricultural areas and road networks, trade routes were also disregarded during the analysis. Based on the available data sets and the consensus with the experts, elevation, aspect, slope, distance to rivers, precipitation, and temperature data are employed in the analysis process.

#### 3.1.1.1. Elevation data

The Elevation data is one of the very important criterion of the selection of suitable settlement sites, main reason is elevation effects human life comfort and economy. The higher the elevation the difficult the life is.

The elevation data is based on The Shuttle Radar Topography Mission (SRTM) data of Space Shuttle Endeavour during February 2000 (NASA JPL, 2010).The original pixel size is approximately 90 by 70 meters and acquired by 1 degree tiles. Firstly all necessary tiles are imported and mosaiced, then resampled with the method of nearest neighborhood to 100 meters and finally cropped to the basin boundary. The elevation values range from sea level to 3.291 meters especially at eastern parts of the Yeşilırmak basin (Figure 3.1 and Figure 3.2).

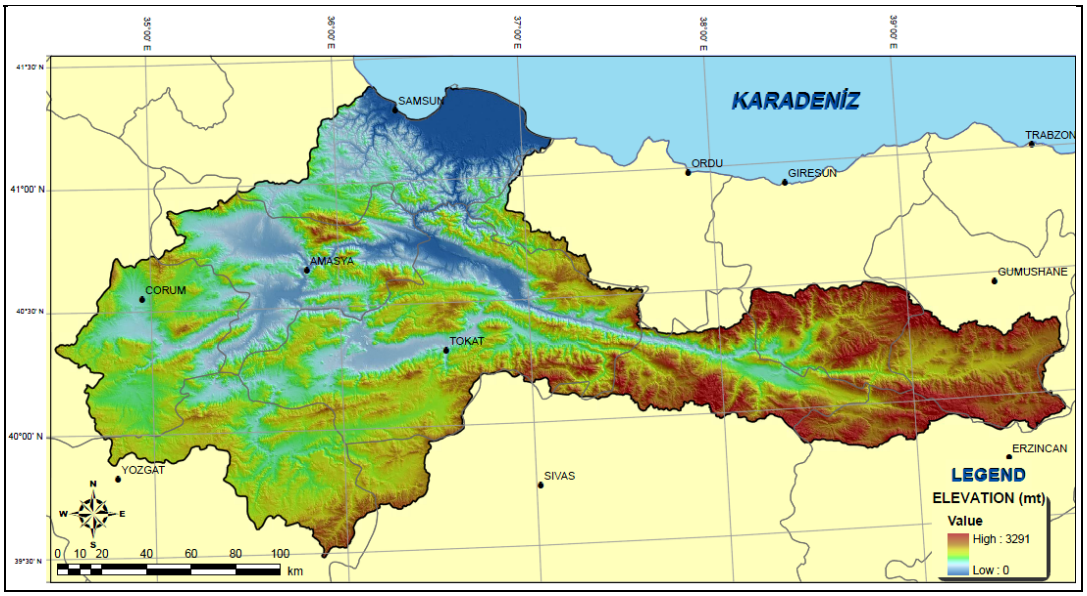



**Figure 3.1** - Elevation map of the project area

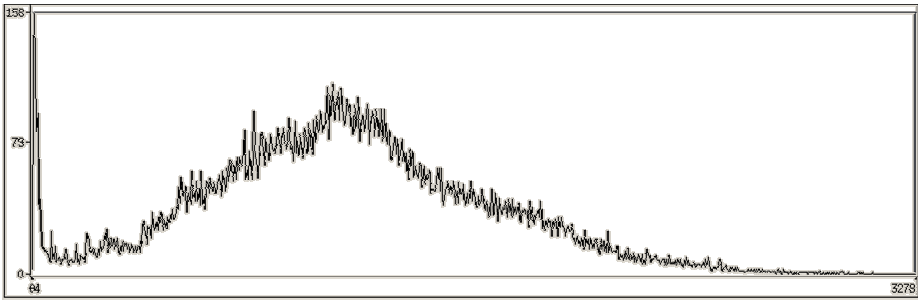
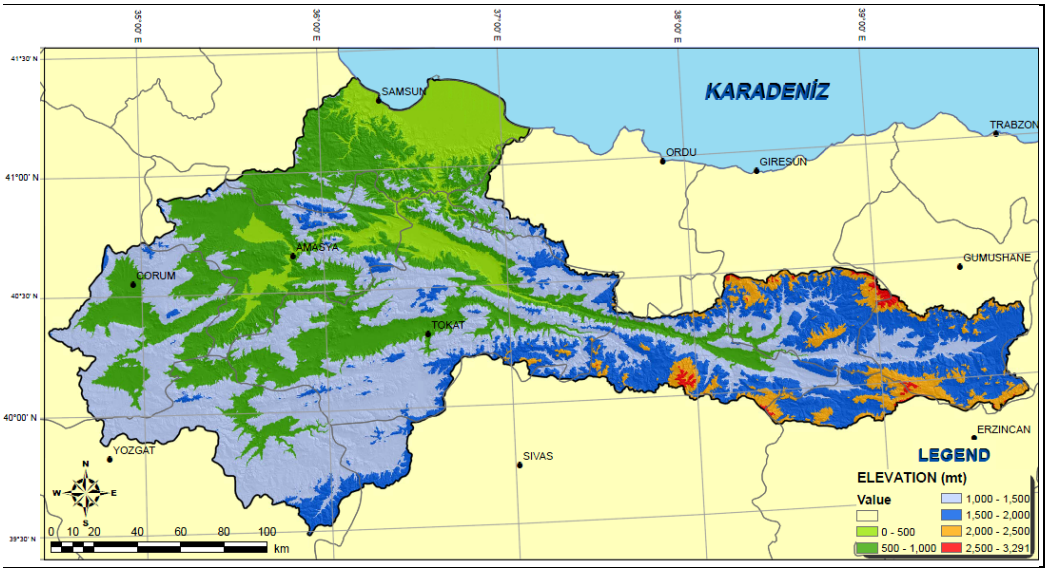



**Figure 3.2** - Histogram of the elevation map

The elevation values for the region were grouped into six classes. Elevations ranging from 0 to 500 meters get the highest score, followed by 500 to 1000, 1000 to 1500, 1500 to 2000, 2000 to 2500 meters and greater than 2500 meters classes in decreasing scores. Normally higher than 2500 meter elevation is believed to be unsuitable to be settled, hence this class gets the minimum score (Figure 3.3).

a




b

| Minimum (mt) | Maximum (mt) | Score |
|---|---|---|
| 0 | 500 | 1.00 |
| 500 | 1000 | 0.70 |
| 1000 | 1500 | 0.50 |
| 1500 | 2000 | 0.20 |
| 2000 | 2500 | 0.15 |
| 2500 | 3291 | 0.10 |

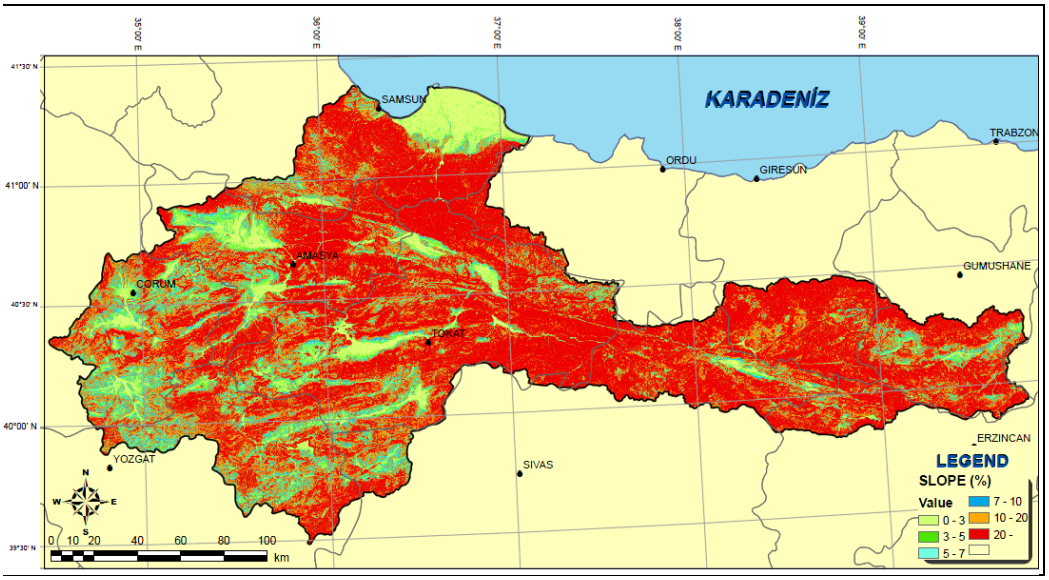
**Figure 3.3** - (a) Classified thematic map and (b) scores of elevation data

### 3.1.1.2. Slope Data

Slope is an important factor while considering settlement areas for ease of comfort, engineering and economy. In today's world humans have the technology to be able to settle regardless of the slope; but before the improvements in engineering and technology, slope is one of the inevitable factors for the site selection. Therefore slope was considered to be one of the major factors during the evaluation process of the Yeşilırmak Basin settlement locations.

The slope map is computed in percentages from the SRTM DEM with TNTMIPS software. The slope data is changing from 0 to 118 percent (roughly equivalent of 50 degrees) with a mean value of 24.5 % (Figure 3.4). Slope data is divided into six different ranks and scored. Flat to gentle sloping terrain get higher scores whereas areas of slope greater than 20% take “0” value because of additional cost and risks (Figure 3.5.b)

a




b

| Minimum (%) | Maximum (%) | Score |
|---|---|---|
| 0 | 3 | 0.80 |
| 3 | 5 | 1.00 |
| 5 | 7 | 0.70 |
| 7 | 10 | 0.40 |
| 10 | 20 | 0.20 |
| 20 | 118 | 0.10 |

**Figure 3.4** - (a) Classified thematic map and (b) scores of slope data

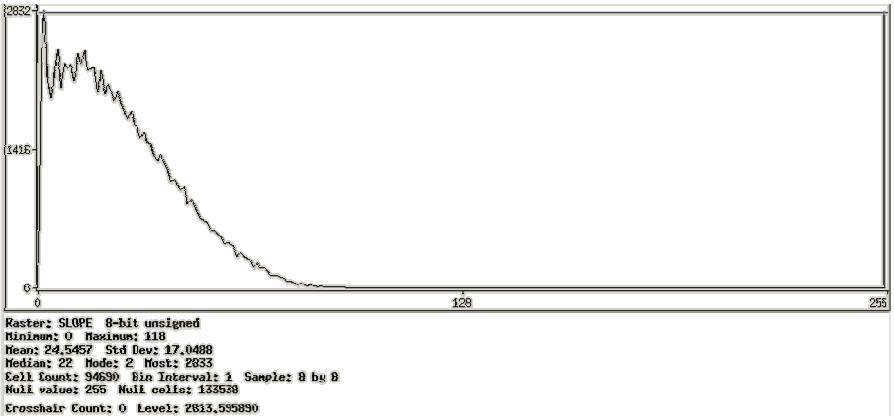


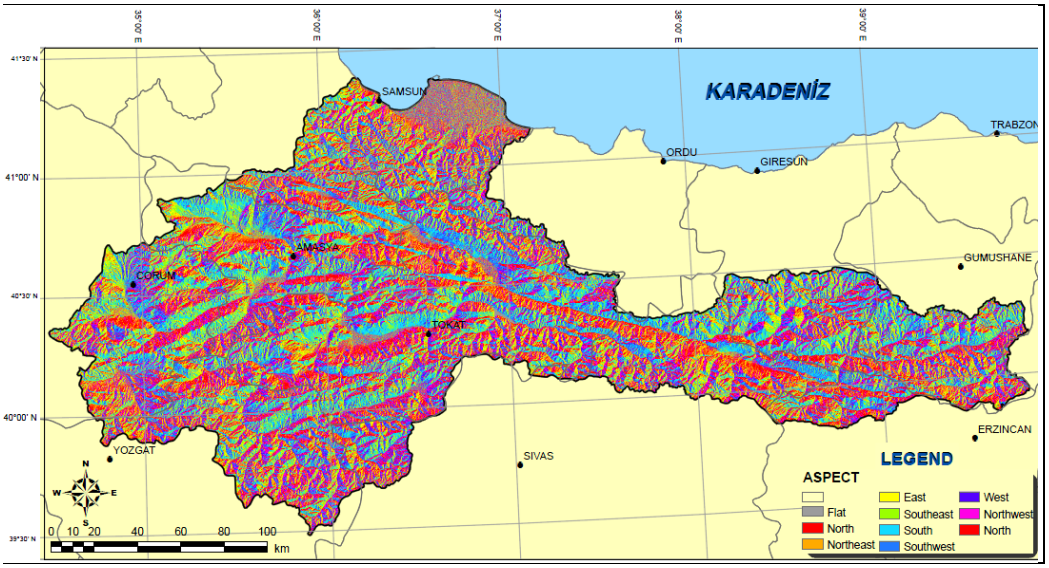

**Figure 3.5** - Histogram of slope map

### 3.1.1.3. Aspect Data

Aspect is an important issue for human health, the presence of sun illumination is decreasing heating costs in winters but increases cooling costs in summers, whereas it is essential for crop production etc. Aspect data is used in the analysis in 8 principal directions and the flat areas with no aspect. Especially south east directed hillsides are the areas for maximized energy saving and high crop yield areas against other directions. Therefore aspect criterion is more fundamental for the former settlement areas than the recently defined modern, technology available settlement areas. The aspect data is derived from the elevation data from SRTM DEM via TNTmips. (Figure 3.6.a)

According to the expert evaluation for this study aspect is the least important criterion with respect to other factors. The main scoring approach is that north faced hillsides get lowest and south faced hillsides get highest ranking values (Figure 3.6.b).

a




b

| Value | Score |
|---|---|
| Flat | 0.50 |
| North | 0.10 |
| Northeast | 0.30 |
| East | 0.70 |
| Southeast | 1.00 |
| South | 0.80 |
| Southwest | 0.60 |
| West | 0.40 |
| Northwest | 0.20 |

**Figure 3.6** - (a) Classified thematic map and (b) scores of aspect map

### 3.1.1.4. Distance to River

Closeness of the water source is vital for not only recent settlement sites but also for ancient settlements. Especially for ancient times it was more important than today, because of technical difficulties to acquire and distribute the water to agricultural lands and built-up areas.

Yeşilırmak River is born in the Sivas province after joining with Çekerek, Tersakan and Kelkit streams it reaches to Blacksea at Samsun, Çarşamba delta. Although many dams have been built on the major rivers, some floods have been reported in literature (Lekesiz et.al., 2010; Yeşilırmak Havzası Kalkınma Birliği, 2010).

Due to intense tectonic activity in the basin it is evident that the positions and the presence of rivers, springs and lakes will be effected throughout time. In order to make the selection process comparable to earlier settlements springs and lakes are ignored, only distance to river information is considered. River data were obtained from 1/500.000 scaled map of permanently flowing rivers produced by General Directorate of Hydraulic Works (Figure 3.7).

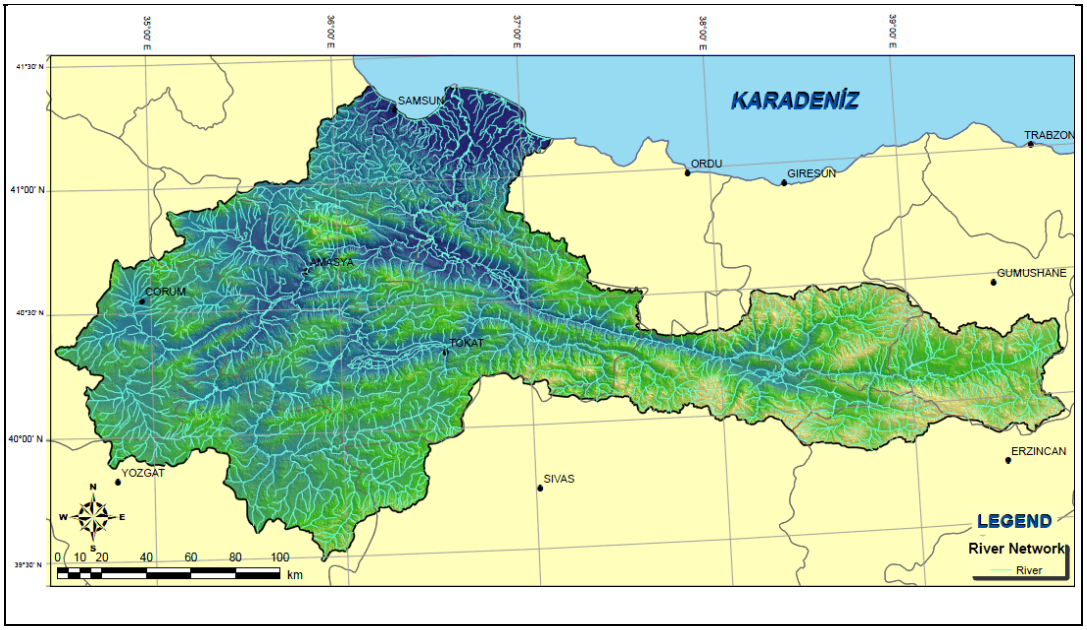
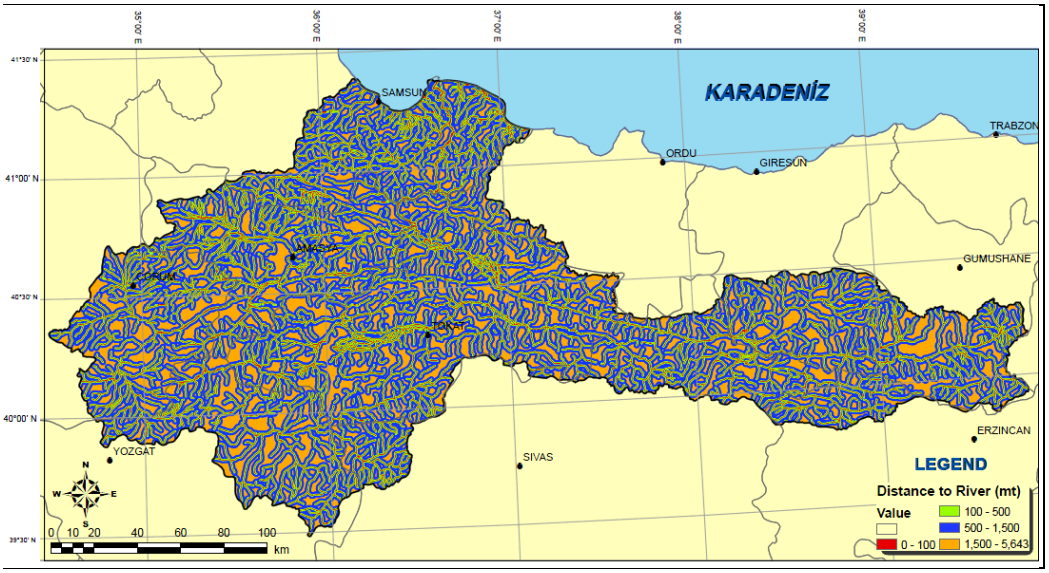



**Figure 3.7** - River network map

After a distance raster has been calculated from the flowing rivers, 4 main distance intervals are defined as 0 to 100, 100 to 500, 500 to 1500 and 1500+ meters (Figure 3.8). First ring is most risky areas due to flooding and also this zone

is defined according to “Coastal Law”, it is said that 100 meters distance from the river settlements cannot be settled (TC Law no: Kıyı Kanunu, 3621, 2010). 100 meters to 500 meters distance to river is the most suitable areas for settlement and agricultural activities. The zones further from the 1500 meters of river have the least significance (or preference) than the third zone.

a




b

| Minimum (mt) | Maximum (mt) | Score |
|---|---|---|
| 0 | 100 | 0.00 |
| 100 | 500 | 1.00 |
| 500 | 1500 | 0.70 |
| 1500 | - | 0.40 |

**Figure 3.8** - (a) Classified thematic map, (b) scores of distance to river data

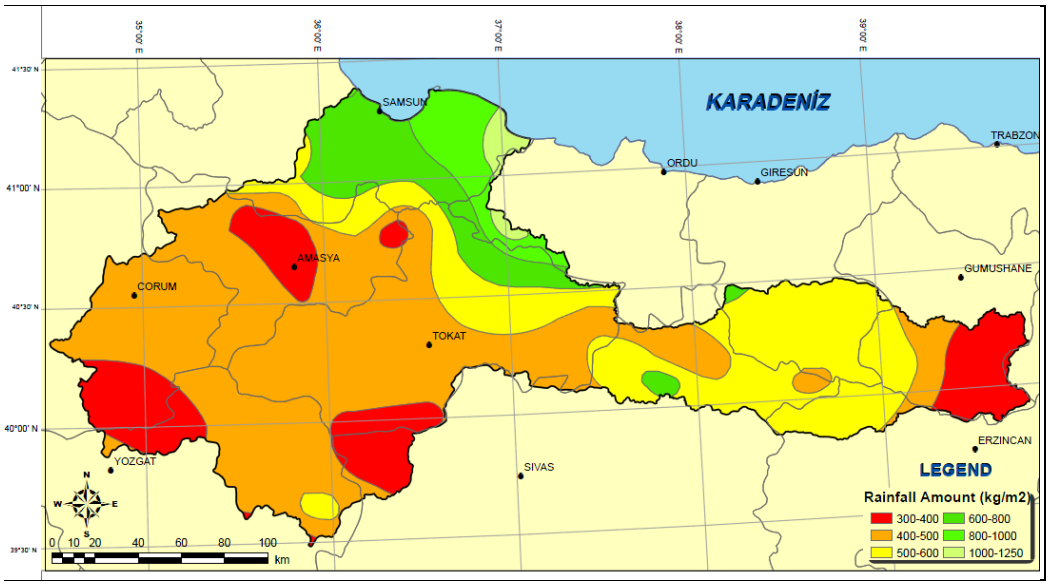
### 3.1.1.5. Rainfall Data

Accessibility and presence of water is crucial for life. However both its scarcity and its excess threat the sustainability of life. In order not to redundantly overweight

the criteria only scarcity is evaluated here, whereas flood potential is assessed in natural hazards section. Hence areas with significant rainfall are considered to be more suitable for settlements beyond the scope of crop production.

Rainfall data is obtained from Turkish State Meteorological Services. It is average of long term periods (1975 to 2008) and the value of rainfall amount in kg/m$^2$. It is plotted and then transformed to a 100 X 100 meters pixel raster map with the ArcGIS software. At the Figure 3.9.a the blue points are the meteorological measurement stations. Rainfall data is evaluate by the experts in 6 groups and scored as shown in the Figure 3.9.b

a




b

| Minimum (kg/m$^2$) | Maximum (kg/m$^2$) | Score |
|---|---|---|
| 300 | 400 | 0.20 |
| 400 | 500 | 0.30 |
| 500 | 600 | 0.50 |
| 600 | 800 | 0.70 |
| 800 | 1000 | 0.80 |
| 1000 | 1250 | 1.00 |

**Figure 3.9** - (a) Classified thematic map and (b) scores of rainfall map

### 3.1.1.6. Temperature map

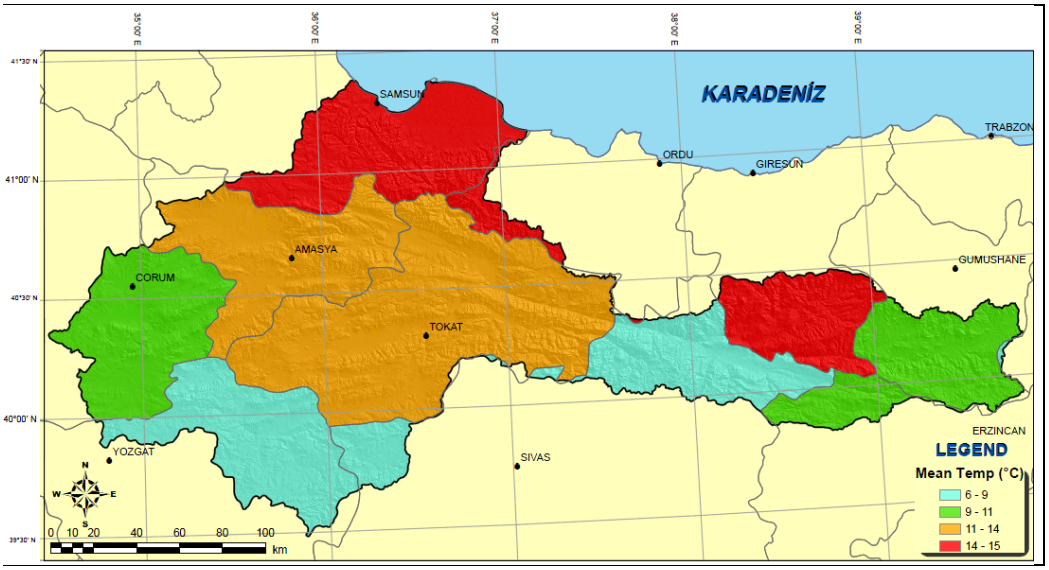
Temperature it is a slightly important factor for selection of settlement areas, considering both the agricultural activities (number of productive cycles, crop yield, etc) and easiness of daily life.

Yeşilırmak basins' province temperature values are obtained from web page of the Turkish State Meteorological Services. Temperature data is long term (1975 - 2008) monthly averages of mean temperature, mean highest temperature, mean lowest temperature, mean insolation time, highest temperature, lowest temperature and fastest wind (Table 3.1). These values are assigned to province boundary polygons in order to visualize spatially. Among these data only mean temperature is decided to be used in further analyses (Figure 3.10.a) The available temperature distribution is grouped into four classes and they are scored as the maximum value is the best and minimum is the least suitable land (Figure 3.10).

**Table 3.1**- Climatic values of Yeşilırmak basin, (DMI web page, 2010)

| | AMASYA | SIVAS | BAYBURT | CORUM | ERZINCAN | GIRESUN | GUMUSHANE | ORDU | SAMSUN | TOKAT | YOZGAT |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Mean Temp (°C) | 13.5 | 9.0 | 6.8 | 10.5 | 10.8 | 14.4 | 9.4 | 14.2 | 14.3 | 12.4 | 8.9 |
| Mean Highest Temp (°C) | 19.8 | 15.2 | 13.2 | 17.4 | 17.2 | 17.7 | 16.0 | 18.3 | 18.0 | 18.4 | 14.5 |
| Mean Lowest Temp (°C) | 7.5 | 3.2 | 0.9 | 3.9 | 4.8 | 11.8 | 4.0 | 10.9 | 10.8 | 7.0 | 3.9 |
| Mean Insolation Time (hours) | 5.7 | 6.7 | 0.0 | 6.2 | 6.4 | 0.0 | 5.8 | 4.5 | 5.2 | 6.0 | 6.8 |
| Highest Temp (°C) | 45.0 | 40.0 | 36.2 | 42.6 | 40.6 | 35.2 | 41.0 | 37.3 | 37.4 | 39.8 | 38.8 |
| Lowest Temp (°C) | -20.4 | -29.6 | -29.0 | -27.2 | -25.2 | -4.9 | -25.7 | -6.7 | -6.8 | -22.1 | -24.4 |
| Fastest Wind (km/sa) | 129.6 | 99.0 | 100.1 | 117.0 | 82.1 | 108.7 | 65.5 | 106.2 | 124.2 | 176.0 | 92.5 |

a




b

| Minimum (°C) | Maximum (°C) | Score |
|---|---|---|
| 6 | 9 | 0.40 |
| 9 | 11 | 0.60 |
| 11 | 14 | 0.80 |
| 14 | 15 | 1.00 |

**Figure 3.10** - (a) Classified thematic map and (b) scores of temperature data

## 3.1.2. Natural Hazard Data

### 3.1.2.1. Earthquake Zones

The earthquake zoning map has been taken from General Directorate of Disaster Affairs (GDDA). This map is based on the probabilistic assessment of the activity of North Anatolian Fault and its splays throughout Yeşilırmak basin (Figure 3.11). Three different zones are present in the basin: 1$^{st}$ degree (assuming that within 90% probability and within 50 years the max acceleration would be more than 0.4

g), 2nd degree (0.3 -0.4 g) and 3rd degree (0.2 - 0.3g) (Figure 3.12). This layer is intended to include the destructive effect of earthquakes to the MCDA.

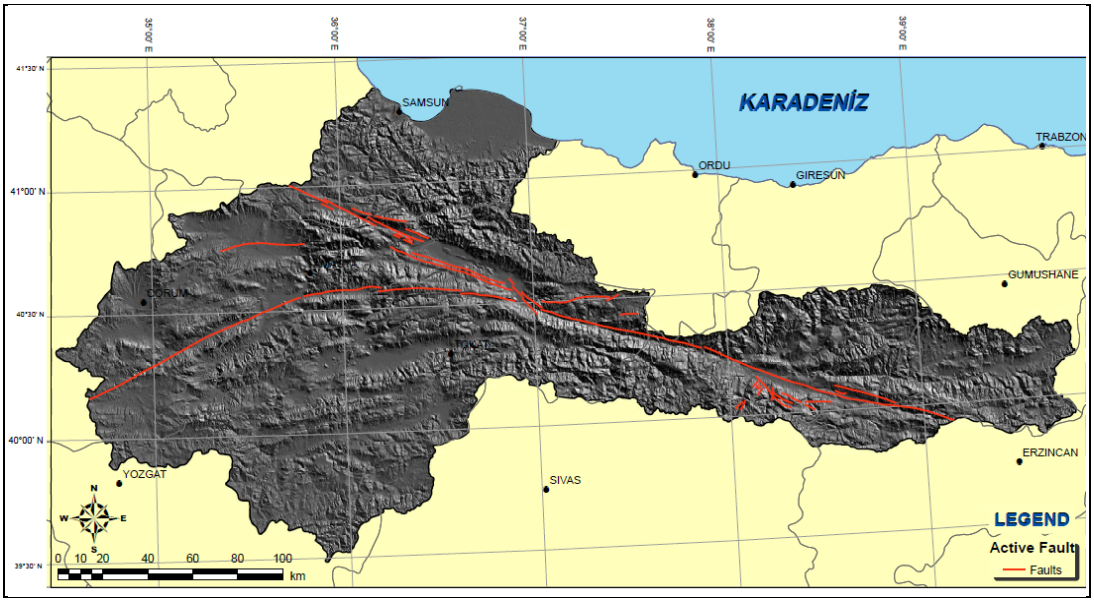
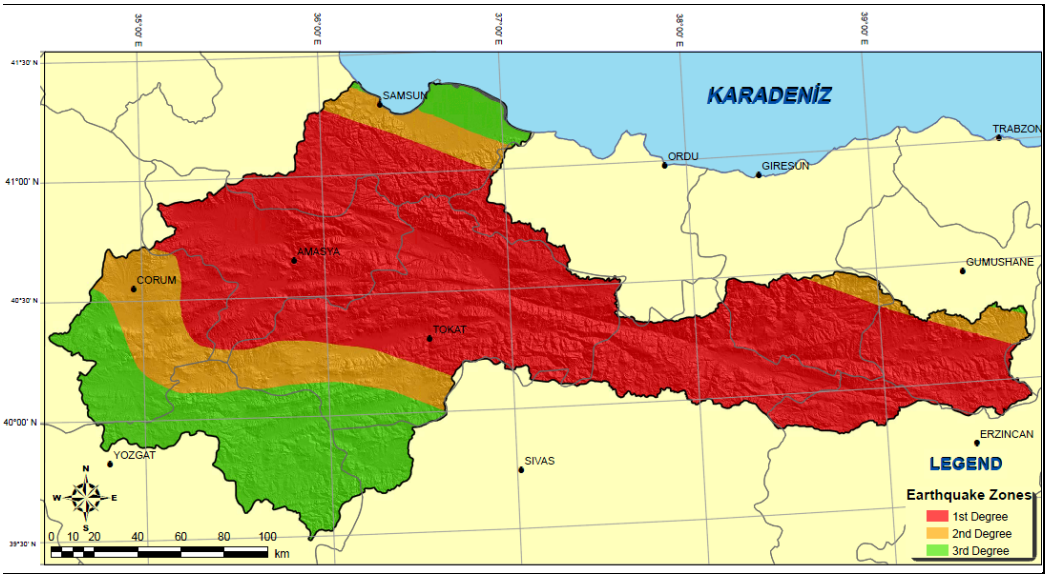



**Figure 3.11** - Active Fault map, North Anatolian Fault and its splays (MTA, 1992)

The earthquake zones map is already a categorical data hence the weight to the categories are reassigned. 1st degree earthquake zone is the most risky areas in the basin so it takes lowest score 0.25 and 2nd degree takes 0.5 and 3rd degree takes 0.75 (Figure 3.12.b).

a




b

| Value | Score |
|---|---|
| 1st Degree | 0.25 |
| 2nd Degree | 0.50 |
| 3rd Degree | 0.75 |

**Figure 3.12** - (a) Classified thematic map (GDDA, 1996) and (b) score of earthquake zone

### 3.1.2.2. Earthquake Activity map

Apart from the destructive effect, the non-catastrophic smaller magnitude earthquakes also effect the environment as they could easily trigger landslides, change the position of springs, hot springs and etc. The earthquake activity data is produced from the Earthquake Catalogue data published by Boğaziçi University, Kandilli Observatory and Earthquake Research Institute, National Earthquake Monitoring Center at the web page (Kandilli, 2010). A sample of the data used is presented at Table 3.2. All geographically relevant data is then imported and cropped to basin vicinity boundaries. (Figure 3.13)

**Table 3.2** - Sample data of earthquakes (Source: Kandilli, 2010)

| Longitude | Latitude | Data | Time | Depth (km) | Magnitude |
|---|---|---|---|---|---|
| 34 | 41.62 | 28.10.2002 | 52:46.8 | 27 | 3.00 |
| 34 | 40.5 | 02.02.2005 | 55:04.1 | 6 | 3.20 |
| 34 | 40.78 | 16.03.2008 | 19:56.3 | 9 | 3.00 |
| 34 | 39.46 | 18.05.2004 | 07:04.2 | 9 | 3.10 |
| 34.01 | 41.67 | 27.10.2005 | 05:42.1 | 26 | 3.00 |
| 34.01 | 40.22 | 11.06.2004 | 57:24.2 | 11 | 3.20 |
| 34.01 | 39.44 | 22.05.2004 | 53:20.7 | 3 | 3.00 |
| 34.02 | 39.86 | 16.01.2008 | 31:09.4 | 5 | 3.00 |
| 34.03 | 41.56 | 22.04.2008 | 06:53.0 | 3 | 3.10 |
| 34.03 | 40.24 | 08.05.2004 | 23:00.5 | 12 | 3.00 |
| 34.03 | 39.57 | 30.09.1996 | 26:56.0 | 34 | 3.00 |
| 34.06 | 40.73 | 18.03.2008 | 24:31.3 | 15 | 3.00 |
| . | . | . | . | . | . |
| . | . | . | . | . | . |

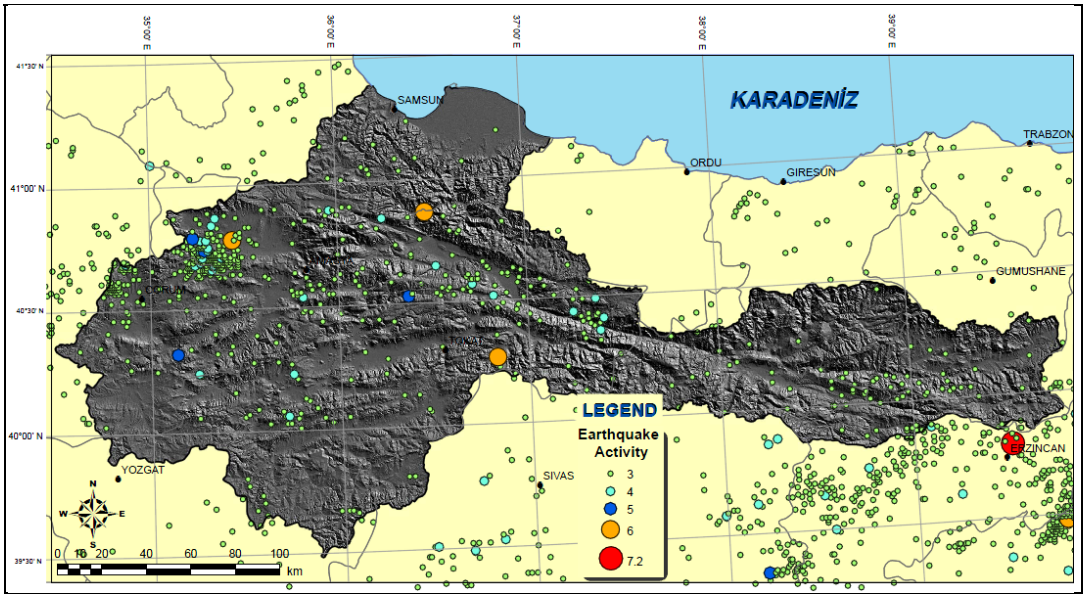



**Figure 3.13** - Epicenters within Yeşilırmak Basin (Source: Kandilli, 2010)

The epicenter densities for every 100 km2 are calculated by counting the total number of earthquakes of falling into each search circle disregarding the magnitude information, hence the number in circular search areas are the count of individual earthquakes (Figure 3.14).

The distribution of epicenter density map is examined and the resultant density is divided into 4 classes giving lesser scores for higher activity classes (Figure 3.15).

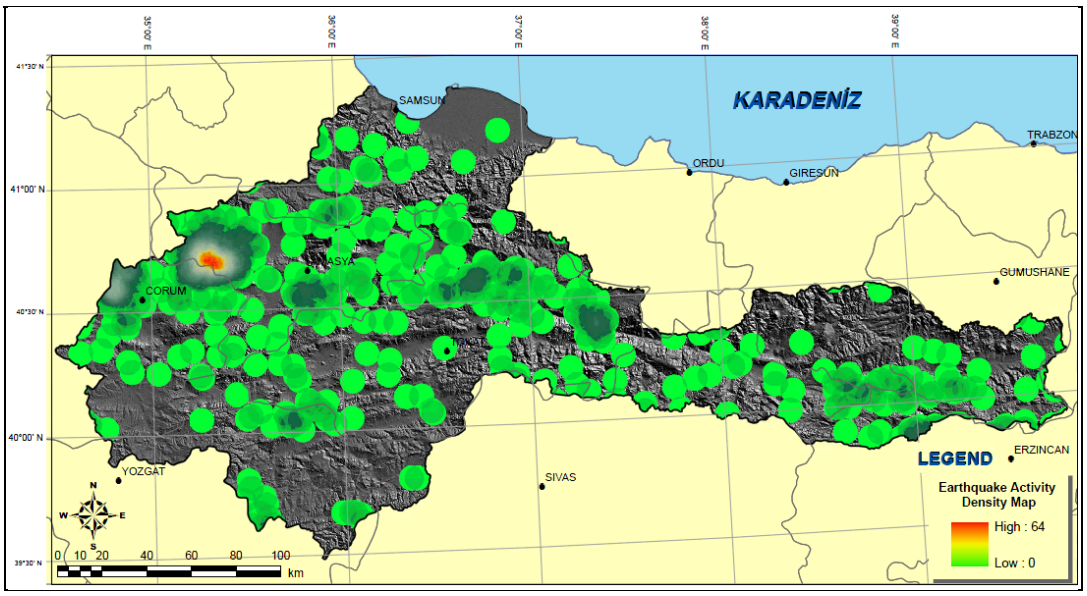
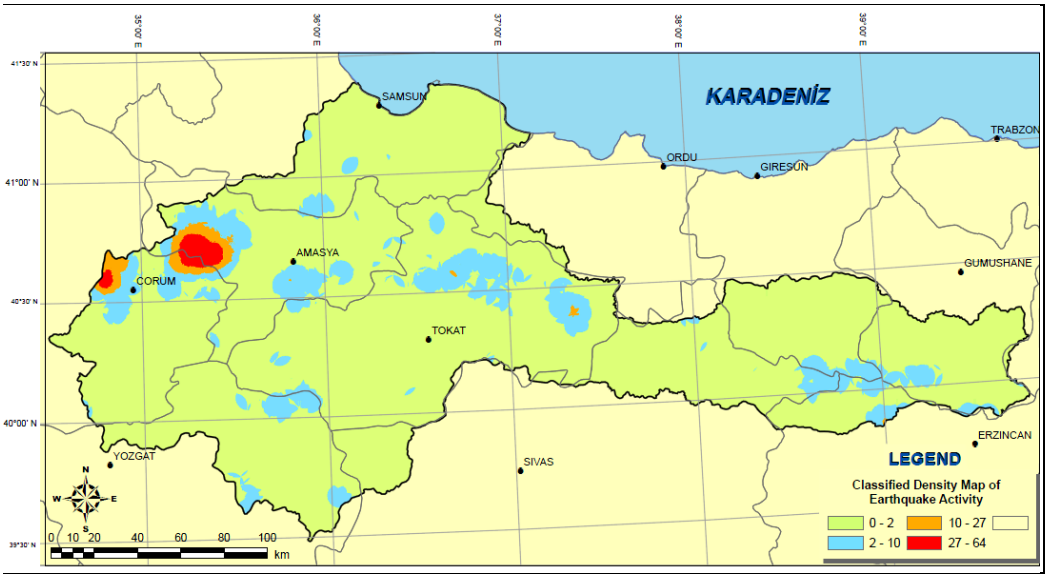



**Figure 3.14** - Density map of earthquake epicenters

a




b

| Minimum | Maximum | Score |
|---|---|---|
| 0 | 2 | 1.00 |
| 2 | 10 | 0.75 |
| 10 | 27 | 0.50 |
| 27 | 64 | 0.25 |

**Figure 3.15** - (a) Classified thematic map and (b) scores of earthquake activity

### 3.1.2.1. Flood Susceptibility Map

The geographic characteristics of the study area bring out flood as one of the natural hazards occurring within the basin. Suitable settlement site selection should be done regarding the flood damages.

No regional flood risk map was presently available for the study area. Normally this kind of map should be prepared using a quantitative hydrological model which considers environmental information such as the infiltration of the soil, geology, slope, precipitation, flow regime of rivers, and has to be calibrated by field measurements of stream flow over seasons. However the absence of such a flood

risk map, the regional scale of the work with very coarse needs lead a conceptual flood susceptibility map; which is produced by interpretation of geological map, slope map and river network. All of the flat to very gentle lying Quaternary Alluvium (excluding debris cones, alluvial fans, scree slopes and etc.) having a stream inside is attributed to potential flood zones. Those areas susceptible to flood is assigned as 0.25 where as the remaining areas are assigned as 1 (Figure 3.16).

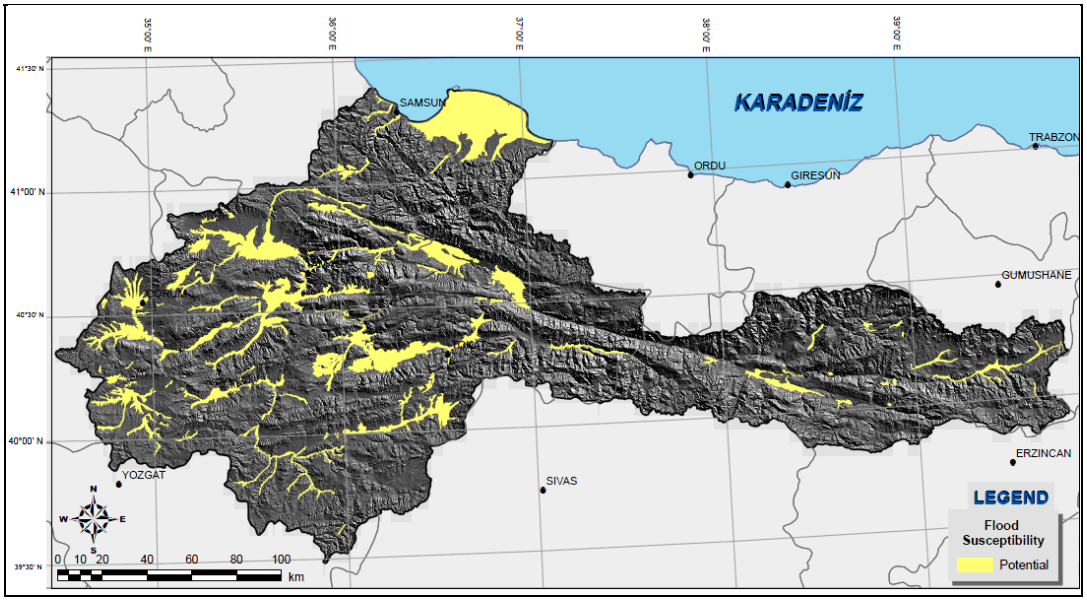



**Figure 3.16** - Flood susceptibility map

### 3.1.2.2. Erosion Map

Erosion is an important criterion to not only settlement areas but also for maintaining the sustainability of agricultural areas. It is seen at table 3.3 more than half of the Yeşilırmak Basin has a strong erosion risk especially at south and central parts of the basin (Figure 3.17). Data is compiled from different scaled soil

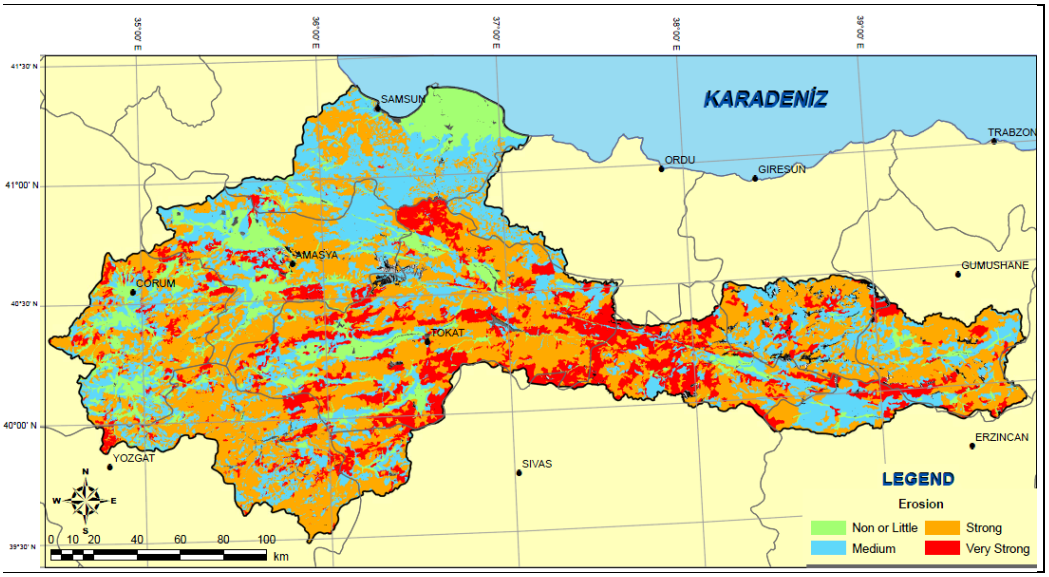
maps published in literature and produced by the General Directorate of Rural Services.

Erosion intensity is grouped into 5 classes. The distribution and rank values are given in figure 3.17.a. Very strong and strong classes get lower rank values, while medium class gets higher values than these. Other (current settlement areas) and non or little labeled areas are the most suitable sites and takes the highest score. The weight of the ranks of erosion susceptibility data is presented in figure 3.17.b.

**Table 3.3** - Erosion Degree distribution

| Erosion Degree | Area (Hectare) | Percent (%) |
|---|---|---|
| Other | 141,920.85 | 3.6 |
| Non or little | 415,115.37 | 10.5 |
| Medium | 1,125,853.11 | 28.4 |
| Strong | 1,696,748.13 | 42.8 |
| Very Strong | 580,727.02 | 14.7 |

a




b

| Value | Score |
|---|---|
| Non or Little | 1.00 |
| Medium | 0.75 |
| Strong | 0.50 |
| Very Strong | 0.25 |

**Figure 3.17** - (a) Classified thematic map and (b) scores of erosion susceptibility

### 3.1.3. Settlement Data

Yeşilırmak Basin is composed of 11 provinces (Samsun, Tokat, Amasya, Çorum, Giresun, Gümüşhane, Bayburt, Ordu) with different areal contributions yielding in a total of 73 district and 2,862 settlements (Figure 3.18 and 3.19).

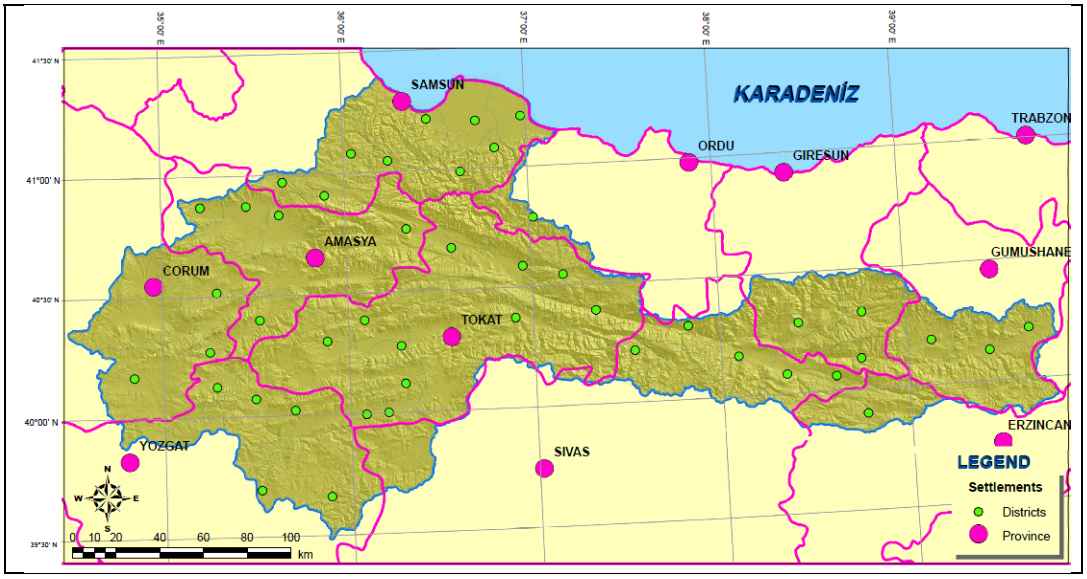



**Figure 3.18** - Province and District Map

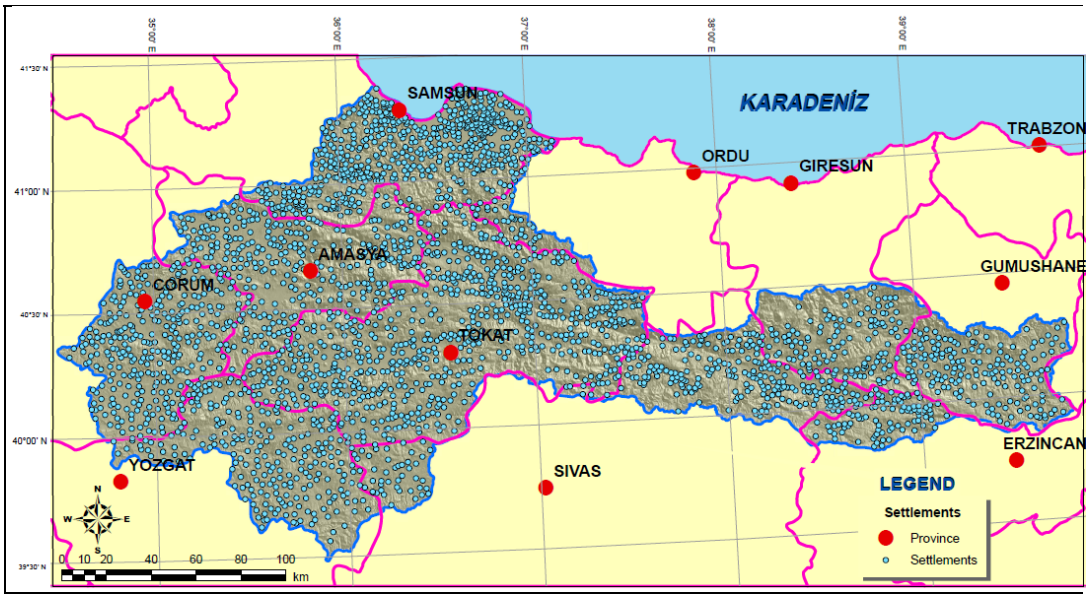



**Figure 3.19** - Settlement Map

## 3.2. Data Evaluation

Analysis processes are mainly composed of the construction of MCDA setup, its implementation and evaluation the results with respect to the opinion of experts whom are group of specialized planners and earth scientists. Environmental data domain and natural hazards domain naturally exhibit contrasts and constraints. Ancient people are assumed to be settling to the most suitable areas considering primarily the environmental data, once they have been settled they are facing with hazard issues. Hence the MCDA routine stages are modified, as each domain is treated individually at the first stage. After score layers of two domains are defined they are joined in a special way that for each possible output one class is present. Finally resultant map of the contemporaneous planner is evaluated with the previously settled settlement areas.

Analysis process has been fulfilled through the MCDA's main 5 stage workflow.

1. **Specifying the problem –** Where are the suitable settlement areas concerning, environmental and natural hazards data sets in the Yeşilırmak Basin beyond the scope of contemporaneous planner?

2. **Specifying the criteria –** Determining correctly the data layers necessary for the solution of the specified problem is critically important for the outcome of the activity. It is evaluated that two different data domains are believed to be important and sufficient to solve the problem according to experts which are environmental and natural hazards data domains.

    - **Environmental Data;**
        - Elevation,
        - Aspect,
        - Slope,
        - Distance to River,

- Rainfall,
- Temperature,

- **Hazard Data;**
  - Earthquake Zones,
  - Earthquake Density Map,
  - Flood Susceptibility Map,
  - Erosion Map

3. **Specifying the priority of the criteria according to each other –** In order to solve the pre-defined problem, pairwise comparisons of different criteria within domains are done with AHP comparison judgment scale (Table 2.2). Pairwise comparison matrix is prepared assessing possible conditions at the Yeşilırmak basin (Malczewski and Rinner, 2005).

4. **Normalizing the data –** To process the data together, the attributes of the layers should be of same kind. So all of the relevant data is rescaled within 0 to 1 range.

5. **Specifying the appropriate sites –** The normalized data are multiplied with layer weights calculated from AHP and final score maps are calculated.

### 3.2.1. Environmental Data Evaluation

Each pair of the environmental data domain is compared with each other, according to their relative contribution to the solution of "where are the suitable settlement areas concerning, environmental data sets in the Yeşilırmak Basin beyond the scope of contemporaneous planner?" problem. At the end of each comparison, importance value is assigned to the pairwise comparison matrix according to AHP Comparison Judgment Scale (Alparslan et al., 2008; Bertiller et al., 2010)

Environmental data is grouped into 3 according to their dominance. The first group formed by elevation and slope data, hence the weights of these criteria were defined as greater than others. From the perspective of economy, life standards, comfort and engineering, higher than 2500 meters and %20 slope areas are not appropriate to the settlement. Furthermore, when compared in pairs the importance of elevation is slightly more important than the slope.

The second group data is water resources, hence the River network data. Water is an important factor in choosing settlement areas from ancient times because of agriculture, health and economy. The contribution of the distance to the river network to the solution of solving problem was hypothesized to have a moderate effect.

Third group data are the least effective group in the selection of settlement areas so it is least important one. This group of criteria is rainfall map, temperature map and aspect map.

The resultant Pairwise comparison matrix of environmental data is presented in table 3.4. The computation of the comparison matrix with the AHP method, yielded in a consistency value of 0.091 which is found to be consistent as it is smaller than 0.1. The weights of the all environmental data is shown table 3.5. It is seen that elevation criteria with 36.7% got the highest value where aspect gets the smallest weight with 3.24%.

**Table 3.4** - Pairwise comparison matrix of environmental data

| Feature | Elevation | Slope | River | Rainfall | Temperature | Aspect |
|---|---|---|---|---|---|---|
| **Elevation** | 1 | 2 | 3 | 5 | 5 | 7 |
| **Slope** | 1\2 | 1 | 5 | 4 | 4 | 7 |
| **River** | 1\3 | 1\5 | 1 | 3 | 2 | 7 |
| **Rainfall** | 1\5 | 1\4 | 1\3 | 1 | 2 | 3 |
| **Temperature** | 1\5 | 1\4 | 1\2 | 1\2 | 1 | 3 |
| **Aspect** | 1\7 | 1\7 | 1\7 | 1\3 | 1\3 | 1 |

**Table 3.5** - Weights of environmental data

| Feature | Weight |
|---|---|
| Elevation | 36.70 |
| Slope | 29.83 |
| River | 14.98 |
| Rainfall | 8.36 |
| Temperature | 6.87 |
| Aspect | 3.24 |

#### 3.2.1.1. Ranking of environmental data

After definition of the weight of all criteria, the internal ranks of each environmental data layer should be determined. In order to process the data together, the attributes of the layers should be of same kind. As the obtained data differ in terms of the attributes (such as number, raster or text attributes).

Maximum and minimum values ranging from 0 to 1 has already be given to the attributes in data preparation stage with appropriate class boundaries designed by the experts. These values are allocated according to the contribution (0 being the worst score and 1 being the best possible score) of the parameter to the solution of the problem.

#### 3.2.1.2. Score map calculation of Environmental criteria

With MCDA tools in TNTmips software, all weights and ranks were assigned to the environmental data. Table 3.6 summarizes all environmental criteria, their weights, attributes, attributes' ranks and overall contribution value to the solution of suitable site selection problem.

After assigning values to the environmental criteria's' attributes, running the program with MCDA routines result map was created. Brown colors show to unsuitable scored sites for the settlements according to the environmental data whereas lighter and greener tones represent more suitable sites (Figure 3.20). As the result is examined, it is seen that highest score is 99 it means that in the study area there are suitable sites according to nearly all criteria's best score. Also most of the area gets scores between 25 and 50 as shown in histogram of result map of environmental data (Figure 3.21).

**Table 3.6** - Overall scores of environmental criterion

| Criterion | Weights | Attributes | Ranks | Total Values |
|---|---|---|---|---|
| Elevation | 37.60 | 0 – 500 | 1.00 | 37.600 |
| | | 500 – 1000 | 0.70 | 26.320 |
| | | 1000 – 1500 | 0.50 | 18.800 |
| | | 1500 – 2000 | 0.20 | 7.520 |
| | | 2000 – 2500 | 0.15 | 5.640 |
| | | 2500 – 3291 | 0.10 | 3.760 |
| Slope | 29.83 | 0 – 3 | 0.80 | 23.864 |
| | | 3 – 5 | 1.00 | 29.830 |
| | | 5 – 7 | 0.70 | 20.881 |
| | | 7 – 10 | 0.40 | 11.932 |
| | | 10 – 20 | 0.20 | 5.966 |
| | | 20 – < | 0.10 | 2.983 |
| Distance to River | 14.98 | 0 – 100 | 0.00 | 0.000 |
| | | 100 – 500 | 1.00 | 14.980 |
| | | 500 – 1500 | 0.70 | 10.486 |
| | | 1500 – < | 0.40 | 5.992 |
| Rainfall | 8.36 | 300 – 400 | 0.20 | 1.672 |
| | | 400 – 500 | 0.30 | 2.508 |
| | | 500 – 600 | 0.50 | 4.180 |
| | | 600 – 800 | 0.70 | 5.852 |
| | | 800 – 1000 | 0.80 | 6.688 |
| | | 1000 – 1250 | 1.00 | 8.360 |
| Temperature | 6.87 | 0 – 9 | 0.40 | 2.748 |
| | | 9 – 11 | 0.60 | 4.122 |
| | | 11 – 14 | 0.80 | 5.496 |
| | | 14 – 15 | 1.00 | 6.870 |
| Aspect | 3.24 | Flat | 0.50 | 1.620 |
| | | North | 0.10 | 0.324 |
| | | Northeast | 0.30 | 0.972 |
| | | East | 0.70 | 2.268 |
| | | Southeast | 1.00 | 3.240 |
| | | South | 0.80 | 2.592 |
| | | Southwest | 0.60 | 1.944 |
| | | West | 0.40 | 1.296 |
| | | Northwest | 0.20 | 0.648 |

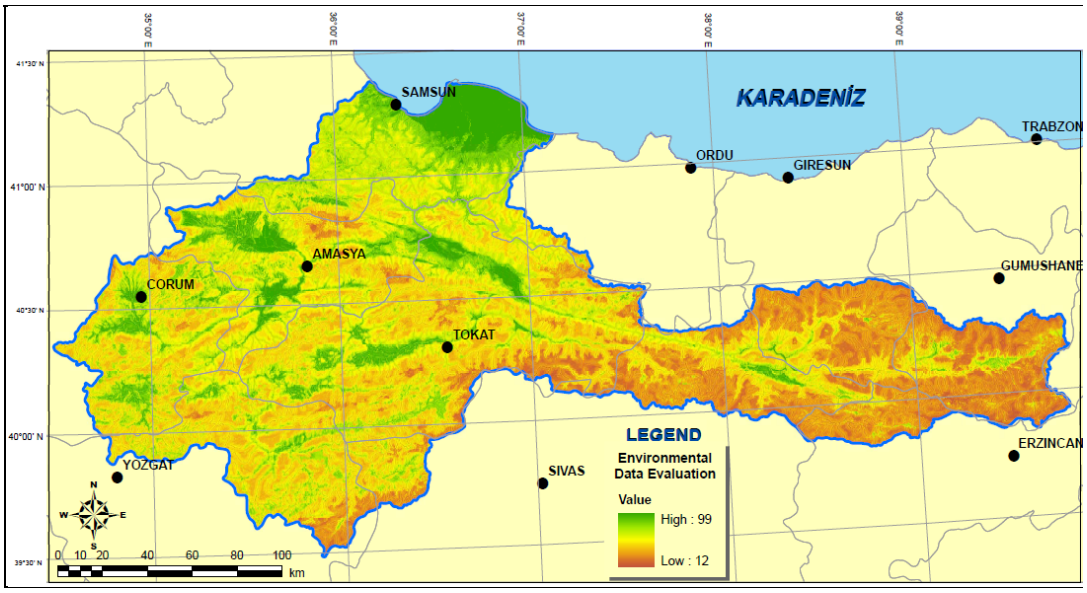



**Figure 3.20** - Result map of environmental data

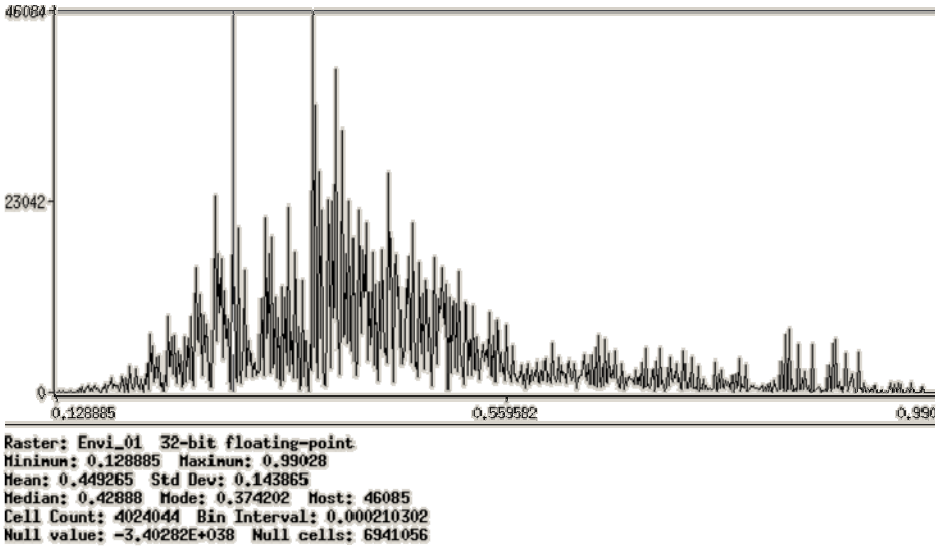



**Figure 3.21** - Histogram of result map of environmental data

### 3.2.2. Natural Hazard Data Evaluation

Similar to environmental data set each pair of the natural hazard data domain is compared with each other, according to their relative contribution to the solution of “where are the suitable settlement areas concerning, natural hazard data sets in the Yeşilırmak Basin beyond the scope of contemporaneous planner?” problem. At the end of each pairwise comparison, importance value is assigned to the pairwise comparison matrix according to AHP Comparison Judgment Scale

There are 4 criteria utilized to solve the problem, earthquake zones, earthquake activity, flood and erosion. The resultant pairwise comparison matrix of natural hazard data is presented in table 3.7. The computation of the comparison matrix with the AHP method, yielded in a consistency value of 0.04718 which is found to be consistent as it is smaller than 0.1. The weights of the all hazard data is shown table 3.8. It is seen that earthquake zones criteria with 59.44% got the highest value where erosion gets the smallest weight with 8.81%.

**Table 3.7 -** Pairwise comparison matrix of hazard data

| Features | Earthquake Zone | Earthquake Activity | Flood | Erosion |
|---|---|---|---|---|
| **Earthquake Zone** | 1 | 4 | 4 | 7 |
| **Earthquake Activity** | 1\4 | 1 | 1\2 | 1 |
| **Flood** | 1\4 | 2 | 1 | 3 |
| **Erosion** | 1\7 | 1 | 1\3 | 1 |

**Table 3.8 -** Weight of natural hazard data

| Feature | Weight |
|---|---|
| **Earthquake Zone** | 59.44 |
| **Earthquake Activity** | 20.59 |
| **Flood** | 11.16 |
| **Erosion** | 8.81 |

#### 3.2.2.1. Ranking of hazard data

After definition of the weight of all criteria, the internal ranks of each hazard data layer are determined. In order to process the data together, the attributes of the layers should be of same kind and weighted to a common scale. Hence all the data is normalized in between 0 and 1, representing worst condition and best condition respectively. In order to include the acceptable risk of the community settled here the minimum value of any natural hazard data is assigned as 0.25.

#### 3.2.2.2. Score map calculation of Hazard criterion

With MCDA tools in TNTmips software, all weights and ranks were assigned to the hazard data. Table 3.9 shows that all hazard criteria, their weights, attributes, attributes' ranks and over all contribution to the solution of suitable site selection problem.

**Table 3.9** - Overall scores of environmental criterion

| Criterion | Weights | Attributes | Ranks | Total Values |
|---|---|---|---|---|
| Earthquake Zones | 59.44 | 1st degree | 0.25 | 14.86 |
| | | 2nd degree | 0.50 | 29.72 |
| | | 3rd degree | 0.75 | 44.58 |
| Earthquake Activity | 20.59 | 0 – 2 | 1.00 | 20.59 |
| | | 2 – 10 | 0.75 | 15.44 |
| | | 10 – 27 | 0.50 | 10.29 |
| | | 27 – 64 | 0.25 | 5.15 |
| Flood susceptibility | 11.16 | 0 | 1.00 | 11.16 |
| | | 1 | 0.25 | 2.79 |
| Erosion | 8.81 | Other | 1.00 | 8.81 |
| | | Non or Little | 1.00 | 8.81 |
| | | Medium | 0.75 | 6.60 |
| | | Strong | 0.50 | 4.40 |
| | | Very Strong | 0.25 | 2.20 |

After assigning values to the hazard criteria's attributes, running the program with MCDA routines result map was created. Brown colors show to unsuitable scored sites for the settlements according to the hazard data whereas yellow to greenish tones represent more suitable sites (Figure 3.22). As the result is examined, it is seen that highest score is 85 and lowest one is 25. Score of 25 mean that in the study area there are risky areas where compose of all criteria's worst condition. Also most of the area gets the scores between 40 and 50 as shown in histogram of result map of hazard data (Figure 3.23)

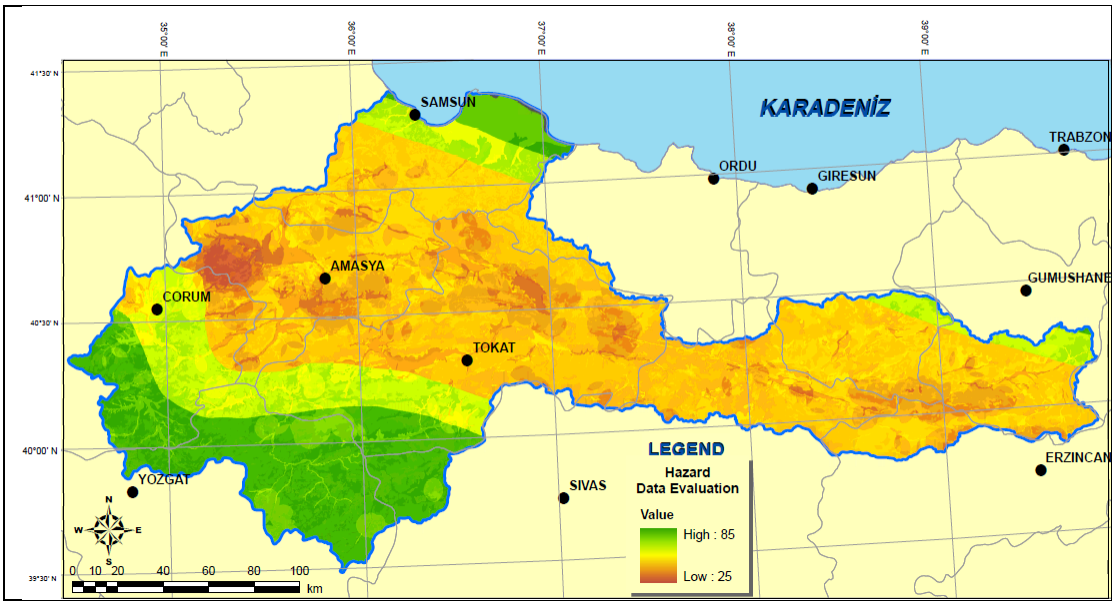



**Figure 3.22** - Result map of hazard data

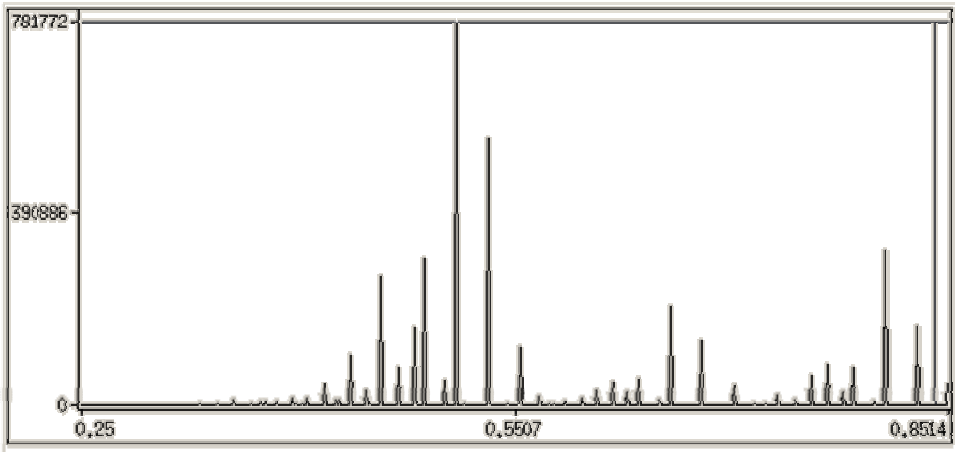



**Figure 3.23** - Histogram of result map of hazard data

### 3.2.3. Resultant Score Map Evaluation

There are two main criterion data set, environmental data and hazard data. It is very hard to evaluate these data together, as they are sometimes mutually exclusive, whereas at some conditions one creates the other. As an example earthquake can effect any place, but the fault that causes the earthquake also shapes the valley with gentle slopes forming a nice productive settlement area, at the same time, the valley might be prone to flooding. In order to overcome this problem, each data set classified according to four classes. New values 1, 2, 3 and 4 are assigned to hazard data. 1 is the worst and 4 are the best suitable settlement areas according to hazard criterion (Figure 3.24). On the other hand, environmental data is classified at the same way with hazard data but the result is multiplied by 10. So new values of environmental result set are assigned to 10, 20, 30 and 40 to form the classified map of environmental data. 10 is the worst and 40 is the best suitable settlement areas according to environmental criterion (Figure 3.25).

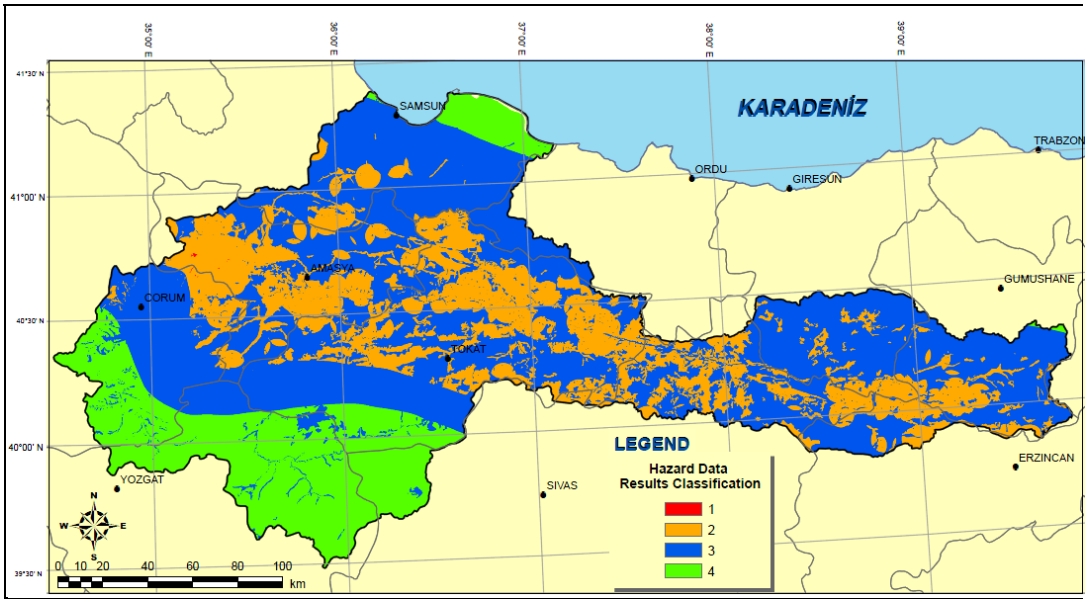



**Figure 3.24** - Resultant score map of natural hazards data

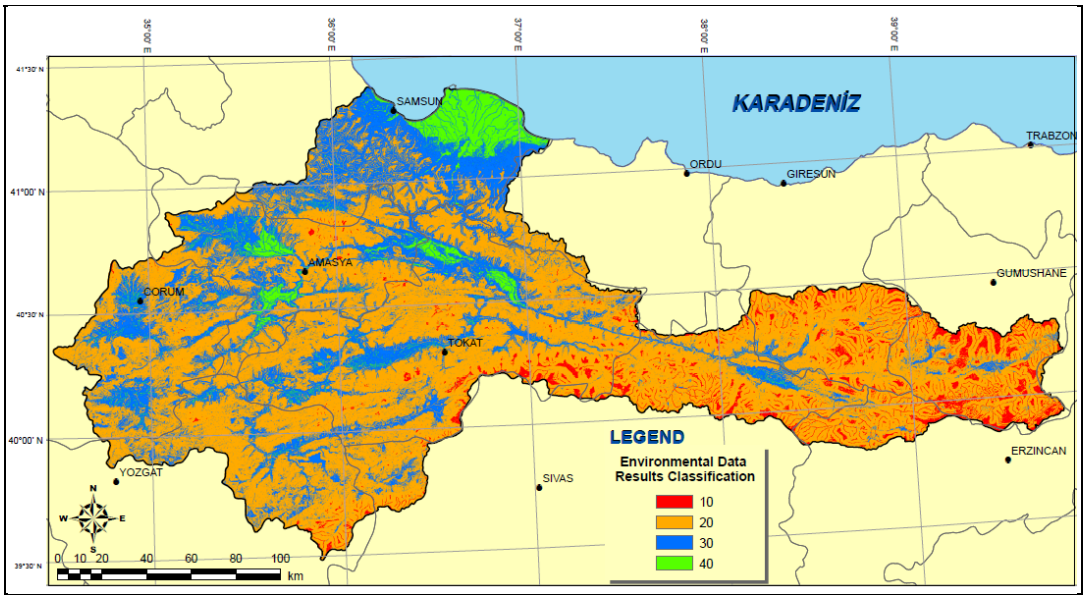



**Figure 3.25** - Resultant score map of environmental data

When the two datasets are summed the resultant value can be re-traceable back to original contributions of two data sets. The comparison matrix of classified maps of environmental and hazard scores are created as shown in table 3.10. This table includes all possible combinations of two maps. Comparison matrix is composed of 4 main parts. First part is the worst areas for settlement according to both environmental and natural hazard inputs (11, 12, 21, 22). Second and third parts are the comprising average suitability for settlement, these parts are mixed in nature, only one data set is favorable but other data asset is not preferred (13, 14, 23, 24, 31, 32, 41, 42). Fourth part is the best suitable areas according to both environmental and natural hazard inputs at the same time (33, 34, 43, 44).

When unfavored areas are considered, 71,12% of the area is found to be not very suitable from environmental criteria and 26,77 % of the area is found to be unsuitable from hazard criteria for residential areas (Table 3.11).. On the other hand, when favoured areas are examined 73,23% and 28,88% of the area is found to be suitable from Hazard and Environmental criteria respectively. However when two criteria are put together at the same time only 21% of the basin is favourable

for settlement of sites and nearly 18,8% of the basin is not preferable both by environmental and hazard criteria. Furthermore, nearly 60% of the whole basin is not favorable by at least one of the criterion.

**Table 3.10** - Comparison matrix of classified value of environmental and hazard score map

| | | Hazard Data | | | | Percentage of Environmental Scores |
|---|---|---|---|---|---|---|
| | | **1** | **2** | **3** | **4** | |
| **Environmental Data** | **10** | 11 | 12 | 13 | 14 | **4.40%** |
| | **20** | 21 | 22 | 23 | 24 | **66.65%** |
| | **30** | 31 | 32 | 33 | 34 | **24.49%** |
| | **40** | 41 | 42 | 43 | 44 | **4.46%** |
| **Percentage of Hazard Scores** | | **0.01%** | **26.67%** | **53.79%** | **19.53%** | |

**Table 3.11** - Areal summary of result map

| | | Hazard Criterion | | Environmental Scores Percent |
|---|---|---|---|---|
| | | 1 – 2 | 3 – 4 | |
| | | Percent | Percent | |
| **Environmental Criterion** | 10 – 20 | **18,73%** | **52,32%** | **71,05%** |
| | 30 – 40 | **7,95%** | **21,00%** | **28,95%** |
| **Hazard Scores Percent** | | **26,68%** | **73,32%** | |

The result map shows that red spotted areas are the un-suitable areas according to both environmental and hazard domains on the contrary green spotted areas are the best favorable sites for both of the domains (Figure 3.26).

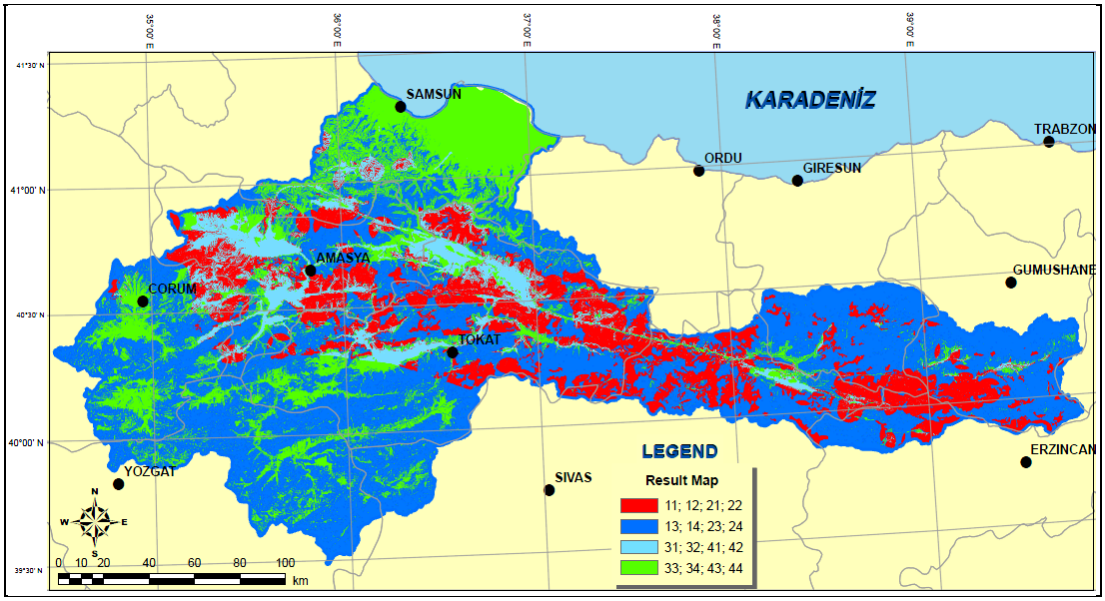



**Figure 3.26** - Combined score map of resultant score map of environmental and hazard data

# CHAPTER 4

# 4. DISCUSSION

The evaluation of site is done in regional scale, because of the necessity of general judgments and consent of the study area. Results maps of environmental and natural hazards with the existing settlement were compared with by transferring the score directly to the center of each settlement which was represented by a point.

In terms of environmentally suitable areas, 28,95% of the field holds approximately 41,37% of all settlements (Table 4.1 and 4.2). When all classes are analyzed individually it is seen a clear bias towards better scored areas as settlement bars are higher than area bars in figure 4.1. On the other hand with respect to the natural hazards, areal percentage of suitability map and the distribution of the settlement percentages are almost identical (73,32% and 73,50% respectively) (table 4.1 and figure 4.2), indicating that there is no preference.

**Table 4.1** - Comparison of existing settlements and suitability map with respect to center point of settlements

| Suitability Scores | Environmental Criteria | | Hazardous Criteria | |
|---|---|---|---|---|
| | Area | Settlement | Area | Settlement |
| Worst – 0.25 | 4,40% | 1,26% | 0,01% | 0,03% |
| 0,5 | 66,65% | 57,37% | 26,67% | 26,47% |
| 0,75 | 24,49% | 33,19% | 53,79% | 54,06% |
| Best – 1.00 | 4,46% | 8,18% | 19,53% | 19,44% |

**Table 4.2 -** Comparison table of combination of environmental and natural hazards result map and existed settlements' center point

| | | Hazard Criterion Percent | | | | Environmental Scores Percent | |
|---|---|---|---|---|---|---|---|
| | | 1 – 2 | | 3 – 4 | | | |
| | | Map | Settlement | Map | Settlement | Map | Settlement |
| **Environmental Criterion Percent** | 10 – 20 | **18,73%** | **15,63%** | **52,32%** | **43,00%** | **71,05%** | **58,63%** |
| | 30 – 40 | **7,95%** | **10,87%** | **21,00%** | **30,50%** | **28,95%** | **41,37%** |
| **Hazard Scores Percent** | | **26,68%** | **26,50%** | **73,32%** | **73,50%** | | |

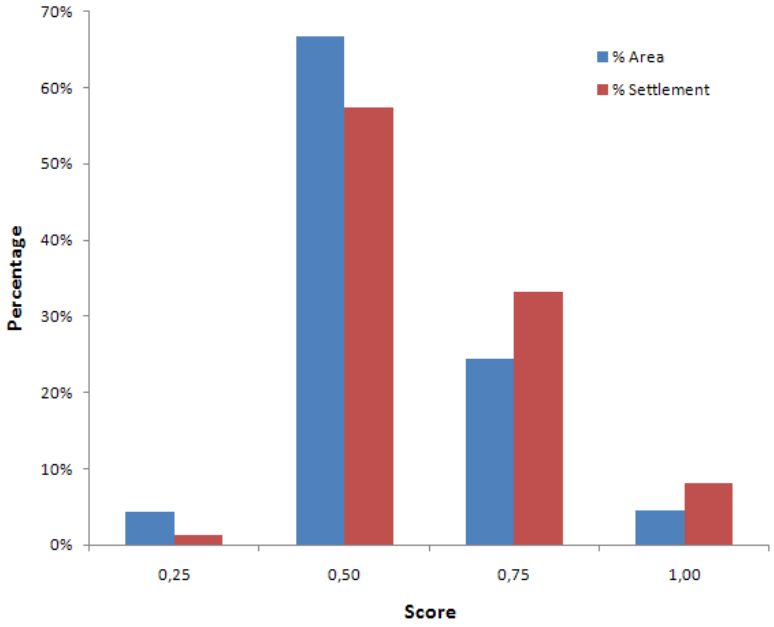



**Figure 4.1** - Comparison of existing settlement points and environmental data

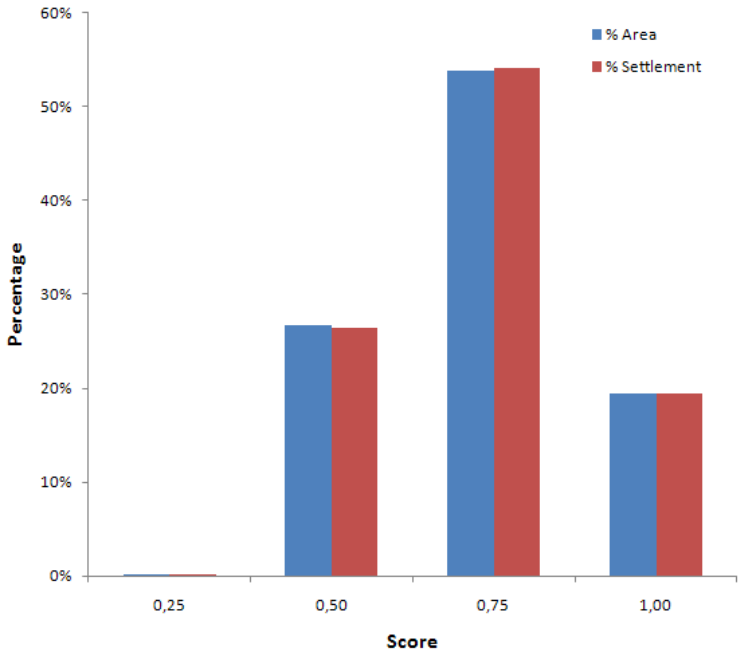



**Figure 4.2** - Comparison of existing settlement points and hazard data

On the other hand, when two data domains are examined simultaneously the bias through environmentally better places is again influencing the selection results. The settlement percentages of classes greater than 31 in figure 4.3 are always bigger than that of area percentages. By the same way classes smaller than the classified value of 31, percentage of settlement sites are always lower than that of area percentages which clearly shows a preference.

Furthermore approximately 73.50% of existing settlements are located in better areas of natural hazards data, similarly the area possesses 73.32%, which can be concluded as there is no preference from natural hazards point of view. In addition most of these areas (52.32%) are not suitable environmentally to settlements.

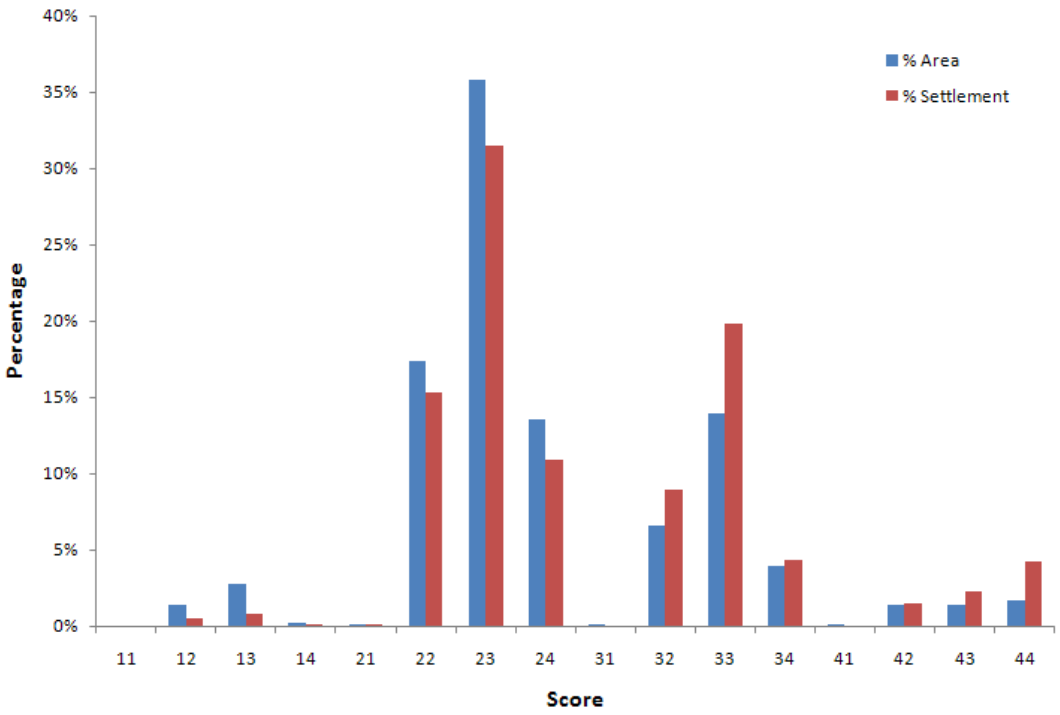



**Figure 4.3** - Comparison figure of combination of environmental and hazardous result map and existent settlements

Although the results are found to be favorable and correct in common sense there are still some issues to be addressed like the scale issue. Definitely if the scale is increased the natural boundary of the basin will be changed and the problem will be decomposed into smaller sub-catchment boundaries, which would result in a better representation of environmental conditions.

Appropriate site selection for settlements cannot solely be based upon spatial information, some other factors should include such as scale dependent localized economies, and social factors which are education, demographics and ethnicities etc. But these kinds of data are not easily obtained and represented spatially. If such data can be included in the analysis process, the results will be more realistic.

As it is mentioned in “Background Information” chapter, in MCDA the decision problems is to divide into smaller understandable parts, analyze each part separately and then integrate the parts in a logical manner. By its nature MCDA contains subjectivity of decisions. In other words the result can be change, if the decision maker is changed, even if the same discipline, people judge the problems differently because of their experiences. In addition to all this handicaps the issue of selecting a suitable site in planning discipline has already significant amount of subjectivity in its classic site selection procedures.

Furthermore there are spatially undefined factors of uncertainties in selection of suitable settlement sites. One of them is political decisions, policy makers decide to develop one particular area or to remain as it was. Once industrialization decision is made in an area, than that area becomes a focal point of the region. The other uncertainty is that closeness of the some important areas or region, for example large empires, trade routes etc. Sparse amount of uncertainties within this context could not be resolved spatially, not only because of the absence or inadequate quality of ancient information, but also the hard nature of modeling social behaviors spatially.

Even if the evaluation of existing settlements score has been made according to the center point of the settlements, it is believed that polygon based evaluations would reflect the real condition more accurately. In the comparison of existing settlements initially a 200m buffer was used, but in evaluation stage it has been realized that the buffer polygon has 3 different values. The minimum, maximum and mean values are 3 transferred attributes of respective MCDA result scores, where none of them is homogenous and neither of them are representative of real conditions. On the other hand for the question of finding suitable places, the size of the area needed for a particular population is one of the basic criteria. As the size of suitable areas directly effects the decisions of planners, prior to such kind of analyses the size needed should be determined, hence the population should be provided, while the approach or the bias through which data domain should be defined.

# CHAPTER 5

# 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusions

A MCDA was set up to seek answer for the question of “Where are the suitable settlement areas concerning, environmental and natural hazards data sets in the Yeşilırmak Basin beyond the scope of contemporaneous planner?”. 10 different data layers in two data domains, environmental and natural hazards domains, are evaluated. The results of the MCDA scores are then transferred to settlement databases to evaluate the number of existing settlements in different environmental and natural hazard related suitability classes, in order to understand if there are any preferences in the settlement site selection.

It is found that almost 29% of Yeşilırmak catchment is environmentally favorable for settlement, and in coherence with that 41,37% of existing settlements are located in this zone, indicating a preference among the perception of environmentally better places to be settled in. On the other hand it is seen that the natural hazards dataset could not create any preference as 73,32% of the area is used by 73,50% of existing settlements, which indicates that the perception of hazards are low and acceptable risk of community is high.

## 5.2. Recommendations

Human perception to environment is different than to natural hazards. Humans live, socialize and work in natural environment every single day and time. They can feel which slope to settle without any measurements, or they can feel how far to settle to a water resource, soil fertility…etc. But humans cannot feel the fault lines, flooding zones or landslide areas unless they experience the hazard themselves or they have been mapped by specialists. This lead us to a conclusion that criteria to select the suitable settlement sites should not only cover environmental and hazard features but also should cover some social factors such as education, ethnicity, demography…etc.

In this research, the study area is the whole Yeşilırmak Basin, which covers around 4,000,000 ha and elevation is changed between 0 to 3000 mt. In the area there are too many smaller catchments. This means that although the elevation values are increasing continuously, it should be considered separately for each catchment area because of the suitability of these areas basically in terms of slope, closeness to water sources and aspect factors. This part of the analysis should be done separately for each catchment zone and the results could be compared to each other, which would definitely changed the scale, purpose and detail of the study.

Beside this issue, examining the area in larger scales would lead us to more accurate results. To achieve this objective it would be necessary to compare the individual catchment settlements' specifications to others', which process would take too much time; and gathering the available data would be costly. Although environmental MCDA setup shows a slight preference, it is concluded that 10 different factors under two data domains are not adequate enough to mimic the cumulated settlement decision criteria in the Yeşilırmak basin. Either some other factors exist and effect decisions, or the priorities have changed over time.

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