A MULTI-CRITERIA DECISION ANALYSIS APPROACH TO GIS-BASED ROUTE SELECTION FOR OVERHEAD POWER TRANSMISSION LINES

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submitted by **YİĞİT DEDEMEN** in partial fulfillment of the requirements for the degree of **Master of Science in Geodetic and Geographic Information Technologies Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen ______________________
Dean, Graduate School of **Natural and Applied Sciences**

Assoc. Prof. Dr Ahmet Çoşar ______________________
Head of Department, **Geodetic and Geographic Information Technologies**

Prof. Dr. Mahmut Onur Karslıoğlu
Supervisor, **Civil Engineering Dept., METU** ______________________

Examining Committee Members:

Prof. Dr. Zuhal Akyürek ______________________
Civil Engineering Dept., METU

Prof. Dr. Mahmut Onur Karslıoğlu ______________________
Civil Engineering Dept., METU

Assist. Prof. Dr. Uğur Murat Leloğlu ______________________
Geodetic and Geographic Information Technologies Dept., METU

Assoc. Prof. Dr. Ali Kılıçoğlu ______________________
General Command of Mapping - Retired

Assist. Prof. Dr. Metin Nohutcu ______________________
Geomatics Engineering Dept., Hacettepe University

Date: 14.06.2013

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last Name: YİĞİT DEDEMEN

Signature:

ABSTRACT

A MULTI-CRITERIA DECISION ANALYSIS APPROACH TO GIS-BASED ROUTE SELECTION FOR OVERHEAD POWER TRANSMISSION LINES

Dedemen, Yiğit

M.Sc., Department of Geodetic and Geographic Information Technologies
Supervisor: Prof. Dr. Mahmut Onur Karslıoğlu

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Multi-criteria decision analysis (MCDA) techniques are popular to select the route of linear structures. In this study, Geographical Information Systems (GIS) is employed to assess all the criteria, which are requested to determine the preferable route of power transmission line (PTL). A MCDA model is established on the basis of the Analytic Hierarchy Process (AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE). Because of the complexity of the routing problem, GIS and MCDA technologies are used synergistically to generate a complete solution.

In this thesis, a GIS-based route selection for overhead power transmission lines is presented in detail taking advantage of the MCDA methods. On the contrary to previous works, this study resolves the routing problem with a combination of the MCDA methods integrated with multi-decision maker. In addition, the risk index, impact factor, and cost are defined as some criteria for evaluation of alternative routes. The cost criterion, derived by the PTL design, contains the material, installation, and transportation expenses; and in addition, the extra cost of the cell where the power structure is located on the cost surface. The multi-layers are relatively compared to specify the weight of each layer using the AHP method by the three decision makers with different professional backgrounds on PTL. Four different routes are generated according to preferences of the decision makers and the mean of individuals' judgments. In the PROMETHEE process, supported by the AHP method, the weight of each criterion is derived from the consensus of the decision makers. Finally, the route alternatives are compared according to criteria and then, the outranked route alternative is specified.

Keywords: Power Transmission Line, Route Selection, GIS based MCDA, AHP, PROMETHEE

ÖZ

YERÜSTÜ ENERJİ İLETİM HATLARI İÇİN CBS TABANLI GÜZERGAH SEÇİMİNE ÇOKLU KRİTERLİ KARAR ANALİZİ YAKLAŞIMI

Dedemen, Yiğit

Yüksek Lisans., Jeodezi ve Coğrafi Bilgi Teknolojileri
Tez Yöneticisi: Prof. Dr. Mahmut Onur Karslıoğlu

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Çoklu Kriterli Karar Analizi (ÇKKA) teknikleri doğrusal yapıların güzergah seçminde popülerdirler. Bu çalışmada, Coğrafi Bilgi Sistemleri (CBS) tercih edilir Enerji İletim Hattı (EİH) güzergahının belirlenmesinde istenilen kriterleri değenlendirmek için kullanılmıştır. Analitik Hiyerarşi Prosesi (AHP) ve Zenginleştirilmiş Değerlendirme için Tercih Sıralama Organizasyonu Methodu (PROMETHEE) temelinde bir ÇKKA modeli kurulmuştur. Güzergah probleminin kompleksliğinden ötürü CBS ve ÇKKA teknolojileri sinerjik bir biçimde bütünsel bir çözüm üretmek için bir arada kullanılmıştır.

Bu tezde, ÇKKA metotları kullanılarak, yerüstü enerji iletim hatları için CBS tabanlı güzergah seçimi ayrıntılarıyla açıklanmıştır. Önceki çalışmaların aksine, bu çalışma güzergah problemini çoklu karar vericilerle entegre ÇKKA metotlarının birleşimiyle çözer. Ayrıca, risk indeksi, etki faktörü ve maliyet, güzergah alternatiflerini değerlendirmek için birkaç kriter olarak tanımlanmıştır. EİH tasarımından elde edilen maliyet kriteri malzeme, kurulum ve nakliye masraflarına ek olarak iletim hattı direğinin maliyet yüzeyi üzerinde konumlandığı hücrenin ekstra bedelini de kapsar Çoklu katmanlar, EİH üzerine farklı profesyonel geçmişleri bulunan üç farklı karar verici tarafından AHP metodu kullanarak her bir katmanın ağırlıklarını belirlemek için göreceli olarak kıyaslanmışlardır. Dört ayrı güzergah karar vericilerin görüşlerine ve her birinin yargılarının ortalamasına göre oluşturulmuştur. AHP metodu ile desteklenmiş PROMETHEE işleminde, kriterlerin ağırlıkları karar vericilerinin fikir birliğiyle çıkartılmıştır. Son olarak, güzergah alternatifleri kriterlere göre kıyaslanmış ve daha üstün olan güzergah alternatifi ile belirlenmiştir.

Anahtar Kelimeler: Enerji İletim Hattı, Güzergah Seçimi, CBS Tabanlı ÇKKA, AHP, PROMETHEE

To Ethem Sarısülük, Abdullah Cömert, Mehmet Ayvalıtaş and all chapullers
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TABLE OF CONTENTS

LIST OF FIGURES

FIGURES

LIST OF TABLES

TABLES

,

CHAPTER 1

INTRODUCTION

1.1 Background and Motivation

The increasing energy demand and attention on environmental and social issues increase the significance of routing of overhead power transmission line. The conventional route selection procedures of power transmission line (PTL) are a costly, time-consuming operation in terms of work overload and examination of the route selection problem in details.

The conventional route selection procedures are generally based on the 1:25000 scaled maps and commonly handle the problem to define a shortest path between the starting and destination points. Most of the route definition studies are executed in the field by walking through the study area.

The routing problem is a complex decision problem, which should be approached in multi-dimensions. The technical constraints, engineering limitations, social and environmental sensibility should be handled during the route selection procedure for PTL. The subjectivity of routing procedure should be prevented by multi-decision makers who have different professional backgrounds on PTL. The main issue of the definition of PTL route cannot only be the length of the route. Thus, the routing problem should be solved as a multi-criteria decision making problem in order to approach the problem in all dimensions.

1.2 Objectives and Scope of the Study

The route selection for overhead PTL is a spatial decision problem and should be dealt with in detail and multi-dimensional. The preferable route alternative should carry some qualifications; short length, cost effective, riskless, operable, and environmentally harmless. The route definition cannot achieve success without using multi-layers and evaluating the route alternatives in multiple dimensions.

The approach of this study is to generate a complete solution for the problem of the route selection of PTL. The problem is aimed to solve with GIS based Multi-criteria Decision Analysis (MCDA) to reach the optimum route alternative. Multi-decision maker is used to strengthen and evaluate the criteria in multi-perspective. The spatial layers and various evaluation criteria are exercised to cover the complex decision problem. The generated preferable route in this study carries the feasible characteristics for overhead PTL as well as the route containing minimized cost, risk, and impact factors.

1.3 Overview of the Study

GIS is a collection of three functionality, which are managing spatial information, integrating geographical technologies (remote sensing, global positioning, CAD etc.), and supporting decision-making process (Foote and Lynch, 1996). GIS and MCDA are perfectly complementary tools since GIS provides spatial analysis, data management, storage, and display to the user/decision maker. Carver (1991) states that GIS provides a powerful toolbox for processing and analyzing spatial data. Eastman (1993) illustrates that the combination of GIS and MCDA is a useful integration for decision analyses, since GIS can compute the criteria and MCDA can provide a decision for problems. In Figure 2.6, the framework of a spatial MCDA and integration of GIS and MCDA in a decision problem are presented.
In the studies covered in this section, Simple Additive Weighting (SAW), Analytic Hierarchy Process (AHP) and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods are generally used for decision analyses.

Carver (1991) used GIS to select a suitable radioactive waste site among several of alternatives. He integrated GIS with MCDA to provide the preferable selection regarding some alternatives

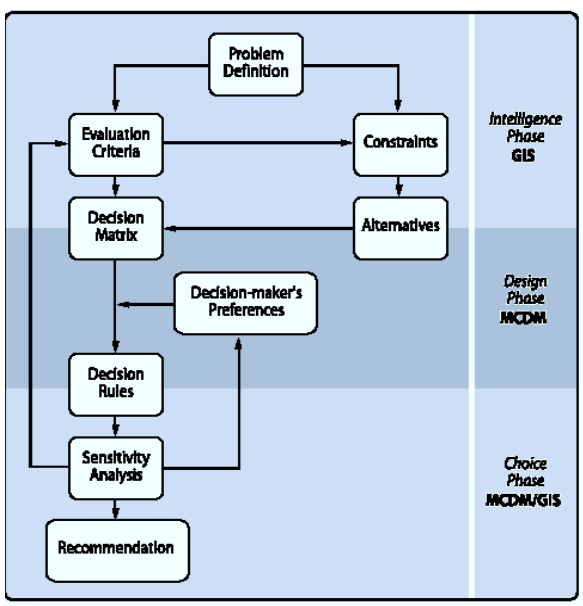


Figure 1.1 Framework for GIS based MCDA (Malczewski, 1999)

like proximity of the urban area, transportation, land use, etc. and objectives. He made an application in UK using ArcInfo for GIS and ideal point analysis, hierarchical optimization and concordance-discordance analysis for MCDA.

Hall et al. (1990) have studied GIS based MCDA for defining land suitability for agriculture. They have examined more than 600 unique areas, several land qualities, more than 10 different characteristics, and two different crop types. They have compared Boolean and fuzzy methods according to usefulness of agricultural sites.

Eastman (1993) illustrated that the integration of GIS and MCDA as powerful method for land suitability analysis. He produced a land suitability map in order to select an industrial site. He used pairwise comparison method, AHP, for ranking the importance of criteria and raster layers in IDRISI.

Pereira and Duckstein (1993) executed land suitability analysis using raster based GIS integrated with MCDA. They examined a case study about habitat evaluation for an endangered species. The AHP method supported with sensitivity analysis and data standardization were used to increase the accuracy for decision analysis. They suggested that GIS with MCDA is useful for rural location planning and facility location.

Siddiqui et al. (1996) presented an approach to a landfill site selection problem using the spatial AHP method. They analyzed the decision-making using with the pairwise comparison of the soil, proximity, and land use layers, and size of landfill site. They examined the comparison of criteria with three different weights and then they ranked the suitable locations of landfill site to define the preferable location.

GIS based MCDA has been used for landfill site selection. Several of input layers (elevation, proximity of urban areas and transportation, geology etc.) reclassified according to suitability of each layer. SAW and AHP methods are compared and the study was showed that the AHP method is more robust than SAW. (Şener et al., 2006).

Kiker et al. (2005) have mentioned about the complexity of decision analyses in environmental problems. They have demonstrated the difficultness of evaluating some criteria in terms of cost. In addition, multi attribute utility theory (MAUT), AHP and outranking methods have been compared and the weaknesses and strengths of each methods have been illustrates by reviewing the literature on MCDA. As a result, it has been shown that for pairwise comparison the AHP method is more relax than MAUT and it also is easy to compare the criteria with outranking method rather than pairwise comparison methods.

Site selection for residential housing construction was performed by using PROMETHEE method as a practical decision making method and GIS as a tool for spatial analysis and visualization (Marinoni, 2006). In this study, it was shown that PROMETHEE is an applicable method for land use analysis. In order to eliminate the computational limits of PROMETHEE method, combining homogenous raster cells instead of evaluating them one by one was suggested (Marinoni, 2005).

For automated distribution line design and optimum route sitting, basic GIS and decision tools have been used. However, the usage of GIS is limited, the routing problem was approached as a geographical problem, and a decision tool supported with artificial intelligence is created (Sumic et al., 1993a, Sumic et al., 1993b). Automated Primary Router (APR) was developed using heuristic algorithms to define the best route for underground cables and it was applied on GIS to handle geographical data (Yeh et al., 1995).

Vega and Sarmiento (1996) studied an overhead transmission line routing using satellite images. They took into consideration economic and environmental constraints for optimum transmission routing. The environmental constraints were defined by them and they generated the layers like land use, hydrology by digitizing satellite images. The layers were weighted by the importance aspects in decision making for line routing. The option having the least environmental impact and being the shortest length was selected.

Öztürk (2007) determined the PTL route using the Euclidean and spatial distances between the starting and destination points. In the study various layers were examined by SAW method to reach the optimum route selection and the generated route alternatives were compared with each other and it was shown that the routing method by using with spatial distance was preferable than the method using Euclidian distance.

For optimum route selection of underground lines, an objective function namely impedance index (II) has been developed by Cheng and Chang (2001). II was obtained from the road section and the weight result of AHP method for defining the preferable path. The aim of the study was designing an automated routing system to obtain the optimal route regarding the physical barriers and the lowest cost goal. They combined the expert knowledge, the weights, acquired from the AHP method, and GIS for sitting the route.

Electric Power Research Institute (EPRI) and Georgia Transmission Corporation (GTC) started working together for a new transmission line routing methodology in 2002. EPRI-GTC sponsored an expert team to combine the transmission line knowledge, GIS technology and decision process for routing problem (French et al., 2011). Roughly, using some basic layers, macro corridor for power line was defined and remaining within that corridor, alternative corridors were generated to achieve optimal route. While selecting corridors and alternative routes, GIS was used as a main body and critical reviews gathered from many stakeholder were used for weighting by using Delphi and AHP methodology (Houston and Johnson, 2006).

A new method was presented by Monteiro et al. (2005) for automated route selection for overhead transmission lines using with GIS. In this study, dynamic programming was used for optimal routing At the route selection, environmental and engineering restraints were involved with installation, maintenance and operating cost of new power line as a criterion. Besides selecting a new route, the other goal of the study was to define a lowest cost corridor for the power line. This methodology can easily be adapted for linear line routing problems.

In this study, more than ten different layers are used to evaluate the route selection problem in a multi-dimensional approach. The AHP method is used for definition of the weights of each criterion. Three decision makers with different professional backgrounds on PTL provide to represent the various preferences of each decision maker in different perspective for route selection. The results of the route selection processes, generated by the rankings of each decision maker and the mean of them, are used to compare the superiority of each alternative. The route alternatives are compared based on the cost, length, risk, and impact factors in the PROMETHEE method. The cost of each route is derived from the real PTL design with a powerful power line design software. The cost criterion contains the material, installation and transportation expenses, and in addition, the cost of the cell coming from the cost surface where the power structure is located. The risk factor is derived from the number of intersection of the route with the linear structures. The impact factor is obtained from the total length of the PTL passing through the forest, agricultural and settlement areas. The weight of each criterion is derived by the consensus of the decision makers. Finally, the outranked route alternative is specified by the PROMETHEE supported by the AHP method.

1.4 Structure of the Thesis

The following chapters represent the route selection process of the study in a detailed perspective. Chapter 2 covers MCDA and the integration of it with GIS. MCDA methods, commonly used in land suitability analysis are presented and the MCDA methods used in this study are mentioned in details. In Chapter 3, the data set used in the study is presented. The acquisition, reclassification, and generation of data processes are explained. In Chapter 4, the methodology and analyses are used in the processes of the route selection. The methodology steps and the decision-making calculations and GIS analyses are covered. Finally, Chapter 5 contains the conclusion of the study, discussions, and recommendations for future studies.

CHAPTER 2

DECISION MAKING METHODS

2.1 Introduction

Many researchers and studies have made contribution to improvement of the theory and application of Multi-Criteria Decision Analysis (MCDA). The studies mentioned in this chapter focus on the MCDA concept and Geographic Information Systems (GIS) based MCDA especially for site selection issues.

This chapter provides an overview of previous research, consisting of three main parts. In section 2.2, MCDA and developed methods are discussed. In section 2.3, this chapter is summarized.

In everyday life, people make decisions based on the situation they would like to have. In a personal decision circumstance; like deciding to buy a new car, cars are classified according to price, fuel consumption, environmental impact, color, luxury and so on; another example for decision making can be a man's choice of a male or female partner with respect to his own sexual orientation and other's personality, cleverness, appearance and so on (Hwang and Yoon, 1981).

As in the everyday life, the decision process is the same with the complex spatial decision problem. Figure 2.1 shows the process cycle of the simple decision problem. MCDA problem

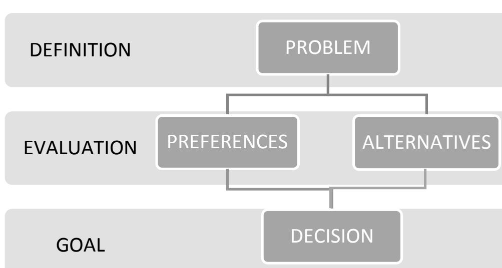


Figure 2.1 Simple Decision Process

can be described as evaluation of alternative options regarding the priorities and preferences of decision maker; for instance, when renting a new house, there is some required criteria like closeness of recreation areas and markets, rental fee and comfort (Belton and Stewart, 2002). The rental house problem can also be considered as a spatial decision problem, so it can be dealt with computer-based solution. As in the case of the previous example, the spatial problems can be solved with spatial multi-criteria decision-making (MCDM) (Malczewski, 1999a). For decision problems, the goal is a statement of a desired accomplishment regarding the criteria (Keeney, 1992). Malczewski (1999a) describes the decision process as a combination of small significant parts; separate analysis of them and reasonable integration of the small solution to generate a complete solution of the problem.

Route selection of linear features, which are power transmission line, pipeline, railway, and highway, is also a paramount decision making problem because of the cost, and environmental and social impact of the structures. Some limitations, different levels of preferences and various requirements exist for routing a linear structure. Therefore, optimum route selection for power transmission line (PTL) can be also thought as a multi-criteria decision making problem.

2.2 Multi-Criteria Decision Analysis (MCDA)

For sophisticated spatial site selection problems, it is necessary to give a complex decision in a limited period simultaneously regarding the economic limitations, environmental restrictions and sustainability of the project (Joerin et al., 2001). One dimensional decision methods cannot support comprehensive solutions for complex decision problems. Due to the weakness of the conventional decision methods in handling plenty of criteria simultaneously, in 70's MCDA was started to use commonly and exponentially in many fields (Köksal et al., 2011; Carver, 1991).

MCDA brings useful decision methods and techniques to evaluate the alternatives and to set a decision problem (Malczewski, 2006). Moreover, it provides the user to select the optimum choice from the various alternatives in accordance with decision maker preferences and criteria (Jankowski, 1995).

2.2.1 Framework for MCDA

MCDA begins with stating the problem and continues with the steps in Figure 2.2 until reaching a decision. For any decision process, definition of decision problem is vital. After the definition of the problem, decision maker needs to define the selection criteria and evaluate the feasible alternatives with regarding the constraints to structure the decision matrix

(Malczewski, 1999b). MCDA proceeds with a generation of a decision matrix that includes the scores of the alternatives according to the selected criteria (Carver, 1991).

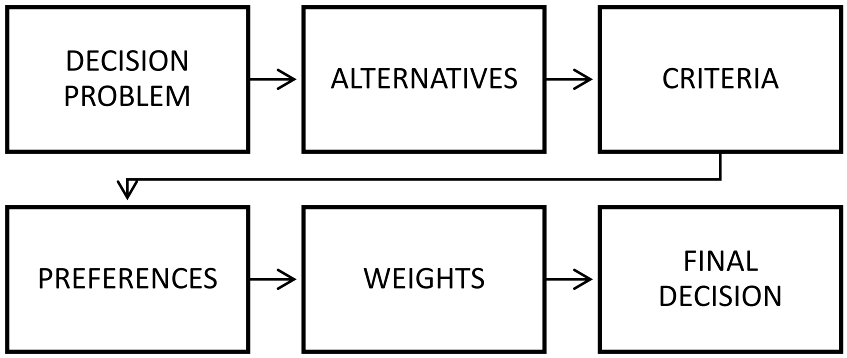


Figure 2.2 Basics of Decision Process

$$\boldsymbol{A} = \begin{bmatrix} A_{11} & \cdots & A_{1i} \\ \vdots & \ddots & \vdots \\ A_{j1} & \cdots & A_{ji} \end{bmatrix} \tag{2.1}$$

$A_{m*} = (A_{m1}, A_{m2}, \dots, A_{mj})$ for $m = 1,2,\dots,i$
$A_{*n} = (A_{1n}, A_{2n}, \dots, A_{in})$ for $n = 1,2,\dots,j$

In equation (2.1), A_{ji} represents the score according to j^{th} criteria and i^{th} alternative, furthermore A_{ji} has the features of j^{th} criteria and i^{th} alternative (Jankowski, 1995; Carver, 1991). In order to ascertain the robustness of the problem structure, sensitivity analysis should be performed (Saltelli, 1999; Malczewski, 1999b). At the end of these processes, the best or a group of alternatives could be obtained.

2.2.2 MCDA Methods

MCDA can be divided into two classes namely multi-attribute decision analysis (MADA) and multi-objective decision analysis (MODA) (Malczewski, 2006). There are general differences between MADA and MODA which are model principles (data vs mathematical model) and alternative options (user defined vs generated with model) (Malczewski, 2004). Figure 2.3 shows the mostly used GIS based MCDA. In this study MADA methods; weighted summation, aggregation, ideal point, and outranking models are covered.

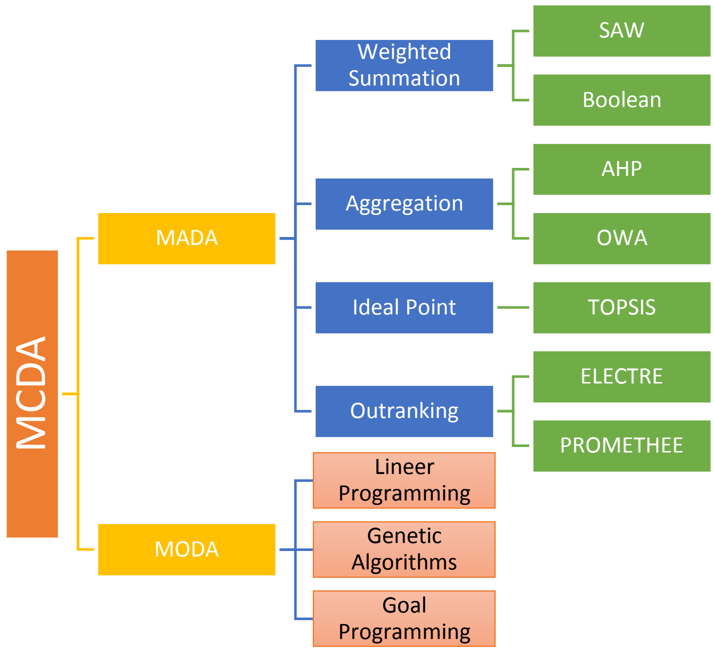


Figure 2.3 Classification of MCDA Methods (Malczewski, 2006)

There are many MCDA methods but only four main groups of them are considered in the study; methods using weighted summation such as: Simple Additive Weighting (SAW) (Churchman and Ackoff, 1954) and the weighted linear combination method of Boolean overlay (Hopkins, 1977; Tomlin, 1990), methods using aggregation like: Analytic Hierarchy Process (AHP) (Saaty, 1990) and Ordered Weighted Averaging (OWA) (Jiang and Eastman, 2000), the method using ideal point which is Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) (Hwang and Yoon, 1981) and outranking methods such as ELECTRE (Roy, 1990) and PROMETHEE (Brans et al., 1986).

In the following sections, the generally most preferred MCDA methods for land use suitability and site selection analyses like waste disposal, landfill, and optimal route problems are explained in detail.

2.2.2.1 Simple Additive Weighting (SAW)

Simple Additive Weighting (SAW) is a weighted sum method. Churchman and Ackoff (1954) are known as the first implementers of the SAW method. The SAW method is one the most applicable method and it is known as an easy method to deal with MCDA (Gwo-Hshiung, 2011). The decision maker defines the weights of each alternative. Then by multiplying the importance factor of the alternative, the score of the alternative is calculated and the alternative with the highest score is selected.

$$A_i = \sum_j w_j x_{ij} \tag{2.2}$$
$$\sum w_j = 1$$

The alternative A_i is equal to the multiplication of the relative weight w_j (Equation 2.2) with the score x_{ij} of the i^{th} alternative in respect to j^{th} attribute (Malczewski, 1999b).

2.2.2.2 Analytic Hierarchy Process (AHP)

AHP is a pairwise comparison method, developed by Saaty (1980). The AHP method is accepted as a powerful tool for MCDA to solve complex decision problems (Saaty, 1980). The AHP method comprises all factors in a hierarchical arrangement. It consists of three steps; first, definition of complex decision problem; second, pairwise comparison of the selection factors; and lastly generation of the decision result using hierarchical structure. The decision maker ranks the factors according to relative importance of them. The priorities of the decision maker for criterion are scored by Saaty scale table (Table 2.1).

Table 2.1 Scale for Pairwise Comparison (Saaty, 1980)

1	Equally important
2	Equally to moderately important
3	Moderately important
4	Moderately to strongly important
5	Strongly important
6	Strongly to very strongly important
7	Very strongly important
8	Very to extremely important
9	Extremely important
Reciprocals	Reciprocals for inverse comparison

The pairwise comparison of the attributes makes it easy to decide for complex decision problems since the decision maker only compares the importance of the two of the attributes at one time (Malczewski, 1999b). One of the fundamentals of AHP method is to check the consistency of decision maker's pairwise scores.

$$C = \{C_j \mid j = 1,2,3, \dots, n\} \tag{2.3}$$
$$a_{ij} (i, j = 1,2,3, \dots, n)$$

In Equation (2.3) C represents the set of criteria and a_{ij} shows the pairwise relative importance of the criteria.

$$\boldsymbol{A} = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \text{ where } a_{ii} = 1\ ,\ a_{ji} = 1/a_{ij} \text{ and } a_{ij} \neq 0 \tag{2.4}$$

In Equation (2.4), $[n \times n]$ evaluation matrix including relative ranks of the criteria is represented. A set of eigenvalues can be obtained from the evaluation matrix as follows:

$$Aw = \begin{bmatrix} \frac{w_1}{w_1} & \cdots & \frac{w_1}{w_n} \\ \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \cdots & \frac{w_n}{w_n} \end{bmatrix} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \lambda_{max} \begin{bmatrix} w_1 \\ \vdots \\ w_n \end{bmatrix} = \lambda_{max} w \tag{2.5}$$

In Equation (2.5) λ_{max} is used to define the normalized eigenvector (Saaty, 1990).

$$a_{jk} = a_{ik}/a_{ij} \tag{2.6}$$

$$CI = \frac{(\lambda_{max} - n)}{(n-1)} \tag{2.7}$$

The decision maker's ranking according to relative importance of each attribute specifies the quality of the result. The pairwise comparison needs to be consistent. The consistency of the evaluation matrix, described by the correlation of scores, should satisfy the condition in Equation (2.6). Consistency Index CI is formulated in Equation (2.7) where n is the number of criteria and λ_{max} is the highest eigenvalue. If $\lambda_{max} = n$, $CI = 0$ and the evaluation could be consistent. However, in practice the decision maker could not compare the many attributes consistently. The consistency of the pairwise comparison can be measured by:

$$CR = \frac{CI}{RI} \tag{2.8}$$

In Equation (2.8) Consistency Ratio CR is obtained by dividing the Consistency Index CI by the Random Index RI, which represents the appropriate CI generated by the random reciprocal matrix. Table 2.2 shows the RI adapted from Saaty (1980).

Table 2.2 Random Inconsistency Index RI (Saaty, 1980)

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

If CR is less than 0.10, the pairwise comparison is accepted as consistant. However if CR is greater than 0.10, the ranking of pairwise comparison should be repeated to improve the constancy of comparison.

2.2.2.3 Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE)

PROMETHEE I (partial) and PROMETHEE II (complete) ranking methods are developed by Brans et al. (1980). PROMETHEE is an outranking method, which shows the comparison of the superiority of the alternatives each other according to the specified criterion. For multi-criteria decision problems, PROMETHEE is a simple method in application. On the other hand, PROMETHEE gives reasonable results if there is a finite set of possible alternatives (Brans and Mareschal, 2005).

Brans et al. (1980) describes the two requirements for implementation of PROMETHEE;

- The information about superiority relationship between the criteria.

This information shows the weights representing the relative pairwise importance of alternatives.

- The preference function of a criterion for comparing the alternatives.

The preference function converts the difference of the two selected alternatives for a selected criterion in a scale of 0-1. Brans and Mareschal (2005) have offered six generalized preference functions in Figure (2.4).

Preference function shows the difference between two alternatives as follows:

$$P_j(a,b) = G_j\left[d_j(a,b)\right] \qquad \forall\ a,b\ \in A \tag{2.9}$$

$$d_j(a,b) = f_j(a) - f_j(b)$$

$$0 \leq P_j(a,b) \leq 1$$

PROMETHEE uses preference function $P_j(a,b)$, Equation (2.9), shows the value difference between two alternatives (a,b) for the criterion j. There are three different parameters for preference function which are;

- q : Indifference threshold is the largest deviation which is considered as negligible. If $d_j(a,b)$ for criterion j is smaller than q, it means that the alternatives a, b are indifferent for criterion j.
- p : Preference threshold is the smallest deviation which shows the strict preference. If $d_j(a,b)$ for criterion j is greater than p, it means that the alternative a is preferable than the alternative b.

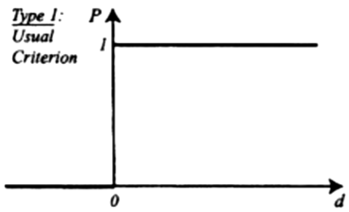
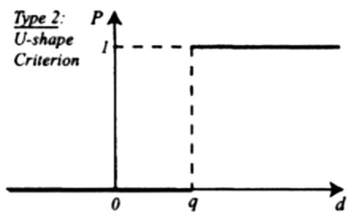
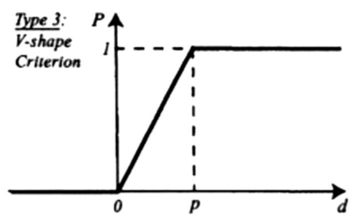
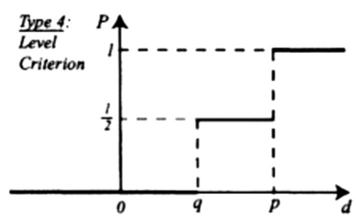
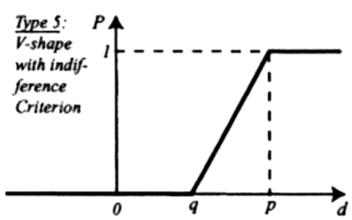
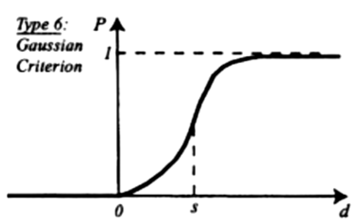
Generalised criterion	Definition	Parameters to fix
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 & d > 0 \end{cases}$	–
	$P(d) = \begin{cases} 0 & d \leq q \\ 1 & d > q \end{cases}$	q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ \frac{d}{p} & 0 \leq d \leq p \\ 1 & d > p \end{cases}$	p
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq q \\ \frac{d-q}{p-q} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q
	$P(d) = \begin{cases} 0 & d \leq 0 \\ 1 - e^{-\frac{d^2}{2s^2}} & d > 0 \end{cases}$	s

Figure 2.4 Preference Functions (Brans and Mareschal, 2005)

- s : Gaussian threshold is the inflection point of Gaussian preference function, between q and p.

Preference index $\pi(a, b)$ is formulated as:
$\forall$ a, $b \in A$

$$\pi(a, b) = \sum_{j=1}^{k} P_j(a, b) w_j \tag{2.10}$$
$$\pi(b, a) = \sum_{j=1}^{k} P_j(b, a) w_j$$

$\pi(a, b)$ is equal to the weighted preference function $P_j(a, b)$ (Equation (2.10)) and it expresses the preferable degree of a and for a better than b or vice versa.

$$\begin{cases} \pi(a, a) = 1 \\ 0 \leq \pi(a, b) \leq 1 \\ 0 \leq \pi(b, a) \leq 1 \\ 0 \leq \pi(a, b) + \pi(b, a) \leq 1 \end{cases} \tag{2.11}$$

$\pi(a, b)$ or $\pi(b, a)$ should be positive and their summation is between or equal to 0 to 1 (Equation (2.11))

For Eq. (2.12) the alternative a is more preferable than the alternative b.

$$\begin{cases} \pi(a, b) \sim 1 \\ \pi(b, a) \sim 0 \end{cases} \tag{2.12}$$

Where $\forall$ a, $x \in A$, positive outranking flow is defined as:

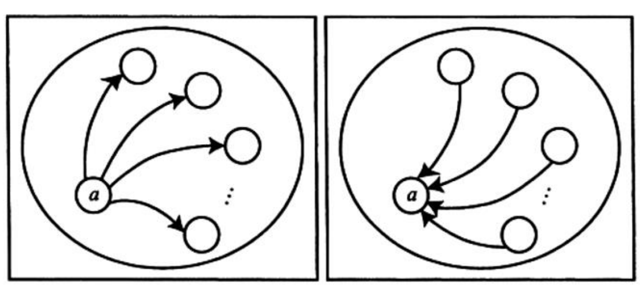
$$\phi^{+}(a) = \frac{1}{n-1} \sum \pi(a, x) \tag{2.13}$$

negative outranking flow is defined as:

$$\phi^{-}(a) = \frac{1}{n-1} \sum \pi(x, a) \tag{2.14}$$

and net outranking flow (Eq. 2.15):

$$\phi\ (a) = \phi^{+}(a) - \phi^{-}(a) \tag{2.15}$$



(a) The $\phi^{+}(a)$ outranking flow. (b) The $\phi^{-}(a)$ outranking flow.

Figure 2.5 PROMETHEE outranking flows (Brans and Mareschal, 2005)

For the alternative a, $\pi(a,x)$ represents the preference index of a by considering each alternative (Figure (2.5)). $\phi^+(a)$ and $\phi^-(a)$ shows that the alternative a is preferable or unpreferable or the compared alternatives are indifferent or incomparable.

$$\begin{cases} \phi^+(a) > \phi^+(b) \; and \; \phi^-(a) < \phi^-(b) \\ \phi^+(a) > \phi^+(b) \; and \; \phi^-(a) = \phi^-(b) \\ \phi^+(a) = \phi^+(b) \; and \; \phi^-(a) < \phi^-(b) \end{cases} \tag{2.16}$$

At the conditions in Equation (2.16), the alternative a is preferable than b.
The alternatives a and b are in different, when:

$$\phi^+(a) = \phi^+(b) \; and \; \phi^-(a) = \phi^-(b) \tag{2.17}$$

The alternatives a and b are not comparable, when:

$$\begin{cases} \phi^+(a) > \phi^+(b) \; and \; \phi^-(a) > \phi^-(b) \\ \phi^+(a) < \phi^+(b) \; and \; \phi^-(a) < \phi^-(b) \end{cases} \tag{2.18}$$

2.3 Summary

A comprehensive literature review has been done in order to summarize previous researches about MCDA and GIS based MCDA for site selection. Previous researches conducted in MCDA methods and applications are criticized in this chapter. Multi-criteria decision-making concept is discussed and the integration of MCDA to GIS is provided. GIS applications in MCDA are mostly focused on land suitability analysis. Optimal route selection analysis for distribution and transmission lines is also covered with the previous studies. Therefore, while the literature study was being made, also with other discipline examples are chosen to demonstrate the usage of GIS based MCDA.

The aim the GIS based MCDA is to solve complex decision problems with regarding the decision makers' preferences and criteria. MCDA provides many decision methods according to type of the decision problem and GIS supports user with spatial tools and visualization. Integration of GIS and MCDA enable to generate a solution for a land suitability problem with many constraints, limitations, and criteria, which cannot be covered by conventional decision methods. When all these reasons are considered, GIS based MCDA increasingly continues to be used for site/route selection problems.

On the way to development of spatial decision system, the data used for decision analysis is also vital. The accuracy and quality of the result of a decision problem depend on the spatial data used in GIS based MCDA. In Chapter 3, the raw and generated data, essential to define transmission line routing, are discussed.

CHAPTER 3

DATA ACQUISITION, RECLASSIFICATION AND GENERATION

3.1 Introduction

The data collection used in the study is covered in this chapter. The characteristics and contents of the raw and derived data are represented. In addition to these, the reclassifications of data for decision analysis are discussed.

In section 3.2, the study area of the transmission line presented and the data layers are explained in details in section 3.3. Lastly, the generated and reclassified data are covered in section 3.4.

3.2 Study Area

The research field is in İzmir in the Aegean region (Fig. 3.1). İzmir region is selected because of the accessibility of data and variability in the dataset. This variety in data helps to highlight the importance of decision maker preferences while defining the route for power transmission line. Furthermore, there is also an existing line in the study area (Fig. 3.2), and that line used to compare with the preferred route selection that will result from the study.

The route of a power transmission line can be between two substations or between a substation and another transmission line. In this study, the route of the line will be optimized, is between Uzundere Substation and Kuşadası-Germecik PTL.

Figure 3.1 Map of Turkey with the Highlighted İzmir

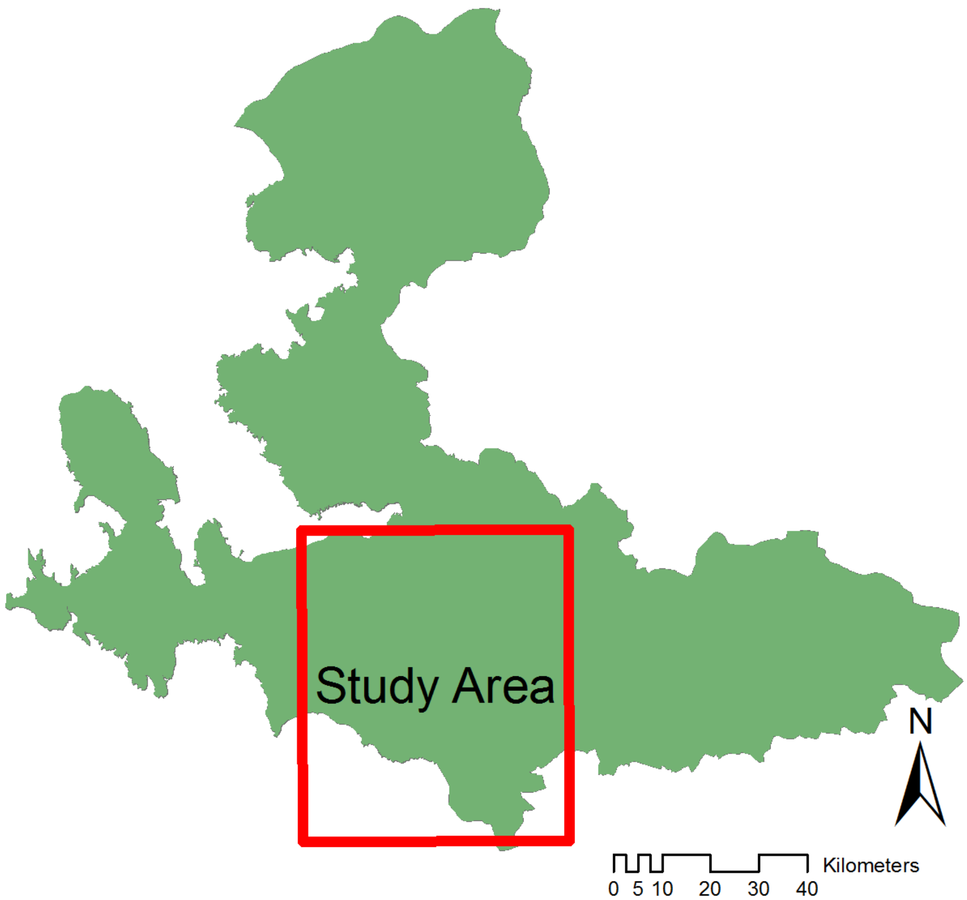


Figure 3.2 The Study Area

3.3 Data Set

In this study, data set consists of DEM, Soil, Settlement, Land Use, Road, Pipeline, PTL, Geology, Water Resources, Protected Zone and Ice Load layers. There are brief description of used layers and their importance for route selection study in the next subchapters. Moreover, GIS is used for displaying, managing, analyzing and storing of large and various dataset.

Table 3.1 Data Properties and Resources

Digital Elevation Model	1:5000 scale – 10 m resolution	Generated by İşlem GIS
Soil	1:100000	General Directorate of Rural Services
Land Use	1:100000	Landsat
Road	1:25000	General Command of Mapping - Topographic Maps
Pipeline	1:25000	General Command of Mapping - Topographic Maps
PTL	1:25000	Turkish Electricity Transmission Company
Geology	1:100000	General Directory of Mineral Research and Exploration
Water Resources	1:25000	General Command of Mapping - Topographic Maps
Ice Load	1:1850000	Turkish Electricity Transmission Company

In the light of the Regulation of Turkish Electricity Transmission Company for PTL Design (2005), these recommended layers are used to achieve a decision standard for route selection processes.

3.3.1 Digital Elevation Model (DEM)

Elevation data is commonly starting point of power transmission line (PTL) design because elevation data is essential for route selection of power lines since the suitability of the terrain can be substantially determined by the elevation data and slope layer generated by elevation data. In addition to route selection, the profile of the terrain generated from the elevation data, is used for spotting the power structures in the transmission line route.

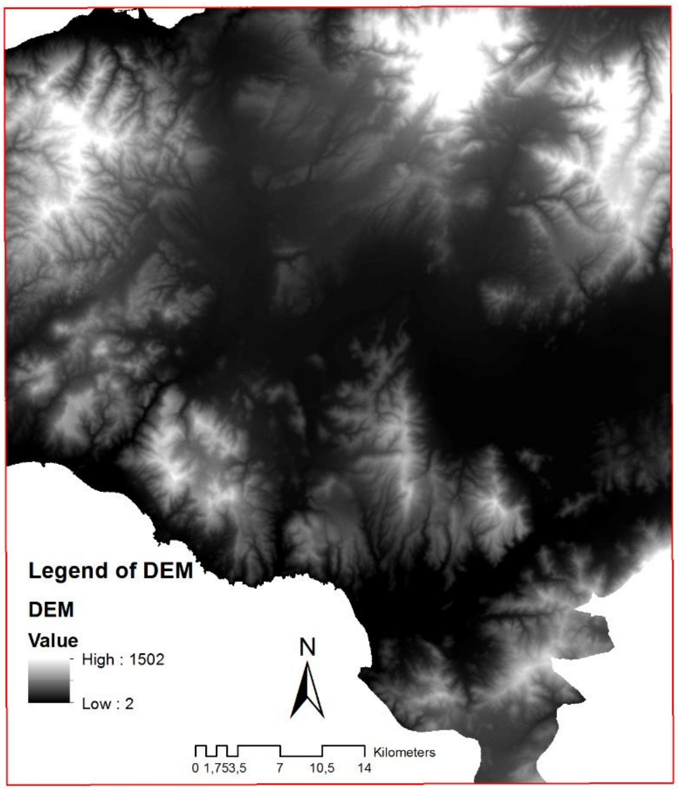


Figure 3.3 DEM

For representing terrain surfaces, DEM has been frequently used and these surface models can be both in raster or vector format in application. DEMs are generally produced by using remote sensing techniques such as LIDAR, photogrammetry, satellites etc. It consists of continuous raster cells or triangulated irregular networks (TIN) created by elevation data.

In this study, raster based DEM (Fig. 3.3) is used for route suitability analyses, generation of slope layer and design of transmission lines. For this study area, DEM has been provided by İşlem GIS Co. Ltd. with a 10 m resolution in ED50 Lambert Conformal and it is 1:25000 scaled.

3.3.2 Soil Layer

One of the essential layers for transmission line sitting is soil layer. In this study, soil layer contains valuable information in vector format about the features of terrain such as; major soil groups, soil features combination, current land use, erosion and land use capability. The explanation of the symbols of Soil layer is published by the Ministry of Forestry and Waterworks (2011).

Major Soil Groups and Combination of Soil Features data give information about the characteristics of the terrain. It contains data about the classification of soil, humidity level of soil, type of vegetation, materials of soil and fertility of soil (Fig. 3.4). It is one of the significant information to understand the fertility and the strength of the soil; and is used to generate Landslide layer.

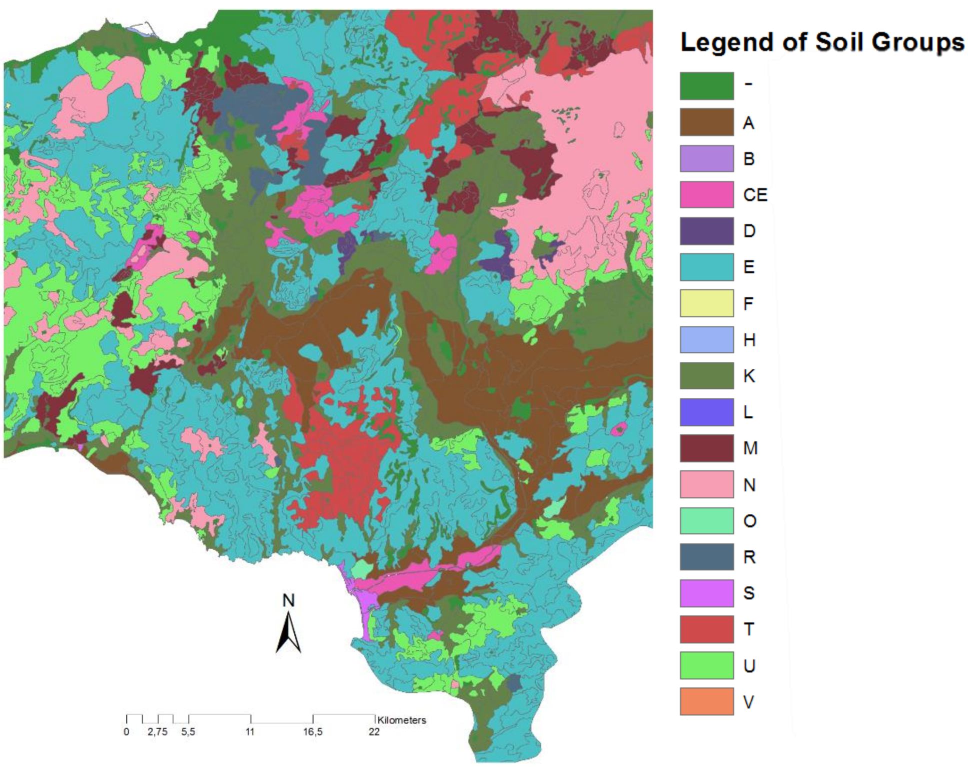


Figure 3.4 Soil Groups Layer

Current Land Use layer is another critical data for site selection of power line. This layer involves the current situation of the terrain such that the terrain can be used for irrigated or dry farming, meadow, forest, and type of growing tree (Fig. 3.5).

Erosion layer contains the information about the erosion degree of the terrain. It is important to have a knowledge about erosion for spotting of the power structures (Fig. 3.6).

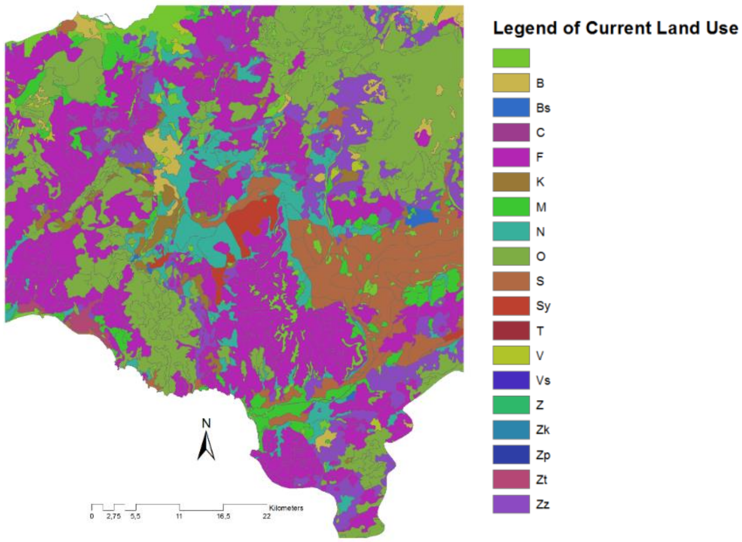


Figure 3.5 Current Land Use Layer

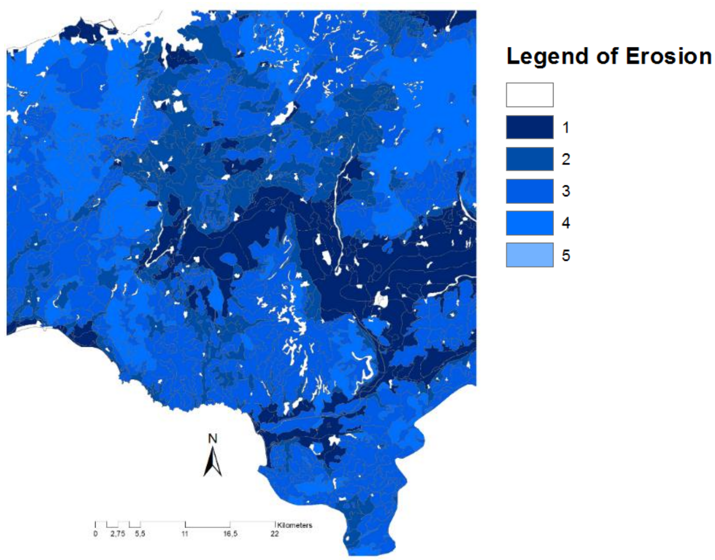


Figure 3.6 Erosion Layer

Land Use Capability layer is the crucial base map for optimal route selection and sitting of power structures. The usage of this layer provides to minimize the agricultural impact of power line routing. The layer contains the degree of the fertility of the land (Fig. 3.7). It also contains eight fertility degrees for soil. These fertility degrees between I to IV show that the land is suitable for agriculture. These capability categories are the scale for the land's fertile soil type and it is economic value. The degrees between V-VII mean that the land is unsuitable for cultivating. The degree VIII represents the unfertile land category. Although it is unsuitable for agriculture, it is favorable for power transmission line routing.

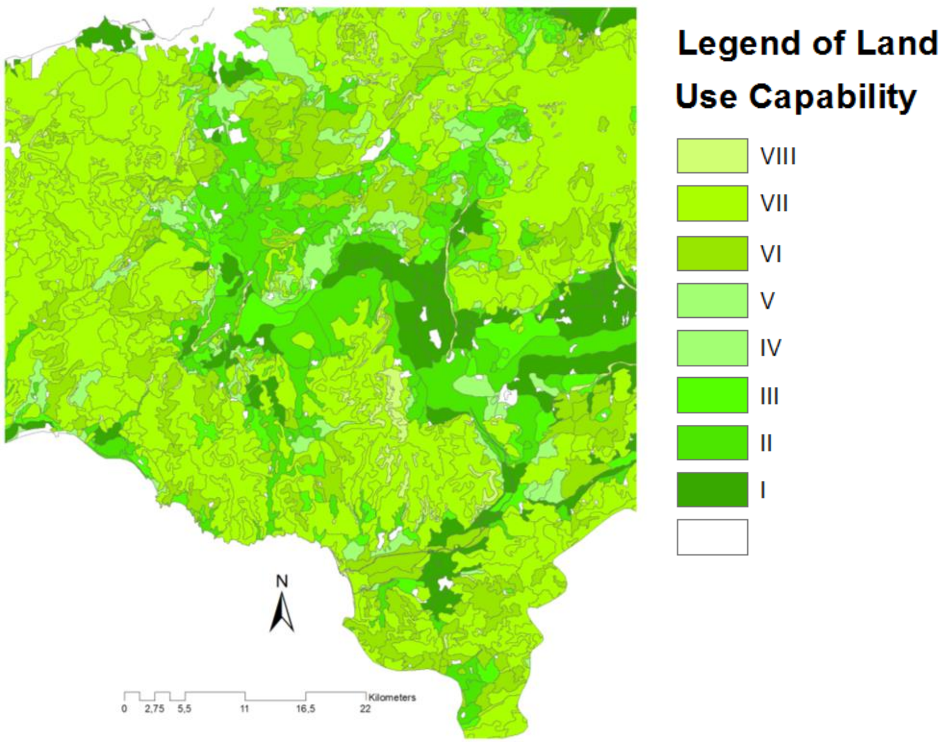


Figure 3.7 Land Use Capability Layer

3.3.3 Settlement Layer

Settlement layer shows the areas people live in. It is a vector-based layer and includes the population density of the area. It consists of polygons, which also show the settlement boundaries (Fig. 3.8).

Overhead power transmission lines can have significant impacts on human body. Although the effects of electro-magnetic field of power lines are not still well-defined in long term, there are many studies about the negative effects on change in protein syntheses, DNA syntheses, enzyme activity, nerve-and muscle cells, heart dysfunction and possible nervous effects

(Bernhardt, 1979; Hossam-Eldin et al., 2012). Therefore routing of power lines in densely populated areas is a critical issue.

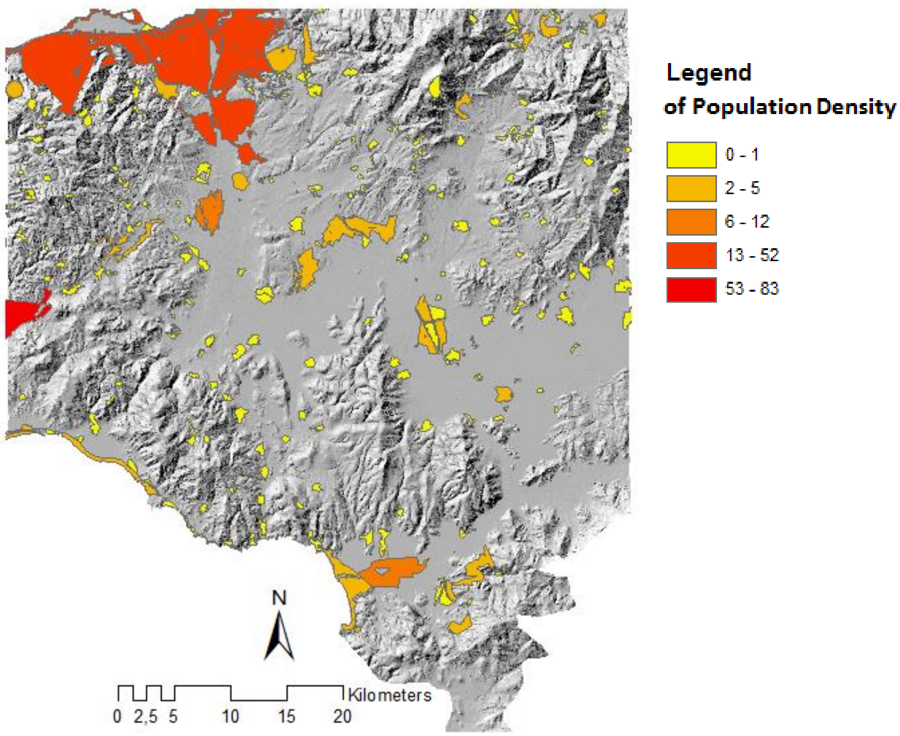


Figure 3.8 The Reclassified Settlement Layer According to Population Density

3.3.4 Land Use Layer

Land Use layer contains general characteristics about the area such as; salt swamp, reed swamp, agricultural area, forest, meadow, scrubland and shoal (Fig. 3.9). Overhead transmission lines have negative effects on environment during constructing and operating for instance cutting of trees around the power structures and under the conductor, disturbing habitat (Söderman, 2006). Therefore, this layer is important to minimize the environmental and agricultural impact of power lines.

3.3.5 Road Layers

Road layer involves the main roads at the selected area. Selection of the route close to main roads is very significant because it decreases the transportation cost of construction and increases the accessibility of the power line during maintenance.

The linear features layer in Figure 3.10 consists of the combination of Road, Pipeline, and PTL layers.

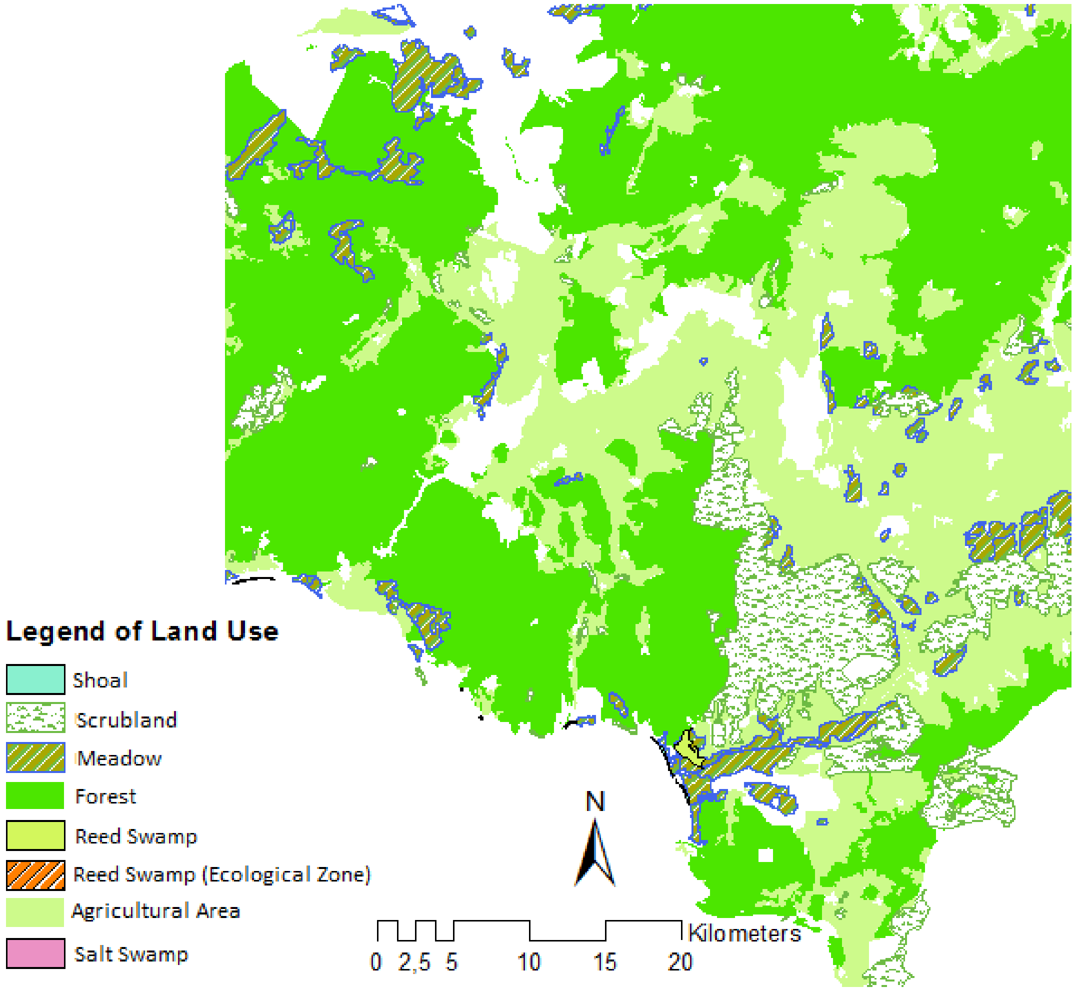


Figure 3.9 Land Use Map

3.3.6 Pipeline Layer

Pipeline layer involves the oil and natural gas pipelines in the study area. It is a notable layer because power line has electro-magnetic effects on pipeline; moreover, there are some regulations on the pipeline crossing power lines, which should be obeyed. Besides, there are some remarkable safety considerations and regulations for pipelines near overhead power lines.

3.3.7 Existing Power Lines Layer

Existing Power Lines layer provides information about the current characteristics, start and destination points and routes of the existing lines. Selecting a route in the parallel of an existing line is the most preferable alternative because it decreases the expropriation and maintenance cost of the new line. On the other hand, crossing of an existing line is a critical issue and there are some specific regulations.

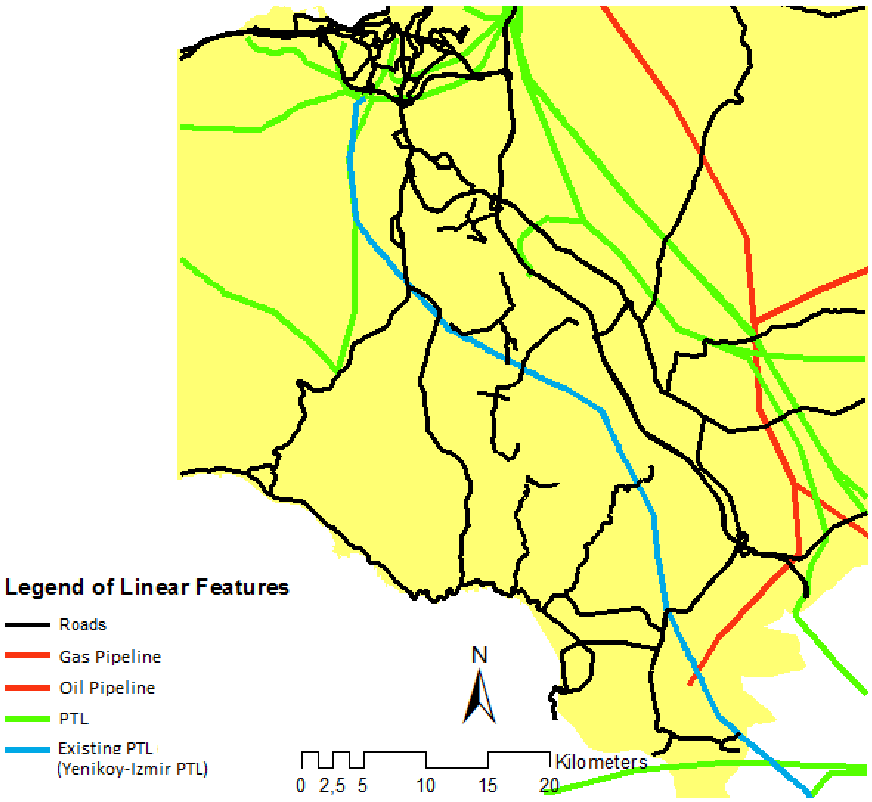


Figure 3.10 Map of Linear Features (Road, Pipeline and PTL)

3.3.8 Geology Layer

Geology layer contains information about the symbols, color, and age of the geologic categories (Fig. 3.11). This layer can be used for the suitable spotting of tower because it shows the strength, soil type, and fertility of the area. The features define the tower foundation type and it is directly related with the construction cost. Geology layer is used to generate the Landslide layer as well. Altun (2008) executed a geological study, which contains the meaning of the symbols and characteristics of the geological features, for this study area.

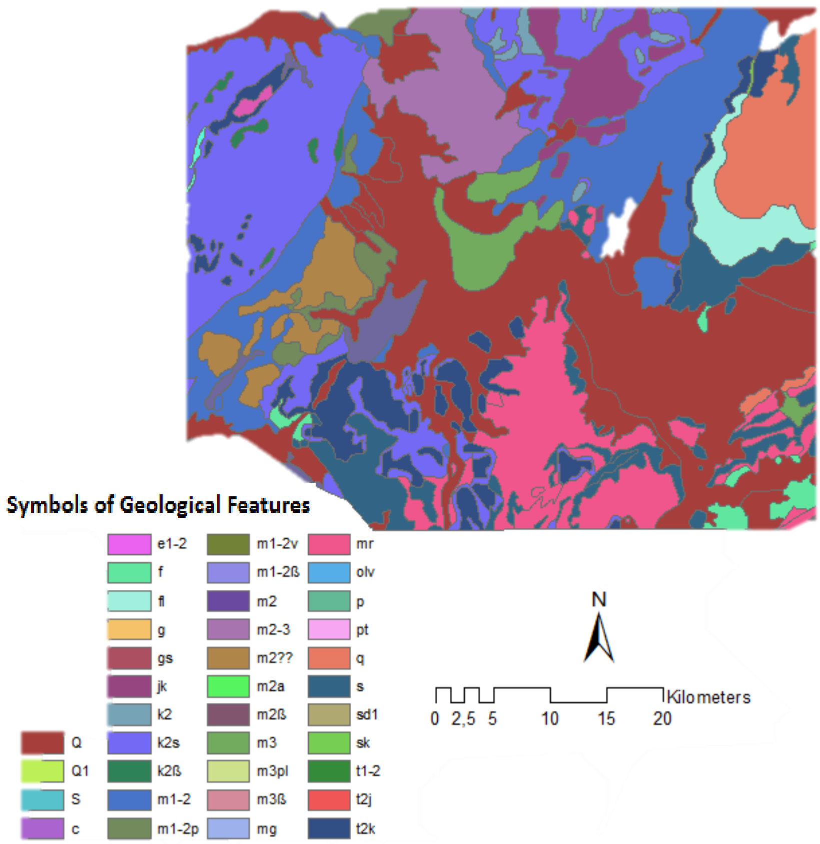


Figure 3.11 Geology Map

3.3.9 Water Resources Layer

Water Resources layer contains lakes, rivers and dams (Fig. 3.12). Dams, lakes and their buffer zones are restricted areas for line routing. In addition, crossing of river should be paid attention.

3.3.10 Protected Zone Layer

Protected Zone layer involves the natural, urban and archeological sites with their importance degrees as attribute values (Fig. 3.13). According to type and degree of the protected site, insertion of that zone is prohibited or limited. This layer directly affects the direction of the route of the transmission line.

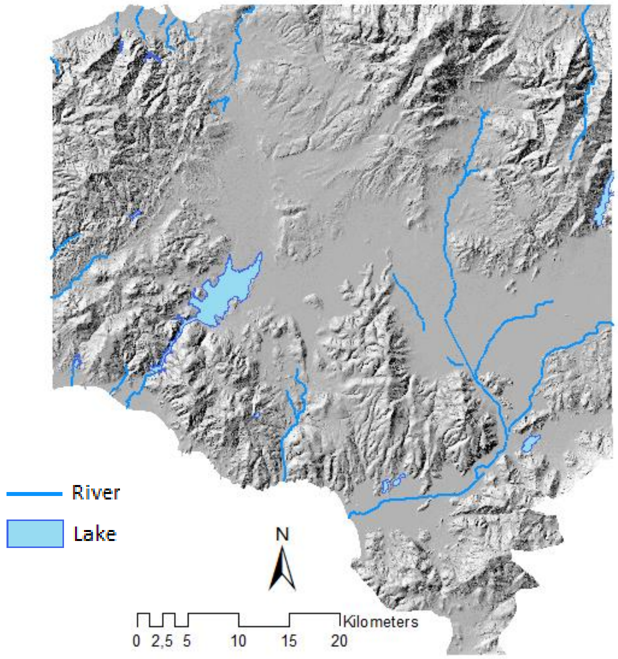


Figure 3.12 Water Resources

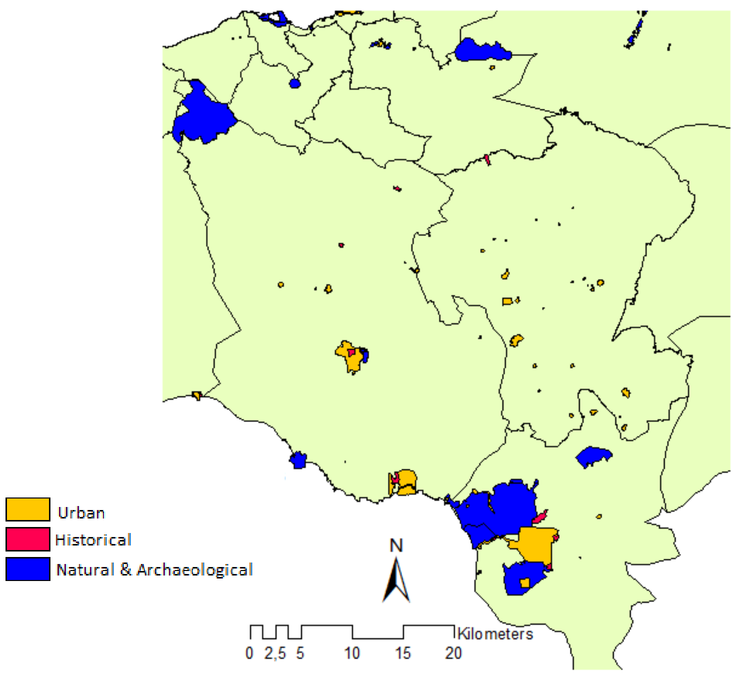


Figure 3.13 Protected Zones Map

3.4 Reclassified Layers

The layers, mentioned above, are reclassified according to the suitability of the features for routing of power line. First, the data is converted to meaningful raster sets for raster calculation. Then the most suitable feature for route selection is ranked as 1 and the worst feature is ranked as 9 like Saaty's scale (1980). By using this method after overlaying the raster layers, the cell that has the minimum value, corresponds to the most suitable cell for routing.

3.4.1 Slope Layer and Reclassification of Terrain Slope

The slope of terrain directly affects the cost of the installation and maintenance of the transmission line. In addition, for power structures (towers) there are some certain engineering limitations about the degree of slope because it is not feasible to construct a structure on a high inclined surface.

The slope map of the study area is generated by using DEM (Fig. 3.14). Then the degree of slope is classified according to suitability of terrain for transmission line. According to The Regulation of Design of Power Transmission Line of Turkish Electricity Company (2004), the slope degree, which is greater than 30%, is defined as unsuitable for the design. Therefore, the slope degrees are reclassified regarding the feasibility of surface.

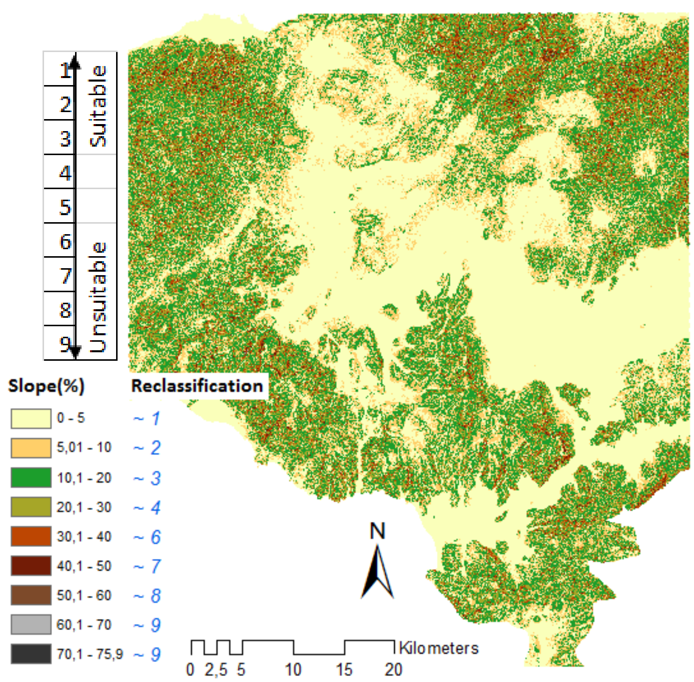


Figure 3.14 Slope Layer with Reclassified Slope Degrees

3.4.2 Reclassified Land Use and Current Land Use Layers

The reclassifications of Land Use and Current Land Use layers are executed by considering the negative effects of the power line to the field and the suitability of the terrain for the line design (Fig. 3.15 and 3.16). Both layers are standardized according to suitability index of the area by using experts' knowledge (Table 3.1 and 3.2). The Current Land Use layer shows the actual using purpose of the terrain different from Land Use map.

Table 3.2 Reclassification of Land Use Map

Land Use Type	Value
Meadow	2
Scrubland	3
Forest	6
Agricultural Area	7
Swamp	8
Beach	9

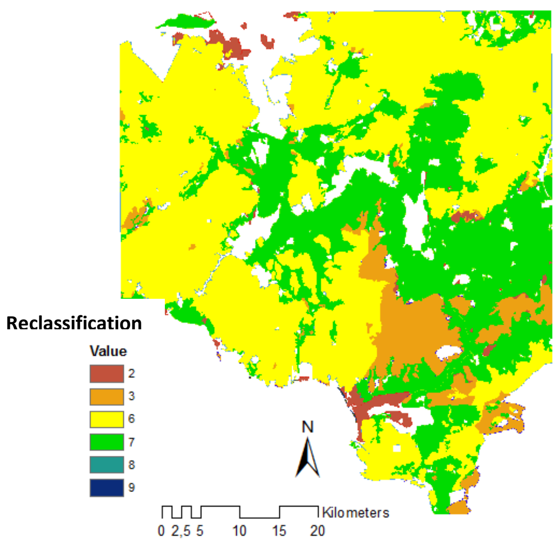


Figure 3.15 Reclassified Land Use Map

Table 3.3 Reclassification of Current Land Use Map

Description	Symbols	Value
Farming (Irrigated, dry, with and without fallowing)	S, Sy, K, N	7
Forest	O	7
Vineyard (dry and irrigated)	V, Vs	6
Orchard (dry, irrigated)	B, Bs	5
Grove (fruits, citrus, olive)	Z, Zt, Zz	6
Scrubland	M, F	3
Meadow	C	2

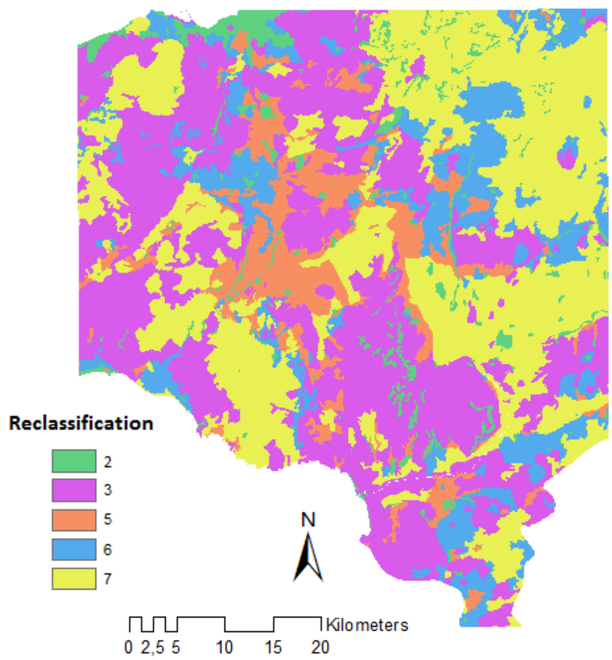


Figure 3.16 Reclassified Current Land Use Layer

3.4.3 Reclassified Erosion Layer

The areas with high-level erosion are not suitable for tower spotting. The erosion layer is classified with respect to erosion level (Fig. 3.17). The lowest erosion level is ranked as 1 and the highest erosion level is ranked as 8.

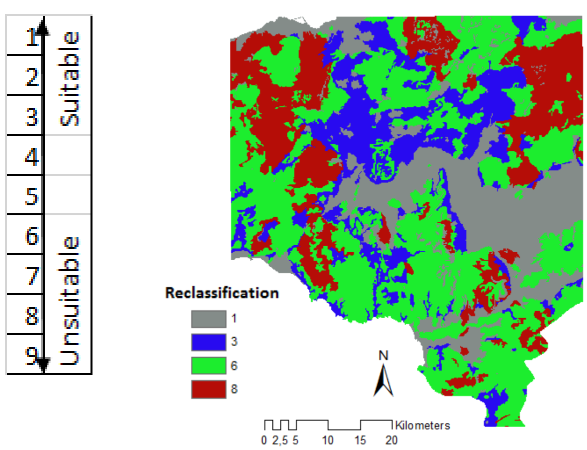


Figure 3.17 Reclassified Erosion Layer

3.4.4 Reclassified Land Use Capability Layer

The terrain having the highest fertility characteristics is assumed as Group I according to Land Use Capability map (Fig. 3.18). These kind of fertile lands are valuable for farming since it is possible to get more products by farming on these soil types. On the contrary the infertile soils are feasible for route of power lines in order to minimize their impacts on agriculture.

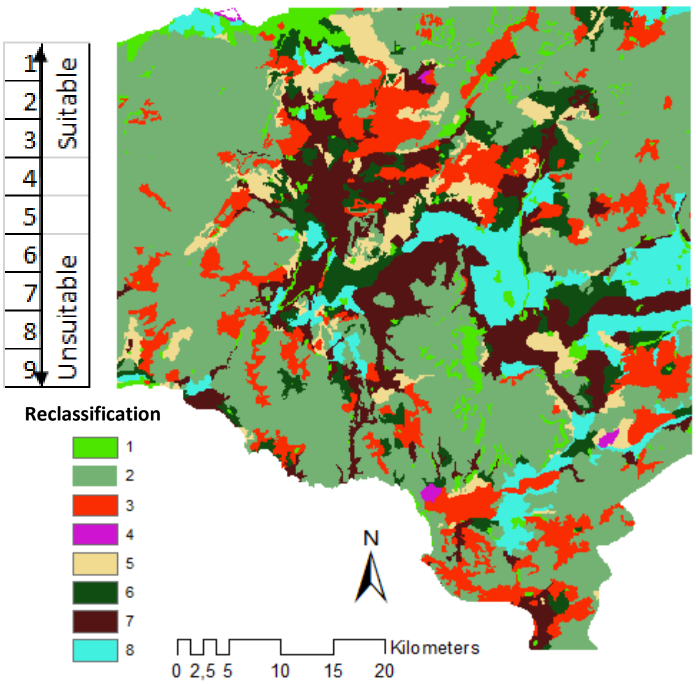


Figure 3.18 Reclassified Land Use Capability Map

3.4.5 Reclassified Settlement and Protected Zones Layer

The settlement areas and their 500 m buffer zones are not adequate for routing of power lines since the power line has negative effects on human health. The urban areas are ranked as 9 which is the most unsuitable value and the other areas are reclassified as 1 which is suitable for power line.

In addition to Settlement layer, the Protected Zones are prohibited to construct transmission lines. The Protected Zones are ranked as 9 which is the most unsuitable value since while overlaying the raster layers, the prohibition of a cell is not useful for overlapping process because the prohibition of a cell gives -1 value to the cell and it causes trouble in the raster summation.

3.4.6 Reclassified Linear Features

The linear features like roads, pipelines and power lines are combined as a layer. The corridors of linear structures are useful for power line routes. For that reason the Euclidean distances from the structures are generated and ranked by the closeness of the features.

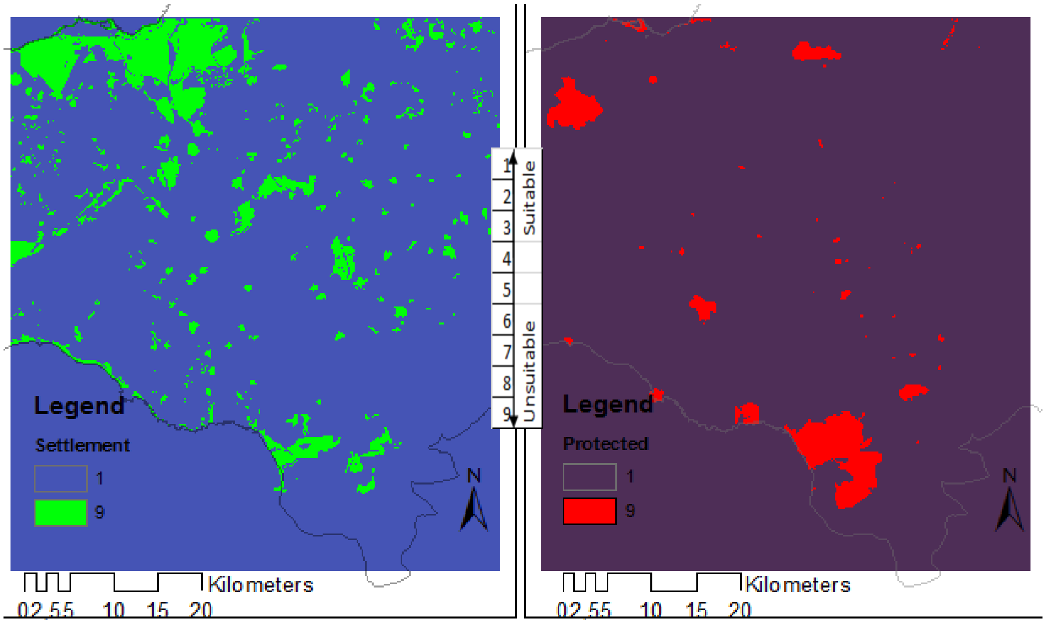


Figure 3.19 Reclassified Settlement and Protected Zones Layers

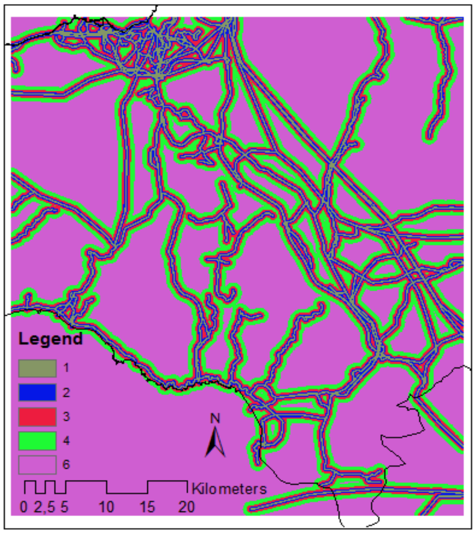


Figure 3.20 Reclassified Linear Features

3.4.7 Reclassified Ice Load Layer

Ice Load Map was generated by the meteorological data of Turkey. Ice Load layer shows the zones of ice loading of the terrain and the design of a PTL is executed according to ice loading zone of the study area. There are five ice-loading zones in Turkey. Zone I represents the places having the least icing (i.e. coastline) and Zone V represents the places getting extreme icing. In addition, the elevation of the terrain also specifies the ice-loading zone of the terrain. This layer combines the Ice Load Map with elevation data and reclassified according to the suitability of the zones.

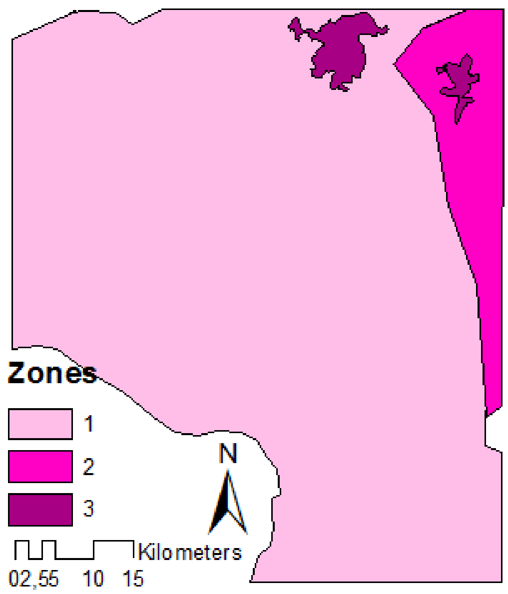


Figure 3.21 The Ice Load Layer

3.5 Landslide Layer

The landslide is a remarkable incident for the operability of a PTL because the locations of the power structures should have a stable base. The failure of a structure causes massive destructions on the line.

The Landslide layer is generated by using Soil Group, Slope and Geology layers regarding the landslide prone areas (Figure 3.21). The SAW method is used to overlay the layers by specific weight derived from the previous notable studies (Akgün, 2008; Ercanoğlu and Gökçeoğlu, 2002).

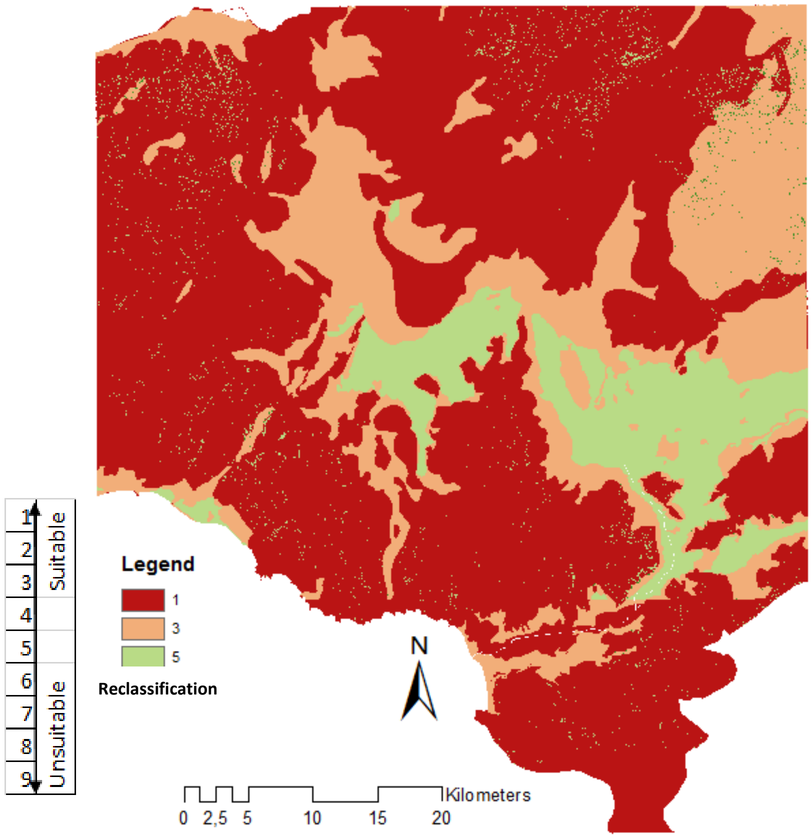


Figure 3.22 The Landslide Layer

Each layer is reclassified according to proneness to landslide. The areas, which have greater slope degree than 40% degrees; alluvial, dacite and pyroclastic soil types; old geologic formations are accepted as landslide prone areas.

CHAPTER 4

METHODOLOGY AND ANALYSES

4.1 Introduction

The methodology, calculations and analyses used for the decision making process in the study are covered in this chapter. This chapter explains the decision making for routing of a power transmission line using GIS. In the previous chapter, the required data collection for executing MCDA is presented and in this chapter, the generation of a complete decision using the mentioned data set is presented. In addition to the spatial data, the preferences of the decision makers, the technical and environmental constraints are taken into consideration to achieve the preferable route for the power line. In section 4.3, the AHP method is presented to derive the decision matrices with calculations for three decision makers from different professional backgrounds and the mean of the three decision makers. In section 4.4, the gathered weights from the AHP are used to create a decision cost map to define the routes for every decision maker. Then in section 4.5, the PROMETHEE method is represented for the comparison of the routes for defining the optimum selection.

4.2 Methodology

The main purpose of this study is to define the spatial preferable route alternative for overhead power transmission line with the multi-criteria decision analysis methods. This approach is applied in İzmir with DEM, Soil, Settlement, Land Use, Road, Pipeline, PTL, Geology, Water Resources, and Protected Zone layers. For this study, there are three different decision makers for MCDA. The flowchart of this study is formed in three parts; data reclassification and production; the AHP method for defining the routes; and the PROMETHEE method for selecting the best alternative. The flowcharts summarize the methodology of the study (Figures 4.1, 4.2, and 4.3) as follows:

- The Slope layer is generated by using DEM with 10 m resolution.
- The Soil Group, Erosion, Current Land Use, and Land Use Capacity layers are produced by converting the vector based soil layer.
- The Linear Structures layer is created by combining the Road, Pipeline, and PTL layers.

- The Landslide layer is produced by overlaying the Slope, Soil Group and Geology layers using the Simple Additive Weighting method.
- All vector-based layers are converted to raster-based layers.
- Each layer is reclassified according to suitability index of each feature. The feasibility of the features is ranked with 1-9 values according to PTL expert preferences.
- Three decision makers' preferences, constraints and the data set are used to generate three different decision matrixes. In addition, the mean of the three preferences is calculated to create another decision matrix.
- Each decision maker ranked the layers according to their own preferences coming from their professional backgrounds on PTL. The decision makers executed a pairwise comparison of the layers.
- The AHP method is used during the generation of the weights of each layer.
- The weights are obtained by the AHP method and the sensitivity of each analysis is checked.
- The reclassified raster layers are summed according to the weight results. Four different cost surfaces are generated by using this method.
- Using the cost surfaces, four different routes are derived by the least cost path method.
- XYZ data of each route is derived and used to create the profile of the route. PTL design of each route is executed by PLS-CADD™ 12.30 (Power Line Systems® Computer Aided Design and Drafting) which is a powerful line design software (PLS-CADD, 2013)
- The cost surface, which is used during the generation of the route according to the preferences of PTL expert, is attached in the PTL design as an extra cost factor. The cost cells are transformed to cost zones, which are directly affecting the cost of installation and expropriation of the PTL.
- The cost of each PTL is calculated by the results of PLS-CADD design.
- The risk factor of each route is calculated by the number of the intersections with roads, pipelines, PTLs, and rivers.
- The impact factor of each route is derived by the intersection length passing through the forest, agricultural and settlement areas.
- The PROMETHEE method is used for outranking the route alternatives regarding the cost, length, risk, and impact factors.
- The weight of each criterion is derived by using the AHP method according to the feasibility of PTL.
- By the consensus of the decision makers, the criteria are compared and ranked. The result of the method is applied to the PROMETHEE method.
- The preference function of each criterion in the PROMETHEE method is selected as V-Shape function regarding the characteristics of the criteria.

- The PROMETHEE I is used for the partial ranking of the route alternatives. The positive and negative flows of each route are calculated.
- The PROMETHEE II is applied for the definition of the best route alternative. The net flow of each alternative is calculated and the Route I is specified as the outranking PTL route.

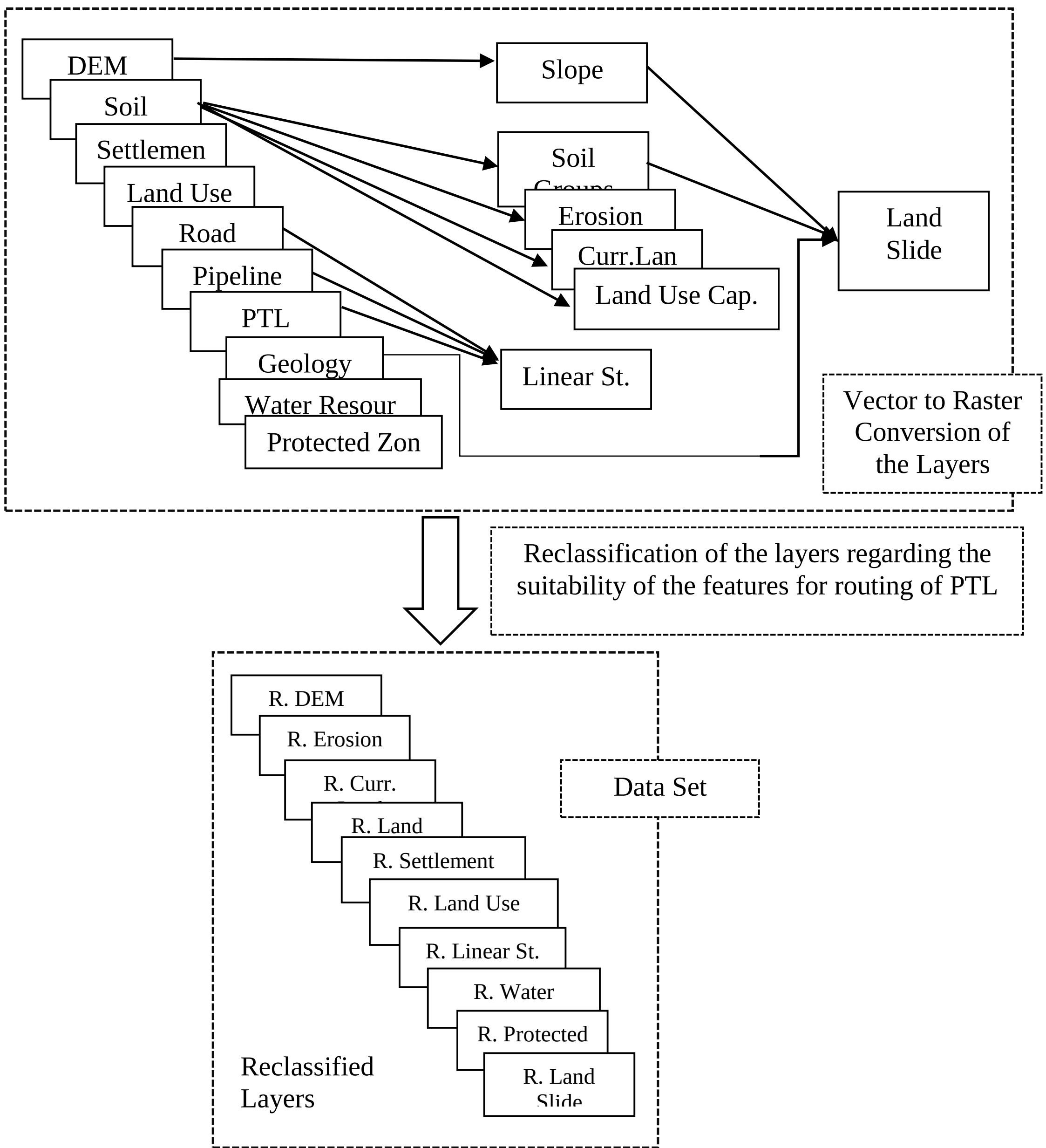


Figure 4.1 Data Set Flowchart

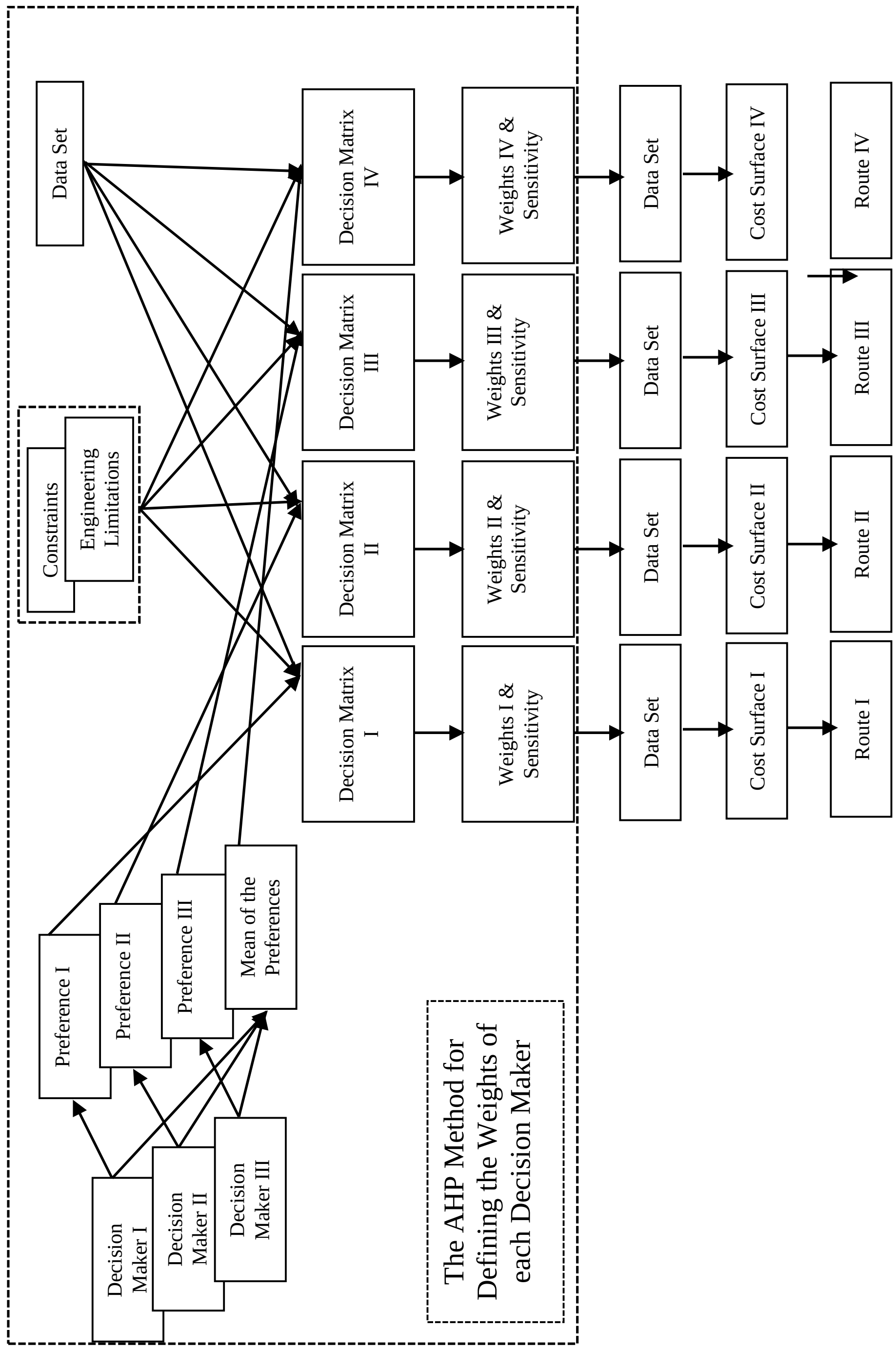


Figure 4.2 The Flowchart of the AHP Method

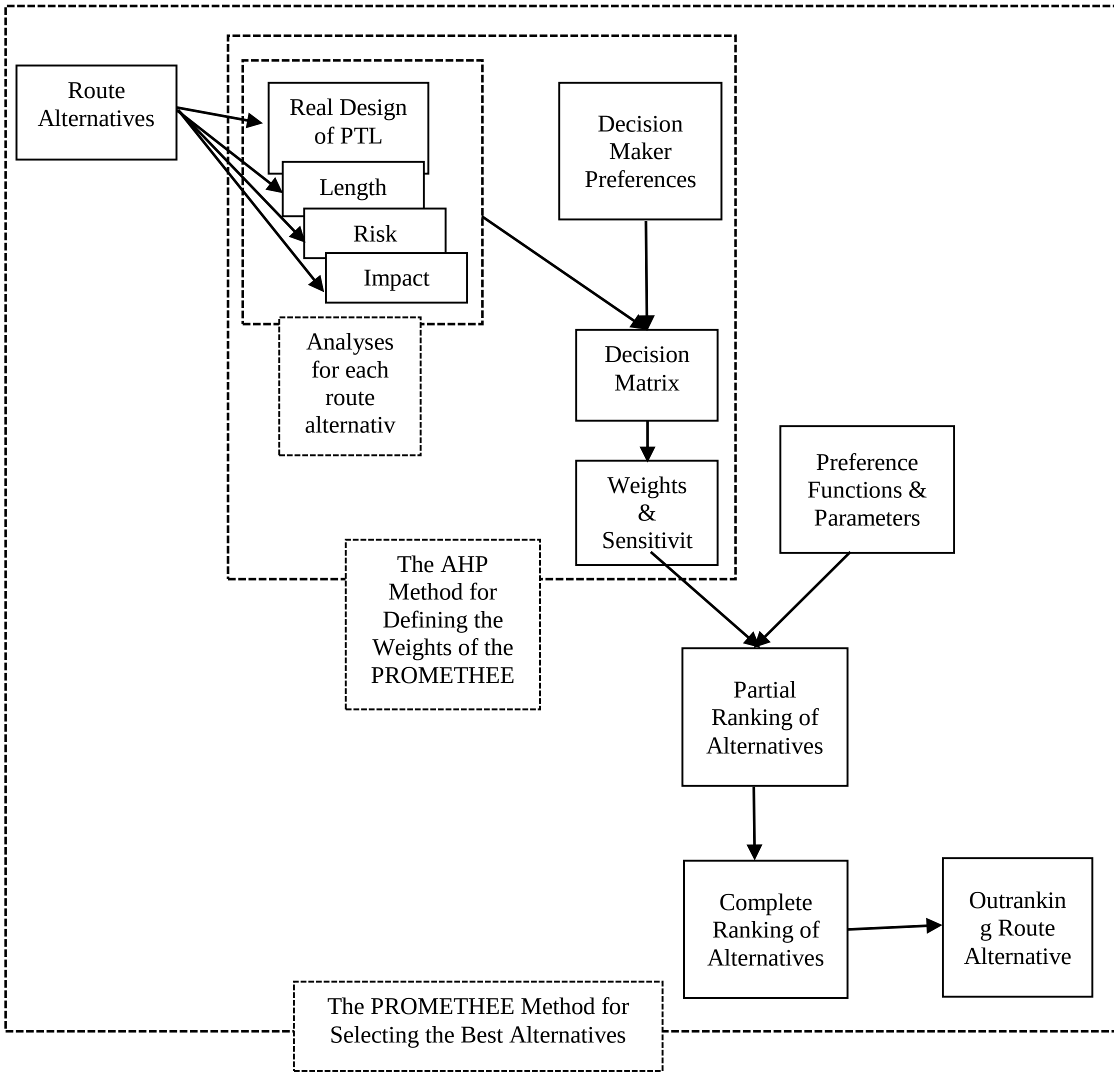


Figure 4.3 The Flowchart of the PROMETHEE Method

4.3 AHP Method

The AHP method is one of the functional pairwise comparison methods for land suitability analysis. The AHP method is used for deriving the weights of layers for overlay analysis. All criteria are organized in a hierarchical arrangement according to decision maker preferences. The steps of the AHP method starts with well defining the problem, which is routing of the overhead power transmission line in this study, and continue with the comparison of layers regarding their importance for decision maker, then finally ends up with the calculation of the weights for each layer (Figure 4.4).

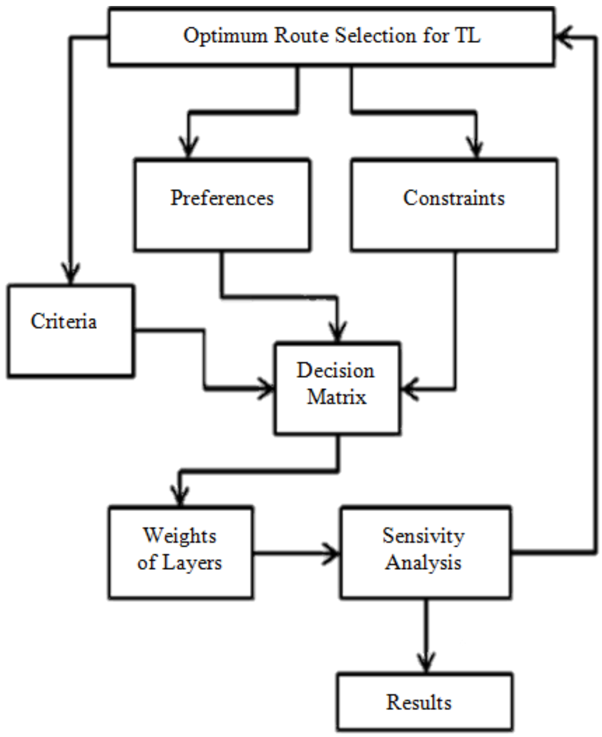


Figure 4.4 Decision Methodology (Malczewski, 1999)

4.3.1 Definition of the Problem

The definition of the problem is the starting point for the decision analysis so that the preferences of the decision makers and the constraints for decision can be more consistent. In this study the problem is defined as the route selection for the power transmission line. In order to solve the decision problem, GIS based MCDA is preferred by benefiting from previous studies on land suitability.

4.3.2 Pairwise Comparison of the Criteria

One of the most practical approaches to assign weights with the AHP method is to divide the complex decision problem into simple segments. Because, the large number of the layers and constraints make the decision process impossible to solve without splitting small problems. Division of the problem can be accomplished by the pairwise comparison. Moreover, the reliability of the weight of one layer derived from various layers cannot be dependable without any pairwise comparison. The pairwise comparison of each criterion helps to create a decision matrix for specifying the weights of the criteria by ranking the relative importance of them.

In this study, there are three different decision makers, which have different professional backgrounds on power transmission line (PTL). One of them is a senior PTL design engineer, the second decision maker is an environmental engineer working on environmental impact assessment of PTL, and the last decision maker is a PTL technician working at maintenance service. They compared the criteria until reaching the consistency level of the decision matrix.

The first decision maker pays attention to feasibility of the terrain for PTL. The decision maker aims to minimize the installation, expropriation, and maintenance cost regarding the technical and environmental regulations. The main purpose of the decision maker is to define the route, which has the shortest length, least cost, low-impact on environment as possible and long-time operability. In the light of these preferences the Decision Maker I has ranked layer with the relative importance on other layers by using Saaty's scale table (Table 2.1). The compared layers are respectively slope, current land use, erosion, land use capability, settlement, land use, linear structures, ice load, geology and protected areas layers.

Table 4.1 Decision Matrix of Decision Maker I

		Slope	CLU	Erosion	LUC	Setlmt	Land Use	Linear Str.	Ice Load	Landslide	Prot. Area
		1	2	3	4	5	6	7	8	9	10
Slope	1	1	3	5	2	2	3	1	3	3	1
CLU	2	1/3	1	2	1	1/3	1	1/2	2	2	1
Erosion	3	1/5	1/2	1	1/3	1/4	1/2	1/3	1/3	1/2	1/4
LUC	4	1/2	1	3	1	1/2	2	1/2	2	5	1
Setlmt	5	1/2	3	4	2	1	3	1/2	3	4	1
Land Use	6	1/3	1	2	1/2	1/3	1	1/2	2	3	1/2
Linear Str.	7	1	2	3	2	2	2	1	4	5	3
Ice Load	8	1/3	1/2	3	1/2	1/3	1/2	1/4	1	2	1/3
Landslide	9	1/3	1/2	2	1/5	1/4	1/3	1/5	1/2	1	1/3
Prot. Area	10	1	1	4	1	1	2	1/3	3	3	1

By summing each column and then dividing each cell with its column sum, the normalized decision matrix is derived. The weight of each layer is equal to average of sum of row elements. Before using the weights, the decision maker's preferences need to be checked to test their consistency. The eigenvector of the evaluation matrix is calculated by multiplying the weights of each layer with the original decision matrix and summing the values over the rows then dividing the sum of each row by the weight of the corresponding layer. The normalization of eigenvector is defined as λ_{max} which is the average of eigenvector. Consistency Index (CI) is computed by subtracting the number of criteria (n) from λ_{max} and dividing the result with (n-1). Consistency Ratio (CR) is equal to the division of the Consistency Index CI by the Random Index RI (See Table 2.2). CR is less than 0.10 therefore the pairwise comparison of Decision Maker I is consistent (Table 4.2).

Table 4.2 Weights of Decision Maker I and the Results of Consistency

	Weights
1	17,66%
2	7,74%
3	3,25%
4	10,28%
5	14,56%
6	7,04%
7	19,04%
8	5,17%
9	3,65%
10	11,62%

$\boldsymbol{\lambda_{max}}$	10,4753
$\boldsymbol{CI}$	0,0528
$\boldsymbol{RI}$	1,4900
$\boldsymbol{CR}$	0,0351

Decision Maker II puts emphasis on minimizing the environmental impact of the new PTL during the construction and operating periods. The Decision Maker II prepares the environmental impact reports for new PTLs and so the Decision Maker II gives decision accordingly. The land use, protected zones, water resources, and settlement layers have more importance according to other layers in his perspective. The main purpose of the Decision Maker II is to pass the route from the areas, which are bare ground, unfertile, far from the habitat and settlement. In the view of such information, the Decision Maker II has ranked the layers in each other.

The steps of the AHP method explained for the Decision Maker I is repeated also for the Decision Maker II. The pairwise comparison matrix is normalized and then the weights of each layer are calculated by using normalized values. Finally, the consistency of the Decision Maker II's rankings are computed. CR is computed as 0.0360 which smaller than 0.10 and this evaluation matrix is assumed to be consistent.

Table 4.3 Decision Matrix of Decision Maker II

		Slope	CLU	Erosion	LUC	Setlmt	Land Use	Linear Str.	Ice Load	Landslide	Prot. **Area**
		1	2	3	4	5	6	7	8	9	10
Slope	1	1	1/2	1	1/5	1/6	¼	3	4	2	1/6
CLU	2	2	1	3	1/2	1/3	1	3	4	2	1/5
Erosion	3	1	1/3	1	1/4	1/6	1/3	2	3	3	1/5
LUC	4	5	2	4	1	½	2	3	4	5	1/2
Setlmt	5	6	3	6	2	1	2	6	7	6	1/2
Land Use	6	4	1	3	1/2	½	1	4	5	5	1/2
Linear Str.	7	1/3	1/3	1/2	1/3	1/6	¼	1	3	1/2	1/7
Ice Load	8	1/4	1/4	1/3	1/4	1/7	1/5	1/3	1	1/2	1/8
Landslide	9	1/2	1/2	1/3	1/5	1/6	1/5	2	2	1	1/7
Prot. Area	10	6	5	5	2	2	2	7	8	7	1

Table 4.4 Weights of Decision Maker II and the Results of Consistency

	Weights
1	4,88%
2	8,30%
3	4,81%
4	14,72%
5	21,02%
6	11,70%
7	3,10%
8	2,07%
9	3,24%
10	26,16%

$\boldsymbol{\lambda_{max}}$	10,5832
$\boldsymbol{CI}$	0,0648
$\boldsymbol{RI}$	1,4900
$\boldsymbol{CR}$	0,0435

The Decision Maker III is a maintenance technician of PTL therefore; he attaches importance to accessibility of the new PTL. The Decision Maker III brings forward to linear structures, slope, settlement and ice load layers according to his preferences. The closeness of existing PTLs and roads of the new PTL makes the maintenance works easier. The stepper surfaces and high ice loading on the PTL affects the operation of the line negatively in a long period. Consequently, the Decision Maker III has compared the layers using his professional knowledge on PTL.

Same as the previous calculations for the Decision Maker I and II are repeated for the Decision Maker III. The CR value of this calculation is 0.0560, which is less than 0.10 and the evaluation matrix is accepted as consistent.

Table 4.5 Decision Matrix of Decision Maker III

		Slope 1	CLU 2	Erosion 3	LUC 4	Setlmt 5	Land Use 6	Linear Str. 7	Ice Load 8	Landslid e 9	Prot. Area 10
Slope	1	1	3	2	3	2	2	1/3	1	3	4
CLU	2	1/3	1	1/2	3	2	1	1/4	1/2	2	1/3
Erosion	3	1/2	2	1	3	1/2	2	1/5	1/2	2	½
LUC	4	1/3	1/3	1/3	1	1/3	1/2	1/6	1/3	1/2	1/3
Setlmt	5	1/2	1/2	2	3	1	3	1/3	2	4	2
Land Use	6	1/2	1	1/2	2	1/3	1	1/6	1/2	2	½
Linear Str.	7	3	4	5	6	3	6	1	3	7	4
Ice Load	8	1	2	2	3	1/2	2	1/3	1	4	2
Landslide	9	1/3	1/2	1/2	2	1/4	1/2	1/7	1/4	1	½
Prot. Area	10	1/4	3	2	3	1/2	2	1/4	1/2	2	1

Table 4.6 Weights of Decision Maker III and the Results of Consistency

	Weights
1	14,58%
2	6,96%
3	7,03%
4	2,97%
5	11,46%
6	5,04%
7	28,83%
8	11,08%
9	3,52%
10	8,52%

λ_{max}	10,7516
CI	0,0835
RI	1,4900
CR	0,0560

Lastly, the mean of the other three pair comparison matrices is generated to create another route alternative, which includes the preferences of the Decision Maker I, II and III. The average of the three evaluations reflects the equal distribution of the weights. The value of the Consistency Ratio (CR) is 0.0100 and it is consistent.

Table 4.7 Decision Matrix of the Mean of the Three Decision Makers

-		Slope 1	CLU 2	Erosion 3	LUC 4	Setlmt 5	Land Use 6	Linear Str. 7	Ice Load 8	Landslide 9	Prot. Area 10
Slope	1	1	1 2/3	2 1/6	1	7/8	1 1/7	1	2 2/7	2 5/8	7/8
CLU	2	3/5	1	1 4/9	1 1/7	3/5	1	5/7	1 3/5	2	2/5
Erosion	3	1/2	2/3	1	5/8	2/7	2/3	1/2	4/5	1 4/9	2/7
LUC	4	1	7/8	1 3/5	1	3/7	1 1/4	5/8	1 2/5	2 1/3	5/9
Setlmt	5	1 1/7	1 2/3	3 5/8	2 2/7	1	2 5/8	1	3 1/2	4 4/7	1
Land Use	6	7/8	1	1 4/9	4/5	3/8	1	2/3	1 5/7	3 1/9	1/2
Linear Str.	7	1	1 2/5	2	1 3/5	1	1 4/9	1	3 1/3	2 3/5	1 1/5
Ice Load	8	3/7	5/8	1 1/4	5/7	2/7	3/5	1/3	1	1 3/5	3/7
Landslide	9	3/8	1/2	2/3	3/7	2/9	1/3	2/5	5/8	1	2/7
Prot. Area	10	1 1/7	2 1/2	3 3/7	1 4/5	1	2	5/6	2 2/7	3 1/2	1

Table 4.8 The Mean Weights of Decision Makers and the Results of Consistency

	Weights
1	12,16%
2	8,51%
3	5,45%
4	8,81%
5	17,31%
6	8,75%
7	13,81%
8	5,62%
9	3,99%
10	15,61%

λ_{max}	10,1336
CI	0,0148
RI	1,4900
CR	0,0100

4.4 The Cost Surface Maps and Routes

A raster based cost surface represents the value of each cell for analysis. The cost concept can be considered as the closeness of a pizza house, the monetarily costs of the parcels or the time amount of reaching a point. A cost surface map, which is created for the early stage of least-cost path analysis, is considered as a cost map of a movement from a starting point to a destination point (Aldenderfer, 2008).

The weights derived from the AHP method for each decision maker are applied to all layers to create the cost surfaces for analysis of route selection for PTL. The weighted sum of reclassified layers, which are multiplied by the weight factor of related layer, is used for the least-cost path analysis. These operations are generated by ArcMap 10.1 (ArcMap, 2012).

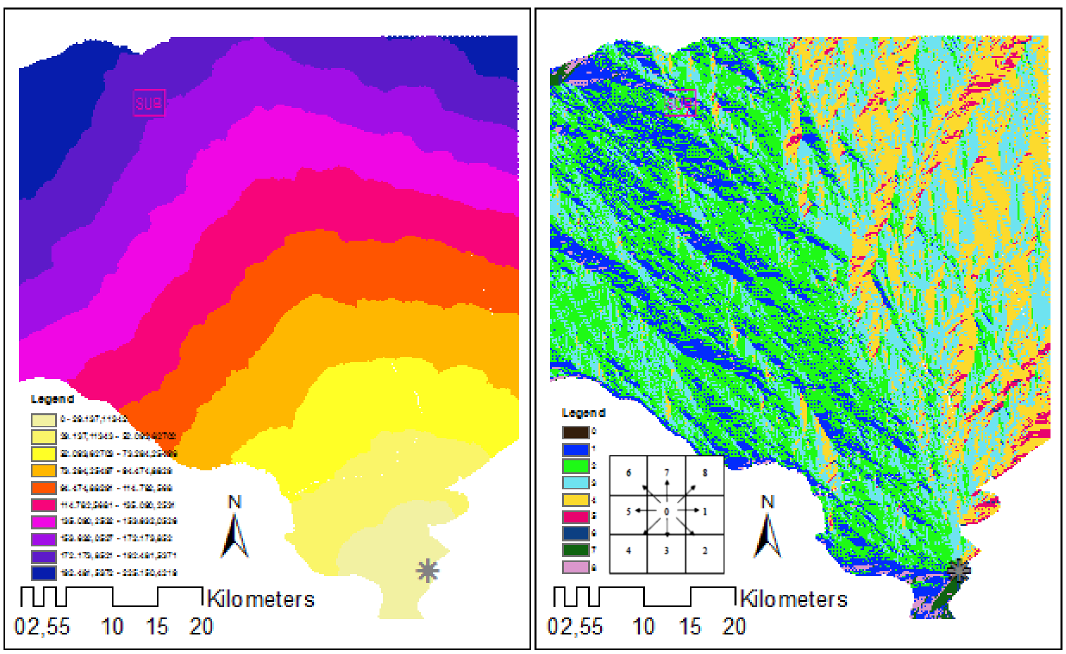


Figure 4.5 The Cost Distance and Backlink Raster Layers

The least-cost path analysis is executed by using the cost distance and back link rasters (Figure 4.5). The cost distance raster is generated with the source cells and the weighted sum. The cost distance operation works similar as Euclidean distance operation at the background, however the cost distance calculates the shortest weighted distance between the cells. The back link raster defines the neighboring pixel to go back the destination cell (ArcGIS Help 10.1).

The first cost surface and the route is formed by the preferences of Decision Maker I (Fig. 4.6)

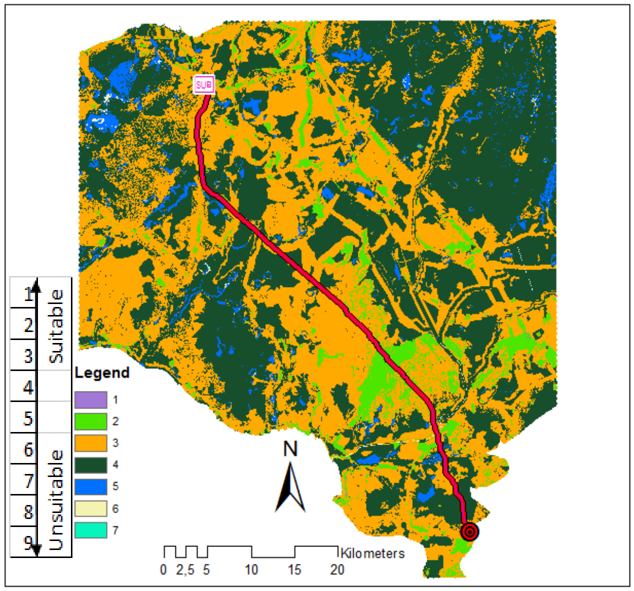


Figure 4.6 The Cost Surface I and the Route I

The Cost surface II and the Route II is formed by the preferences of Decision Maker II (Fig.4.7)

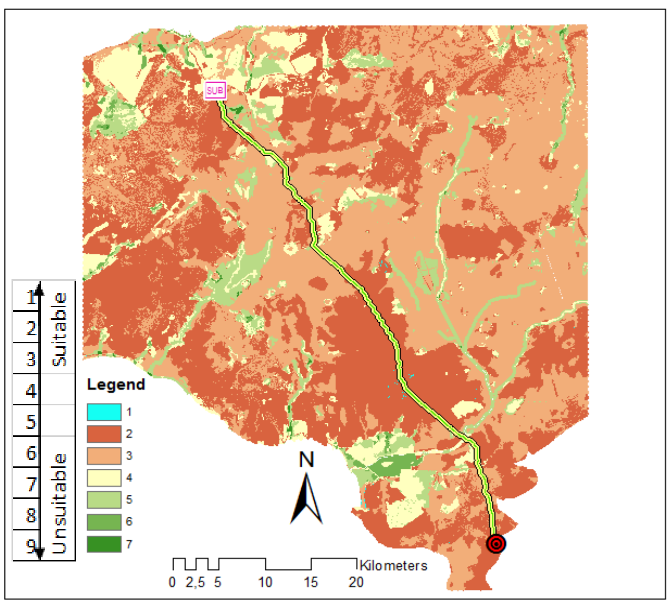


Figure 4.7 The Cost Surface II and the Route II

The third cost surface and the route is developed by the preferences of Decision Maker III (Figure 4.8).

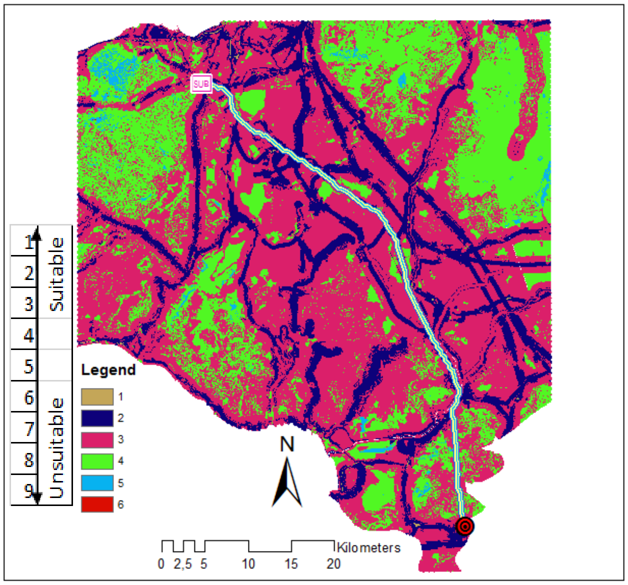


Figure 4.8 The Cost Surface III and the Route III

The last cost surface and the route is created by the mean of the three decision makers (Figure 4.9).

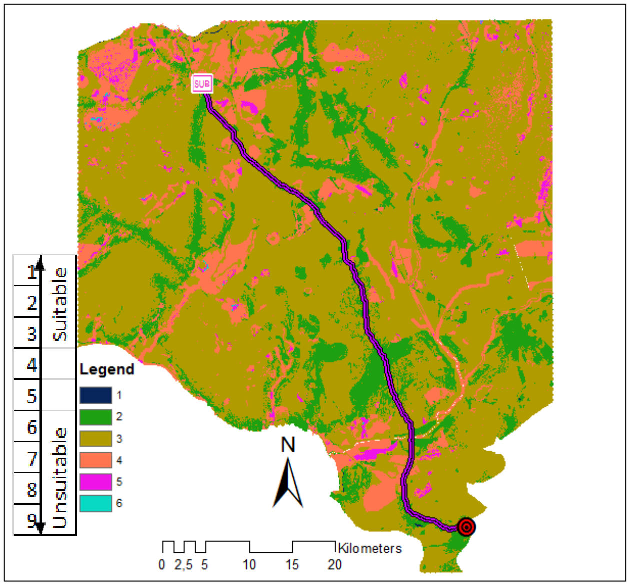


Figure 4.9 The Cost Surface IV and the Route IV (Mean)

4.5 The Comparison Criteria for the PROMETHEE Method

The routes are generated with the preferences of the three decision makers and the mean of their choices. Yeniköy-İzmir PTL is an existing line between the Uzundere Substation and destination points. All alternative routes are provided in Figure 4.10.

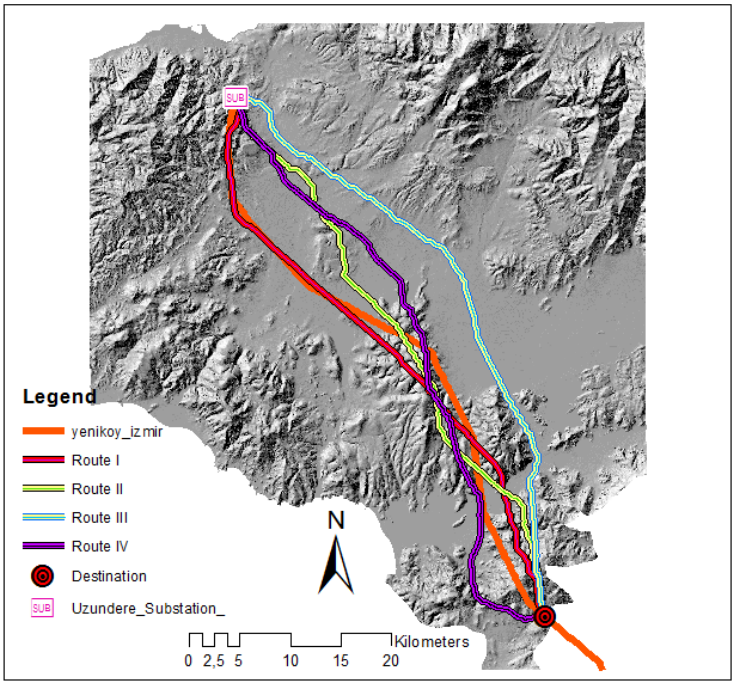


Figure 4.10 The Generated Routes and the Existing PLT (Yenikoy-Izmir)

In order to reach a decision about which one of the generated routes is preferable, the comparison of the generated routes is executed by their characteristics. The PROMETHEE method is used to define the superior alternative. The PROMETHEE method is well adapted for this study because of the limited numbers of alternatives should be ranked. The comparison criteria are specified as the cost of the PTL, the length of the PTL, the risk factor of the PTL and the impact factor of the PTL, which are the most critical issues during the selection of the route by the experts.

4.5.1 The Design of the PTLs and The Cost of PTL

The cost of each route is calculated by designing as a real PTL using PLS-CADD™ 12.30 (Power Line Systems® Computer Aided Design and Drafting) which is one of most common and powerful line design software package (PLS-CADD, 2013). At the end of the design, the results are obtained that show the number of the used structures with their types, the length of the conductors and the number of insulators. While defining the cost of each power structure; the labor cost, the transportation expenses, and the construction cost are also included. By using the design results of each PTL the total cost of each alternative is calculated with the current (2013) prices.

The PTL design starts with the coordinates and the elevation data of the route. The 3D coordinate data of the routes are exported using DEM data. Besides the points on the route, the points in the 100 m buffer zone from the routes are also transferred to create and examine a TIN model, which shows the characteristics of the terrain. The vertices of the route are exported as a different point file in order to use in PLS-CADD as a point of inflection (PI). The terrain points can be distinguished by their feature codes, for example, the ground points derived from the DEM are labeled with “200”, and the exported vertice points are stamped with “900” as Point of Inclination (PI) (Figure 4.11).

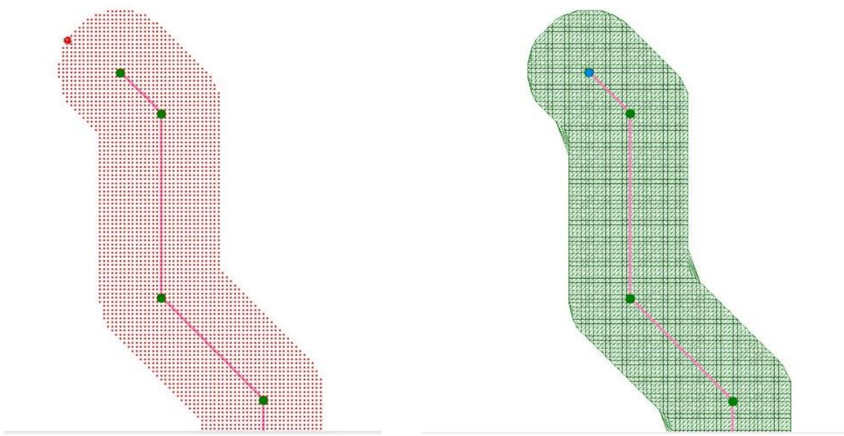


Figure 4.11 The Exported Ground with PI Points and TIN Model

The characteristics of PTL are 154 kV with the Pheasant conductor, it has five types of structures, three of which are suspension towers, and the others are dead-end towers. The design criteria are applied according to the characteristics and the ice load zone of the line. The technical criteria and the engineering limitations like structure allowable usage limits are covered for each route.

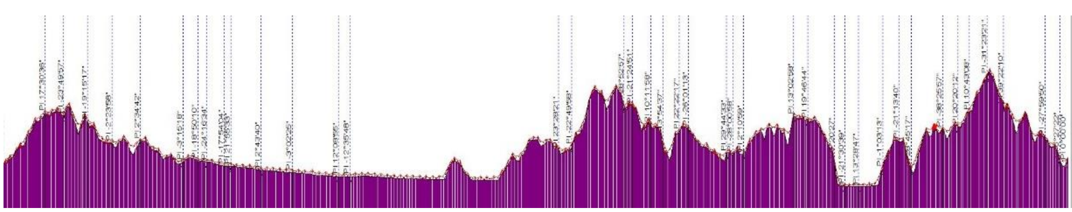


Figure 4.12 The Profile of the Route I

The exported point data from DEM are used to draw the profile of each route for spotting of the power structures (Figures 4.12 and 4.13). While spotting the structures, a cost surface is used for representing the cost of installation and expropriation regarding the slope, soil type and the land use layers.

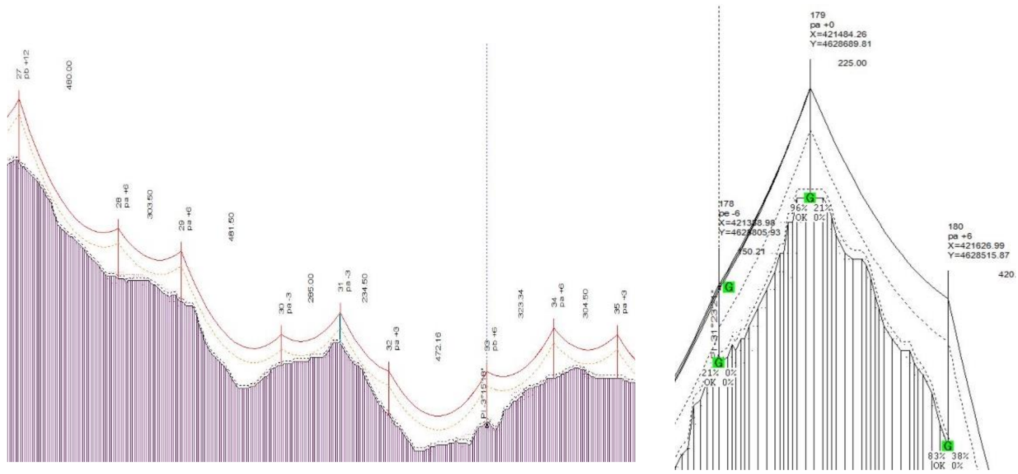
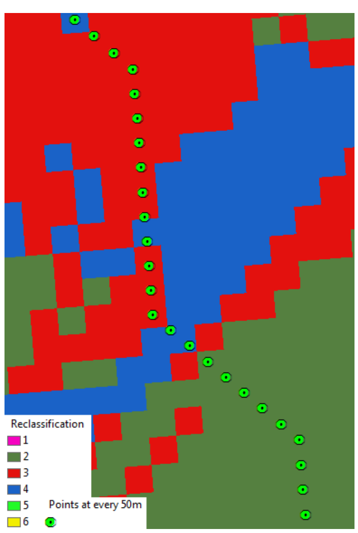


Figure 4.13 The Profile of the Route I with the Structures

These features directly affect the cost of the foundation, the leg size of a structure and the expropriation expenses. The cost factors are implemented by adding the pixel values of the cost surface to the points at every 50 m on the route and then imported as a tabular data into PLS-CADD. Besides the cost surfaces, the designs are performed with paying attention on the wind and weight spans of each tower.



Type	Start Station (m)	End Station (m)	Extra Cost
Extra Cost Zone	13800.00	13850.00	800.00
Extra Cost Zone	13850.00	13900.00	800.00
Extra Cost Zone	13900.00	13950.00	800.00
Extra Cost Zone	13950.00	14000.00	800.00
Extra Cost Zone	14000.00	14050.00	800.00
Extra Cost Zone	14050.00	14100.00	800.00
Extra Cost Zone	14100.00	14150.00	800.00
Extra Cost Zone	14150.00	14200.00	800.00
Extra Cost Zone	14200.00	14250.00	600.00
Extra Cost Zone	14250.00	14300.00	600.00
Extra Cost Zone	14300.00	14350.00	600.00

Figure 4.14 ExpensesExtra Cost Table of PTL Design

The cost of the PTL is calculated by the results of the PTL design with 2013 prices. Regarding the total number of the structures, insulators and the total length of the conductors, earth wires and OPGWs, the cost of each PTL design contains the material, installation, transportation expenses

4.5.2 The Risk Factor

The operating of a PTL in a long period without interruption is also vital. The risk of a PTL is directly connected with the operation of it. The great number of the risk areas puts the operation of PTL in trouble.

The risk areas of a PTL can be listed as closeness of water bodies, intersection with pipeline, road or PTL and locations within the trees. The raise of water level or watery ground near the power structures put the continuousness of working of the PTL and other linear structures at risk. The potential problems about water bodies can be taken into account before defining the route of PTL. Crossing of linear features is another risk factor for PTL. The trouble of a crossing linear structure directly affects the operation of the PTL. For instance, breaking of an insulator of a crossing line causes severe problems on both PTLs and substations. The falling trees and the growing trees under the PTL also entail a risk. Although the vegetation management for PTL can protect interference with the reliable operation of a transmission line, the forested zones contain potential danger.

Table 4.9 The Total Number of Crossing Linear Structures and River

	Road	Pipeline	PTL	River	Forested Area
Route I	8	1	1	1	4,9 km
Route II	12	1	0	1	6,2 km
Route III	27	1	1	2	10,5 km
Route IV	16	0	1	1	2,2 km

Table 4.9 shows the number of intersections of each routes with the linear features and the rivers, and also the total length of forested areas where the route is passing into. The risk factor of each route is calculated relatively regarding the intersection numbers of linear structures and the length of PTL passing through the forested areas.

4.5.3 The Impact Factor

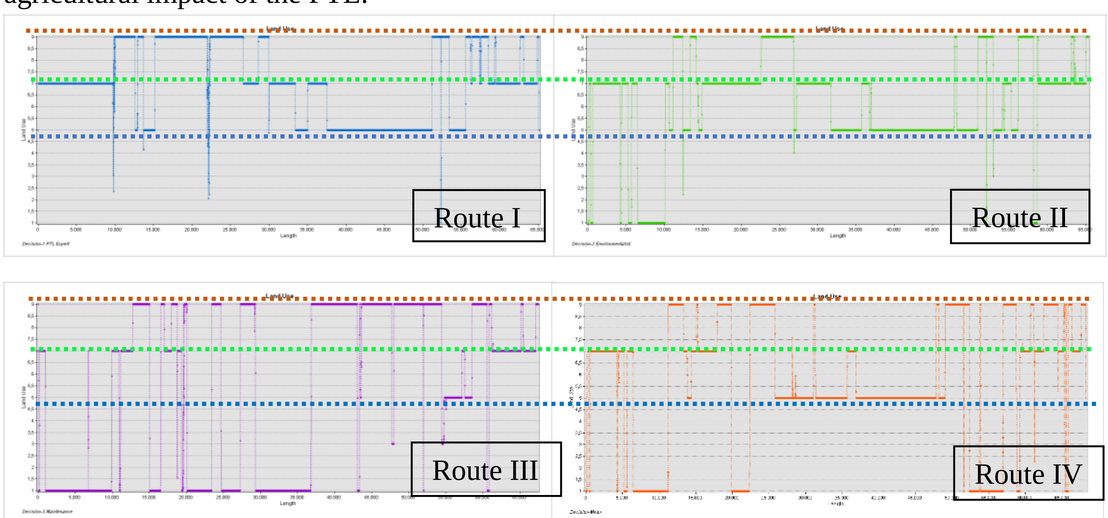
The installation and the operation of a PTL can damage the wildlife, natural habitat, agriculture, and human health. Figure 4.15 shows the view of the forest after the construction of the PTL.

During the construction, the vegetation cover of PTL rights-of-way is cut off to protect the PTL. In other words, the wildlife depending on the trees is exhausted under the PTL.

Figure 4.15 Cutting of Trees for Power Transmission Lines (Barber, 2013)

In addition to natural habitat, the passing through the agricultural areas and the orchards of a PTL harm the agricultural products and plants. It is also difficult to farm near a power structure because it limits the usage of agricultural machinery.

The graphics in Figure 4.16, which shows the profile of each route according to the land use with respect to length, are used to estimate the impact factor of each alternative. The lengths of each land use feature are summed separately and used as a coefficient of environmental and agricultural impact of the PTL.



Agricultural Area / Forested Area / Scrubland

Figure 4.16 The Land Use vs Length Graphics of the Routes

In the previous chapter, the negative effects of PTL on human health are covered. The electromagnetic field pollution can cause some diseases on people living near a PTL. The graphic, which presents the density of settlement with respect to the distance of the PTL for each route alternative is drawn by using the settlement layers. The impact ranking of each route is generated by using the Settlement vs. Length graph in Figure 4.17.

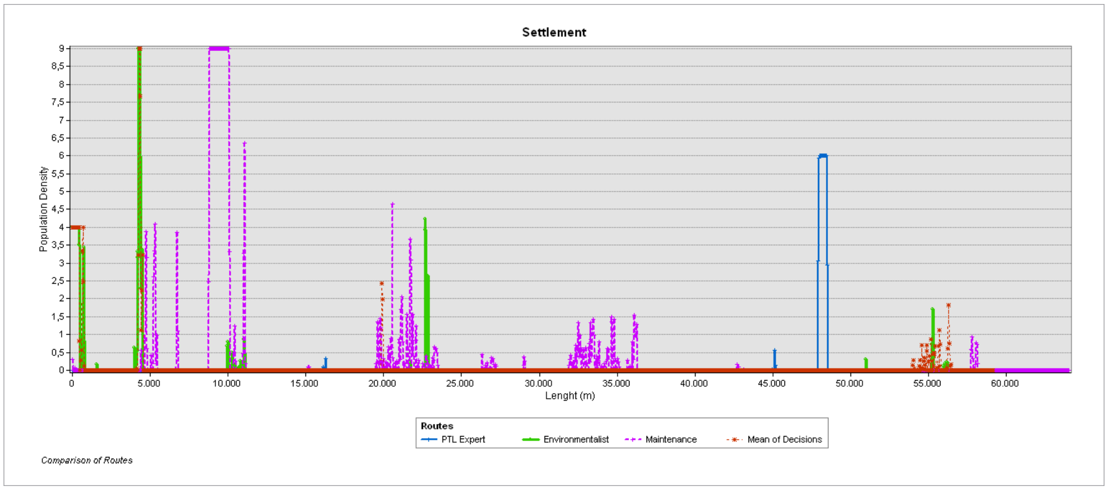


Figure 4.17 The Settlement vs Length Graphics of the Routes

4.5.4 The Lengths of Routes and Profiles

Each route is created by a combination of different preferences; therefore, the product of each route alternative differs from one other (Figure 4.18). For instance, Decision Maker III has ranked the closeness of linear structures in priority. This choice causes that the route goes through the linear features and without great elevation chances. The lengths of each route are accepted as coefficient for the outranking analysis.

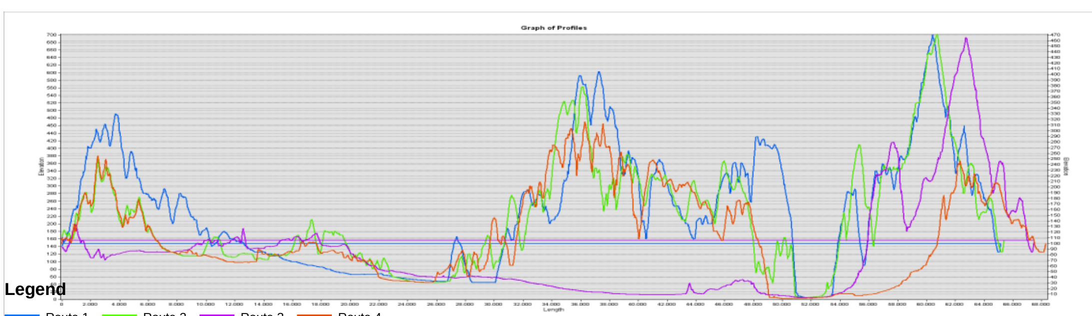


Figure 4.18 The Profiles of the Routes

Table 4.10 The Length of Each Route

	Length (m)
Route I	65164
Route II	65397
Route III	67486
Route IV	68293

4.5.5 Outranking with the PROMETHEE Method

The PROMETHE method is one of the functional outranking methods, which show the superiorities of the alternatives. The required information about superiority relationship between the criteria is derived regarding the preferences of the consensus of the decision makers by using the AHP method. This information shows the weights representing the relative pairwise importance of criteria.

The cost, length, risk factor, and impact factor are considered as the evaluation criteria for route alternatives. The weight of each criterion is determined regarding by the feasibility of the PTL design by the consensus of the decision makers. In order to generate the weights of the criteria the pairwise comparison matrix is formed rather than specifying the weigh ts without any comparison with each other. The calculation procedures of the AHP method is covered in section 4.1, and the decision matrix and the result are shown in Table 4.11.

Table 4.11 The Decision Matrix, The Results of Consistency and The Weights of Decision Makers for the PROMETHEE Method

		Cost 1	Length 2	Risk 3	Impact 4
Cost	1	1	5	3	2
Length	2	1/5	1	1/2	½
Risk	3	1/3	2	1	1
Impact	4	1/2	2	1	1

λ_{max}	4,0155
CI	0,0052
RI	0,900
CR	0,0057

	Weights
1	49,67%
2	9,98%
3	19,14%
4	21,21%

The values of the cost, the length, the risk, and the impact factors are preferred to be minimum because of the feasibility of the new PTL design. The weight of each criterion is gathered from the result of the AHP method and typed in the Visual PROMETHEE software (PROMETHEE, 2013).

The preference functions of all criteria are selected as V-Shape function (Figure 4.19) because the V-Shape preference function enhances the relationship of two compared alternatives. An alternative has a strict preference over another route alternative in case of specified amount of difference.

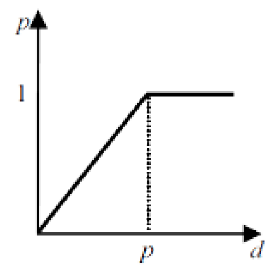


Figure 4.19 V-Shape Preference Function

Table 4.12 The Preferences Functions and Thresholds

	Cost ($)	Length (m)	Risk	Impact
Route I	7.710.442,00	65164,00	1,51	4,91
Route II	8.164.502,00	65397,00	1,19	4,38
Route III	8.929.435,00	67496,00	2,33	3,44
Route IV	10.178.727,00	68293,00	1,00	2,94

The decision maker has specified the preference functions with thresholds for each criterion (Table 4.12). Table 4.13 shows the values of the criteria used for defining the outranked alternative in the PROMETHEE method.

Table 4.13 Compared Alternatives using the PROMETHEE Method

		Thresholds		
Criteria	***Preference Funct.***	***q***	***P***	***s***
Cost	V-Shape	-	454060,00	-
Lenght	V-Shape	-	651,00	-
Risk	V-Shape	-	1,13	-
Impact	V-Shape	-	0,50	-

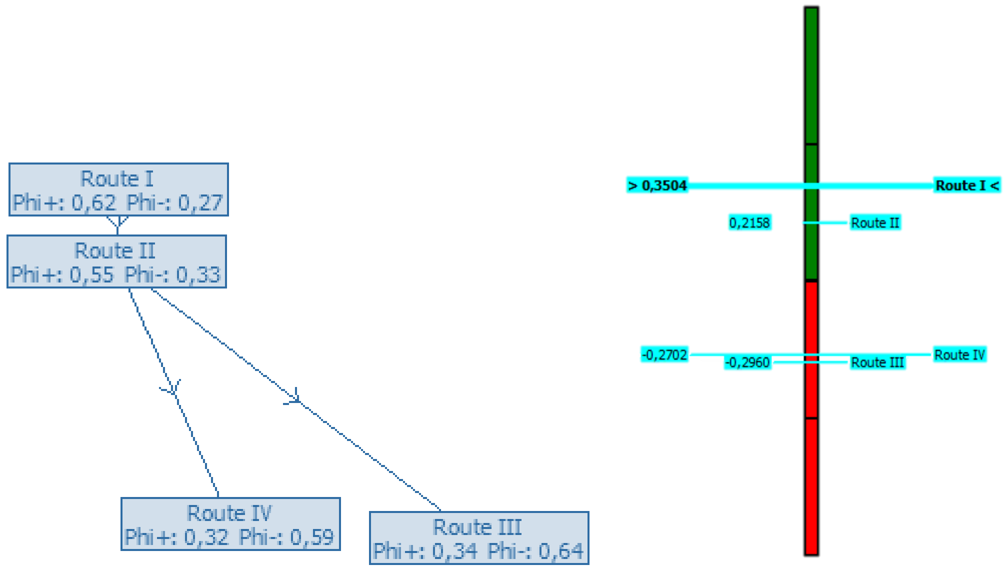


Figure 4.20 The Partial and The Complete Ranking

The partial ranking of alternatives is specified by the PROMETHEE I method. Route I is the best alternative and Route II is preferred to Route III and IV according to partial ranking method. Figure 4.20 shows the partial and complete ranking. Table 4.14 represents the flows of the PROMETHEE method.

Table 4.14 The Positive, Negative and Net Flows

	ϕ^+	ϕ^-	ϕ
Route I	0,6161	0,2657	0,3504
Route II	0,5485	0,3327	0,2158
Route III	0,3214	0,5917	-0,2702
Route IV	0,3432	0,6393	-0,2960

The net flow (ϕ) of Route I has the largest value according to other alternatives, so Route I is the best alternative and it outranks the other PTL route alternatives.

GAIA (Graphical Analysis for Interactive Assistance) which is a module of Visual PROMETHE provides the visual representation of the result of the PROMETHEE method. GAIA plane is obtained by principal component analysis, projecting the 4-dimensional space of criteria onto a two-dimensional plane. In Figure 4.21, GAIA plane provides to see the similar and conflicting alternatives. The similar alternatives go to the same direction and conflicting alternatives locate the opposite directions in the plane. The cost and length criteria locate to the similar directions but they differentiate the risk and impact criteria. The distance between the point of route and the criteria axis gives the preference index of the route alternative.

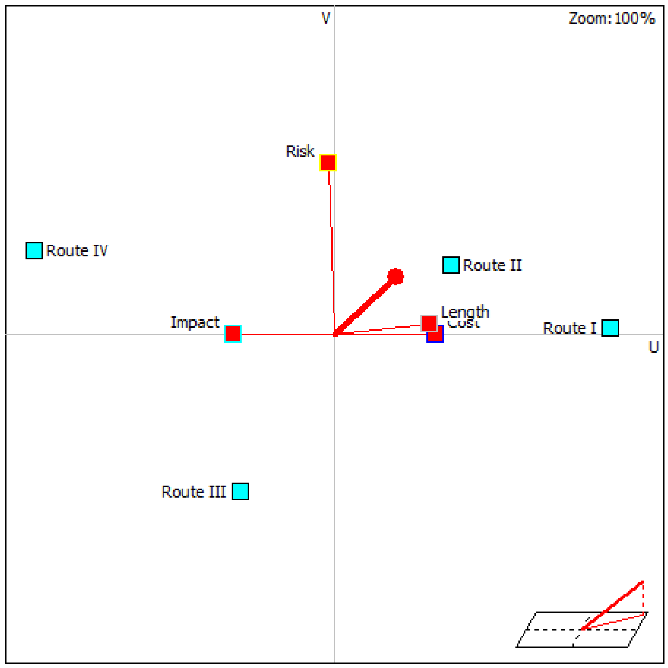


Figure 4.21 GAIA Plane of the PROMETHEE Method

4.6 Results

The conventional route selection procedure, which is performed in the field, is still the optimized solution for the routing problem of PTL. The PTL experts are indirectly taking into account all the criteria and constraints in the field study. The result of the conventional route selection method would be feasible since the PTL experts aim to reach a PTL design, which is cost-effective, harmless, and riskless alternative.

In this study, the preferable route alternative, which is selected at the end of the PROMETHEE method, is compared with the existing Yeniköy-Izmir PTL. In Figure 4.22, the outranking route alternative (red line) shows similarity to the existing PTL. It can be assumed that there is an agreement on the ideas behind the route selection for PTL with conventional methods and the approach applied in this study. The used layers, criteria, and constraints in this study succeed in reflecting the real decision conditions for the route of a PTL. The decision notion, in the conventional method, is transferred into the MCDA approach and a satisfying route alternative is generated successfully.

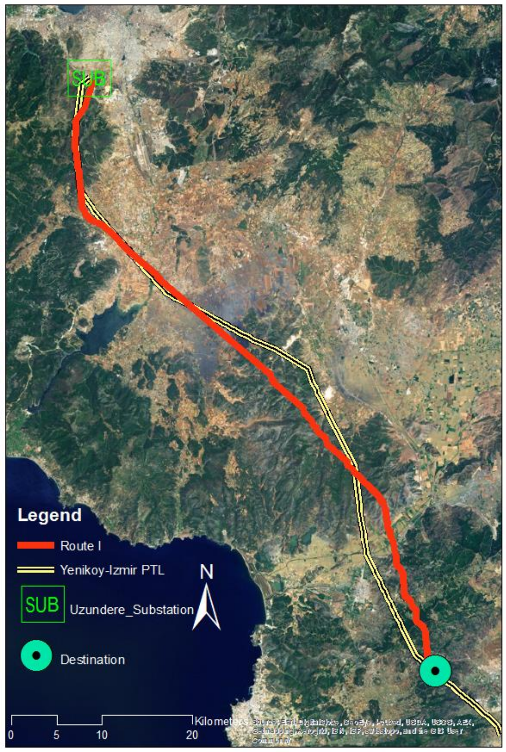


Figure 4.22 The Outranking Route Alternative and Existing PTL

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This research on integration of GIS with MCDA to define the route of an overhead power transmission line mainly focused on the selection of outranking route alternative using multi layers and multi decision makers. The study area is chosen in Izmir region and the distance between the substation and the destination point is 60 km. Thus in the summary part the results of the study, the methods and analyses in this study is covered. In subsection 5.2, conclusions of the study, in section 5.3, discussion of the study and in section 5.4 recommendations for the future works are discussed.

5.2 Conclusion

In this study, the data set consists of DEM, Soil, Settlement, Land Use, Road, Pipeline, PTL, Geology, Water Resources, Protected Zone layers. In addition to these layers, the Slope, Soil Group, Erosion, Current Land Use, Land Use Capacity, Linear Structures, and Landslide layers are produced within the study. These layers are put into process to create reclassified layers. The reclassification applications are executed regarding the feasibility of the features of the layers. The features are ranked by the values between 1 to 9 according to the knowledge of the PTL expert.

There are three decision makers with different professional backgrounds on PTL. In consequence of studying with the multi-decision maker, the outputs of the route selection analyses are compared to reach the superior route alternative. The AHP method provides opportunity to reflect the preferences of the decision makers. Each decision maker prioritizes different layers because of the consideration of the route selection process for PTL from a different perspective. In the lights of the preferences of each decision maker, the cost surfaces are generated in order to specify the least cost paths.

The route alternatives are ranked with the PROMETHEE outranking method, which shows the superiorities of the alternatives. The route alternatives are compared based on the cost, length, risk, and impact factors. The cost of each route is derived from the real PTL design with a powerful power line design software. The cost criterion contains the material, installation and transportation expenses; as well as the cost of the cell where the power structure is located. The risk factor is derived by the number of intersection with the linear structures. The impact factor is obtained from the total length of the PTL passing through the forest, agricultural and settlement areas. The weight of each criterion is derived by the AHP method with the consensus of the decision makers. The convenient preference functions and thresholds are specified with respect to the characteristics of each criterion by the decision makers. Finally, the superior route alternative is stated as the alternative having the maximum net outranking flow.

By the comparison of the preferable route with the existing PTL, it is shown that there is an agreement on the ideas behind the route selection for PTL with conventional methods and the approach applied in this study. The used layers, criteria, and constraints in this study succeed in reflecting the real decision conditions for the route of a PTL. The decision notion, in the conventional method, is transferred into the MCDA approach and a satisfying route alternative is generated successfully.

The route selection approach executed by MCDA methods will be supersede the conventional route selection method, and the GIS-based MCDA approach, which is applicable on any study area, can provide consistency, flexibility and accuracy of the route selection processes. In addition, this approach would be applied in the route selection process of any linear structure by making small criteria changes.

5.2 Discussions

The man made data generation, decision making etc. is still more reliable in some study areas, for example; extraction of natural and artificial structures and classification from images generated by optical and microwave remote sensing platforms. Because these kind of processes require some expert knowledge and complicated analyses, which can easily be done by the human brain. In this context, the conventional route selection procedure, which is performed in the field, is still the optimized solution for the routing problem of PTL. The PTL experts are indirectly taking into account all the criteria and constraints in the field study. The result of the conventional route selection method would be feasible since the PTL experts aim to reach a PTL design, which is cost-effective, harmless, and riskless alternative. In this study, the automated route selection method as a kind of intelligent system approaches almost the same solution in the reality.

The pairwise comparison of the criteria in the AHP method is a quite difficult process because the relative ranking of ten layers is an inconvenience to the decision makers. The decision makers may not give consistent rankings because of the number of the criteria. However, the Consistency Ratio of the AHP method checks the sensitivity of comparison process.

The isotropic cost model is used in this study. In some previous studies on routing problems, the anisotropic cost model is preferred in calculation of the cost of slope layer. However, the top of hill, in other words the locations where occurs rapid slope changes, is suitable location for spotting of power structure.

The Slope, Soil Group and Geology layers are converted to a significant layer by combining the layers with SAW method. The SAW method is selected to generate Landslide layer by using the weight gathered previous studies. The AHP method is not preferred because of the lack of the expert on landslide area.

The accuracy, resolution and currency of the data set affect the reliability of the study. In addition, the preferences of a decision maker may cause to domination of some layers. Thus, it is essential to attach importance on these issues because of the reliability of the study.

5.2 Future Studies

The MCDA model represented in this study is planned to be included as a script in a GIS software containing the AHP and PROMETHEE methods. This will make the decision-making process and definition of the outranking route alternative easier.

The resolution and currency of data directly affect the accuracy of the outputs. The DEM layer will be generated from LiDAR data, which will be high resolution and contemporary. The DEM will be more sensitive on the small elevation changes.

The numbers and backgrounds of the decision makers will be increased to achieve an objective solution of routing problem.

The main parts of the model generated for this study could be applicable for the route selection problems of other linear structures. By making small changes this model will be used for other routing problems. Besides, due to the computer-based model, the approach can save time of this complex route selection procedure.

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