FINDING THE OPTIMUM ROUTE FOR TRANSMISSION LINES WITHIN GIS

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Approval of the Graduate of Natural and Applied Sciences

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This is to certify that we have read this thesis and that in our opinion it is fully adequate, in scope and quality, as a thesis for degree of Master of Science.

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ABSTRACT

FINDING THE OPTIMUM ROUTE FOR TRANSMISSION LINES WITHIN GIS

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This study defines the optimum route planning for Electric Transmission Lines by Multicriteria Decision Analysis which is based on Geographic Information Systems (GIS). Determination of the optimum route is performed by using both the spatial and Euclidean distances between two points located on the Earth's surface.

The criteria needed to be taken into account to define the route of the Electrical Transmission Lines were evaluated with help of the experts who are doing this business in the available system and for this study the decision about the usage of needed data such as landuse map, landuse capability map, geology map, road map, zone plan and digital elevation models is also made with their knowledge.

A Matlab code, which computes the optimum distance between two transformers by using real distance (spatial distance) method and by considering materials mentioned above is written. The results are compared with the ones found from the Euclidian distance, which is the common distance finding method in the available commercial GIS softwares.

The spatial resolution effect in finding the spatial distance is also analyzed. The routes obtained by two different distance computation methods are compared with the existing route. The economical expectations in finding the optimum route are also discussed.

Keywords: GIS, spatial distance, optimum route, Multicriteria Decision Analysis

ÖZ

İLETİM HATLARI İÇİN GIS ORTAMINDA OPTİMUM GÜZERGAH BULUNMASI

ÖZTÜRK, Tünay

Yüksek Lisans, Jeodezi ve Coğrafi Bilgi Teknolojileri Ana Bilim Dalı

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Bu çalışma Coğrafi Bilgi Sistemleri (CBS) tabanlı çok ölçütlü karar analizi ile Elektrik İletim Hatları için optimum güzergah planlamasını anlatmaktadır. Optimum güzergah tasarımı, yeryüzünde bulunan iki nokta arasındaki gerçek uzaklık ve öklid uzaklığı kullanılarak incelenmiş ve karşılaştırılmıştır.

Elektrik İletim Hattı güzergahının belirlenmesi için dikkate alınması gereken kriterler bu işi mevcut sistemde yapan uzmanlar ile birlikte değerlendirilmiş olup bu çalışma için çalışma alanına ilişkin arazi kullanım haritası, arazi kullanım kabiliyeti haritası, erozyon haritası, yol haritası, imar planı ve sayısal yükseklik modelinin kullanılmasına karar verilmiştir.

Gerçek uzaklık yöntemi kullanılarak ve yukarıda belirtilen tüm öğeler de dikkate alınarak Matlab ortamında iki trafo merkezi arasındaki optimum mesafeyi bulan bir kod yazılmıştır. Elde edilen sonuçlar mevcut CBS yazılımlarında yer alan klasik uzaklık bulma yöntemi olan öklid uzaklığından bulunan sonuçlarla karşılaştırılmıştır.

Gerçek uzaklık bulmada mekansal çözünürlüğün etkisi analiz edilmiştir. İki farklı mesafe bulma yönteminden elde edilen optimum güzergah mevcut yöntemler ile bulunan güzergah ile karşılaştırılmıştır. Optimum güzergah bulmada etkili yöntem ekonomik beklentiler de dikkate alınarak tartışılmıştır.

Anahtar Kelimeler: CBS, gerçek uzaklık, optimum güzergah, Çok Ölçütlü Karar Analizi

To My Parents

And

To My Husband

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INTRODUCTION

1.1 Introduction

GIS have been used since the 1960's for city planning, utility management, facility management, hazard management, address matching, agriculture and crop estimation, applications in geology, hydrology, biology, archeology, forestry, emergency services, social/medical studies, transportation, military (Aronoff, 1989).

Analysis such as the profile analysis, the engineering design of towers and wires, the cost estimation, the site selection and the optimum path finding can be carried out by using GIS tools. One of the areas of GIS application has been in facilities management for electric sector (Aronoff, 1989).

Electric transmission lines retain a vital role in power supply systems. During site selection process in ahead to construction of those facilities, it is essential to take into account of impacts on environment and local communities as well as effect of regulations in addition to technical issues.

General Directorate of TEIAS is the responsible authority in Turkey for planning and development of transmission systems in accordance with the principles and procedures given in the Transmission System Supply Reliability and Quality Regulation. The voltage values of the transmission system are classified as 380 Kv, 154 Kv, 220 Kv and 66 Kv which represent the high voltage transmission lines.

The length of electric transmission lines owned by TEİAŞ has reached to approximately 46000 km since 1977. The Directorate of Survey and Planning operating under TEİAŞ is responsible from the design of most economical paths of electric transmission lines lied between two transformer centers. The number and lengths of electric transmission lines maintained by TEİAŞ in 2006 are presented in Table 1.1.

Table 1.1 The statistics relating to electric transmission lines belonging to TEİAŞ by 2006.

The Transmission Line Voltage	The Numbers of Electric Transmission Lines	The Length of The Lines (km)
154 kV	1002	31163
220 kV	2	84
380 kV	122	14307
66 kV	25	477
Overall	1151	46031

In fact any inappropriate decision taken during route design process of an electric transmission line, other related authorities are also affected by this failure such as Directorates of Environment, Real Estate, Expropriation and Map, Project and Foundation and Progress Payment. The organization structure in TEİAŞ is shown in Figure 1.1. Giving an example, before erecting a corridor which has a range of 2.5 km around all electric transmission line routes, Department of Environment is required to prepare an "Environmental Impact Assessment Report" for submitting to the Ministry of Environment and Forestry. Besides, Departments of Real Estate, Expropriation and Map should consider "Decision of Public Interest" issued by the Ministry of Energy and Natural Resources for each electric transmission line.

Any wrong decision taken during selection of route, such as changing locations of utility pole, affects the bureaucratic processes besides the technical processes for each electric transmission line. The electric transmission line is designed by two stages in the available system. First of all, the route has been designed only by using hardcopy maps, such as embossing map and topographic maps at 1/100000 and 1/25000 scales, belonging to the study area depending on the subjectivity of an operator in the available system for the route determination.

A corridor around the preliminary route that can be 500 m. width is defined before determining the final route. Secondly, land survey is realized for designing the final route. The maps excluding topographic maps, that are hardcopy maps relating to the criteria in technical regulation for the route determination, are collected such as zone plan, DSİ projects in the study area during land surveying. The factors that affect the expropriation and foundation costs are collected during land working in hardcopy form instead of overlaying all maps in digital form. The most critic process for TEİAŞ is the route determination for electric transmission line depending on the effective factors due to the optimum time, cost and staff.

After determination of the final route, TEİAŞ can encounter some problems due to incorrect site selections in terms of expropriation and establishment by the operator. The proposed route for an electric transmission line by the available system must be replaced with a new route for the same electric transmission line because of expropriation or establishment reasons. In fact any revision made in the route of electric transmission line would result in loss of productive effort, time and money supplied by TEIAS.

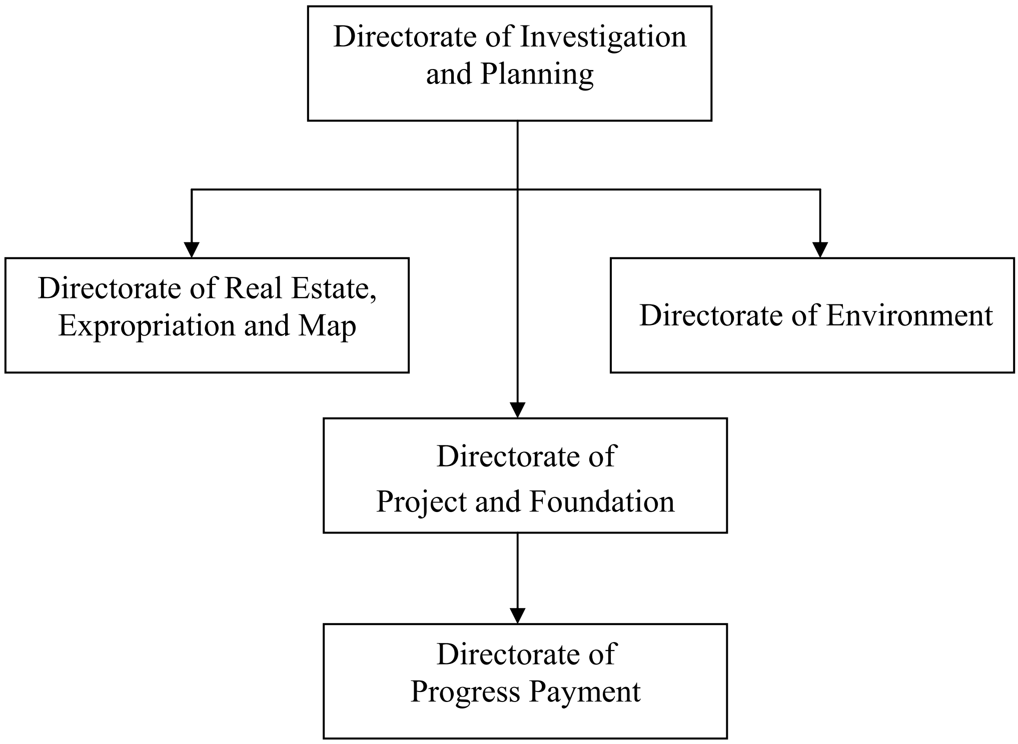

Figure 1.1 The organization structure of TEİAŞ

The route is designed according to the technical regulations of TEİAŞ in line with expert analysis which are conducted by using hardcopy maps. In addition to the mentioned facts above, the route may need to be completely changed during land survey. Consequently, the most important part of the route determination for electric transmission lines has been realized by land survey in TEİAŞ.

The land survey should be done certainly for checking the correctness of the optimum route after the office works, but spending time for this process must be minimized considering the time and cost limitiations, and efficient use of manpower.

The electric transmission line route from Temelli to Gölbaşı transformer centers has been modified two times after the land survey by Directorate of Investigation and Planning in TEİAŞ, because the location of three utility poles belonging to this transmission line coincides with road. It is only one instance that causes the addition cost and labor for one electric transmission line route determination. The units of TEİAŞ that have worked depending on Directorate of Investigation and Planning must repeat the bureaucratic processes and the technical processes that must be done after identifying the route for the electric transmission line.

The total length of electric transmission lines that will be scheduled in 2007 is 4668 km. The planning and managing procedure needs to be done very accurately and efficiently. It is impossible that the optimum route problem between two transformer centers belongs to TEİAŞ can not be solved by available system due to the above-mentioned reasons.

It is getting difficult to find the most suitable site for a transmission line depending on the additional time needed for process of planning and foundation of the electric transmission line and the increasing cost of establishment and expropriation processes.

The derived and existing maps can be in digital or paper form. The attributes associated with maps can be in different locations and can be kept on different databases. The required analyses for determining the optimum route for the electric transmission line can not be performed by considering the defined criteria in the regulation and overall cost owing to lack of the data integrity. There are also a number of deficiencies for determining the optimum route of the line. These are:

- Creating maps and graphs in the required formats,
- Compiling geographic data from diversified sources including field observation, satellite imagery, aerial photographs, existing maps, and etc.,
- Obtaining, analyzing, and integrating spatial and attribute data which are obtained from working units,
- Decreasing error margin in available system,
- Designing and updating the spatial and attribute data in confident and rapid ways,
- Reducing the minimum level of bureaucratic processes.

Spatial Information functions distinguish GIS from other information systems. Least cost path finding is an important sub-function of the Geographic Information Systems that is introduced as an important application in route determination problems. In this study, GIS is an efficient tool for overcoming these deficiencies.

The main objective of this study is to find the optimum route for electric transmission line based on Geographic Information System analysis between two transformer centers. In this respect, it is intended to assess the improvements of GIS as a decision making tool for the route determination in this study.

The another objective of this application is to acquire more accurate results by using actual distances between two transformer centers instead of Euclidian distances provided by the available system within GIS. It is proposed to examine the effect of data precision for two methods used in the study.

The optimum and alternative routes could be detected and compared very accurately and quickly with the help of the proposed methodology. The proposed system for the design of the electric transmission line between Gölbaşı and Temelli transformer centers are obtained semi-automatically. The new system is proposed according to the technical regulations and the minimum cost and time criteria.

The study is presented in six chapters. The problems and goals relating to the study are defined in the first chapter.

In Chapter 2, the optimum route determination is introduced by the main points. Graph theory, shortest path analysis and previous works related to the study are introduced. The basis of the proposed system is summarized in Multicriteria analysis part of this chapter.

In Chapter 3, the study area and the methodology are presented. The input datasets, such as landuse map, landuse capability map, digital elevation model of the study area, erosion map, built up area and road map are described.

The analysis performing for determining the optimum electric transmission line between two transformers centers are described in Chapter 4. The structure of two methods and the processes carried out for the Euclidian distance calculation method and the actual (spatial) distance between two locations are described. The criteria affecting the performance of two methods are also explained.

Chapter V is reserved for evaluating and discussing the performance of two systems according to determined criteria and data precision.

In the conclusion chapter, the goal and objective of the study, processes performed to achieve these objectives are reviewed, main conclusions of the study are evaluated and the recommendations related to the study are given for the further studies.

CHAPTER 2

THE OPTIMUM ROUTE DETERMINATION

A useful application in GIS is finding the shortest path by combining different data from various sources. The geographic features in the real world can be represented in vector or raster-based spatial model. Either one of two spatial models can be used for the same shortest path algorithms based on the graph theory.

The decision of spatial model choice, vector or raster model depends on the application and the analyst. Either raster or vector spatial models can be preferred depending on the GIS application. If there is not any predefined path across a terrain, Raster-based GIS is used to find the least cost path between these locations (Noordin, 2006). Raster model is preferred rather than vector model for the optimum route determination for electric transmission lines because of taking into account the movement from the cell to cell not through a finite line (Husdal, 1999; Zhan, 1997).

2.1 Graph Theory

A network model can be demonstrated in a graph. The graph is a tuple G = (V,E) consist of a set of vertices (V) or nodes and a set of edges (E) or arcs, which is a collection of pairs of nodes. Each arc is mapped as a relation f. If the pairs are ordered, then the arc is directed (Zhan, 1997). As shown in Figure 2.1 (a), the first node 1 is the origin and the second one is the destination, such as AA 849 shows a flight from one city to the other, represented as nodes 1 and 2. If the pairs are unordered, then the edge is undirected. The flight route is an example of this type of the edge, as illustrated in Figure 2.1 (b).

Figure 2.1. A directed graph (a), An undirected graph (b)

If all the arcs in a graph are directed, then the graph is called directed. The undirected graph has undirected arcs. The undirected graph consists of a finite cluster of vertices, not null, a finite cluster of edges and a function $f : E \rightarrow P(V)$, f(e) is a subset of vertices, has one or two elements, for every edge in the graph. The function f is used to define the relation between vertices and edges as shown in Figure 2.2 and 2.3 (Ahuja, 1993).

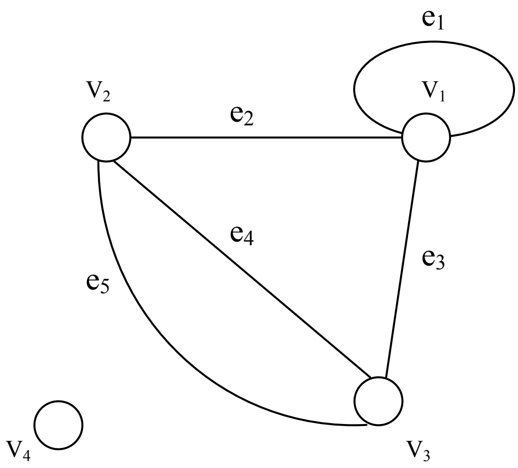

Figure 2.2. An example for an undirected graph

$f{:}E \rightarrow P(V)$

$e_1 \longrightarrow \{V_1\}$
$e_2 \longrightarrow \{V_1,V_2\}$
$e_3 \longrightarrow \{V_1,V_3\}$
$e_4 \longrightarrow \{V_2,V_3\}$
$e_5 \longrightarrow \{V_2,V_3\}$

Figure 2.3. The relations of vertices on the graph

There is also one type of graph, called as weighted graph. All edges on a graph are weighted with some of value related to it. These types of graphs are used to solve the shortest path problems (Zhan, 1997). The path is sequence of alternating nodes and arcs, begins with a node and finishes with a node; each edge is preceded and followed by its endpoints.

Figure 2.4 shows the path between “a” and “e” nodes containing 3 nodes and 2 arcs. P_i = {a,I,d,K,e}

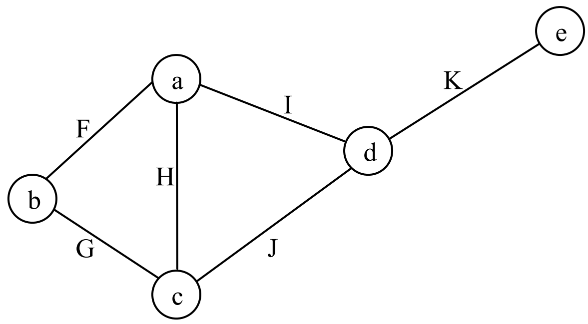

Figure 2.4. The weighted graph

2.2 Shortest Path Analysis

Shortest path algorithms are developed for many kinds of networks, such as roads, utilities, water, electricity, telecommunications and computer networks (Husdal, 1999).

The classical shortest path algorithm is developed by Dijkstra in 1959. The algorithm finds a distance between nodes in all directions from a departure node until reaching the destination node. The basic Dijkstra algorithm requires two or more nodes and searches possible routes for the shortest result based on specific weights of the edges that connect them. All nodes are connected to each other by these edges. The edges contain weight which could be cost, distance, or time. In a network of nodes the shortest path is the result of the lowest sum of weights between two nodes. The algorithm computes a path taking into account all directions from the source node to the destination node. It terminates the searching process if the destination node has been reached (Husdal, 1999). Hakbilir (2004) implemented the Dijkstra’s algorithm with priority queue for finding the path between two nodes.

Heyes and Jones (2001) have examined A^* Heuristic algorithm that is a slight generalization of Dijkstra’s algorithm. The algorithm is used to find a shortest path from one source node “s” to one destination node “d”.

A^* algorithm uses a guess distance (heuristic) function that returns on estimate of the distance from “s” to “d”. The key of a node “s” is dist (s) + Guess Distance (s,d) for A^* algorithm. The heuristic function is called tolerable, if the function (s,d) never overestimates the actual shortest path distance from s to d. If the guess distance function is tolerable and the actual edge weights are all non-negative, the A^* algorithm computes the actual shortest path from the source node “s” to the destination node “d” at least quickly as Dijkstra’s algorithm (Shad et al., 2003).

In addition to these algorithms, a number of researches have proposed to design the least cost or shortest path route, such as Bellman-Ford-Moore, topological ordering, incremental graph, threshold and genetic algorithm (Delavar et al., 2004; and Zhan and Noon, 1996).

Raster network modeling provides a different approach to find the shortest path compared the vector model (Husdal, 1999). Firstly, the exact shapes of the elements in a network, which are lines and nodes, are estimated by applying the grid cell approximation. Secondly, the vector model gives us the direction information explicitly rather than the raster model. Thirdly, the line and node attributes must be stored as a separate layer for each attribute. As a result, a network using a raster model normally consists of a vast number of layers. Even if it does not appear so explicitly, a grid is in fact a graph representing a network, with each node’s eight neighboring directions. Since the grid has a given resolution, the cells will only approximate the exact shapes of the network (Husdal, 1999).

The cells that are the destinations of all the edges of a given cell are called its neighbors. Ideally, all cells should be neighbors to all other cells. The physically adjacent cells as neighbors to a given cell are only defined because of having an incredible number of edges. The eight neighbors of a “node 5” are shown in Figure 2.5.

1	2	3
4	**5**	6
7	8	9

Figure 2.5. The neighboring cells of the source node

The physical length of an edge is taken into account for the determination of the shortest path. The Pythagoras Theorem in three dimensions for calculating the edge lengths can be used but the length of planar projection of the edge is used by ignoring the height difference between cells. The two edge length approximations facilitate the determination of which edge, an axial (2,4,6,8 nodes in Figure 2.5.) and a diagonal edge (1,3,7,9 nodes in Figure 2.5.) , should be used to find the path from the source node to the destination node.

Several algorithms have been developed for determining the shortest or least cost path algorithms in a raster based surface. An accumulation cost surface associated with cost of crossing the surface has been derived to get the least cost path from one cell to another.

Husdal (2000) has evaluated the proposed least cost path algorithms proposed by Tomlin (1991), Eastman (1987), Douglas (1994), Xu and Lathrop (1995), McIlhagg (1997), Collischonn and Pilar (2003). It is stated that Tomlin (1991) has presented a spread algorithm for determining a corridor of the shortest path from a source point to a destination point by using waves and refraction as a spread function. Eastman's (1987) algorithm has been proposed to develop Tomlin's approach for applying this algorithm into large areas. The path distance between the source and destination nodes follows a zigzag line due to grid derived from the cost surface. Douglas (1994) has been introduces the least cost path model by interpolating the zigzag path line acquired from previous works. Xu and Lathrop (1995) have been attempted to overcome the zigzag representation of the path between two defined nodes caused by grid resolution by using spread distance with regards to 8 adjacent cells in the region of a cell.

McIlhagg’s (1997) research has been presented to develop Eastmen’s (1987) algorithm in terms of target numbers. Collischonn and Pilar (2003) have introduced the least cost path algorithm by assigning accumulated costs in 8 directions around a cell (Husdal, 2000).

The actual distance is not equal to the cell width between neighboring cells in the terrain. The terrain is in 3D but the representation of the surface is expressed in 2D. The difference between the distance connecting the same cells in 2D and 3D stems from slope and direction factors. The spatial distance on the DEM (Figure 2.6) between $0P_3$ will not always equal to cell width. It can be longer or shorter than Euclidian distance because it varies with changing direction and slope as depicted in Figure 4.7 (b).

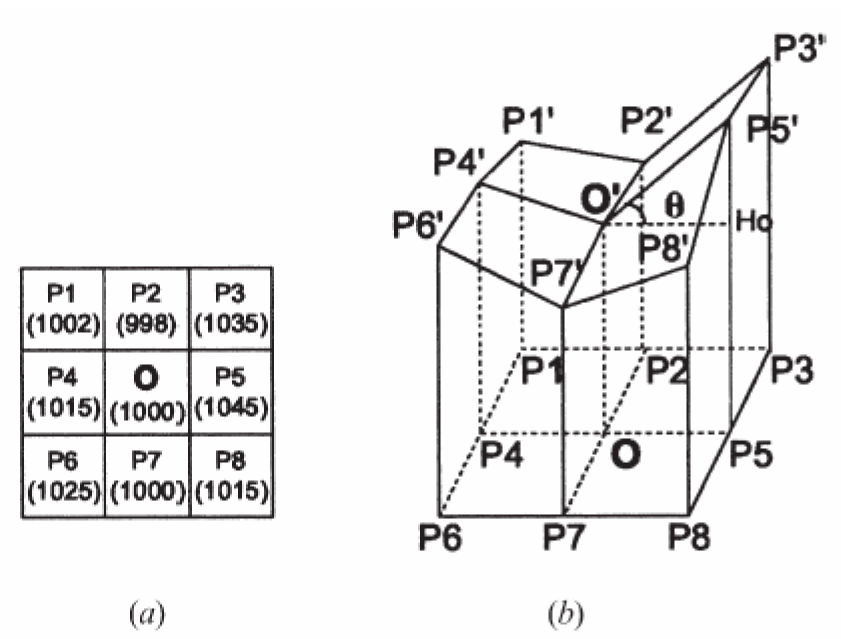

Figure 2.6. A digital elevation models **(a)** and its geometric representation **(b)**

Determining the least cost path is one of the oldest network problems as known. During the last decade, a number of researches have been implemented for designing the route of pipelines, roads, electric transmission lines, and etc. by using GIS analysis. The least cost path analysis for pipeline routing within a GIS environment have been studied by Delevar et al. (2003) and Wan-Yusof et al. (2004).

The optimal path finding method was developed based on map features topology namely independent of centerline topology that can be defined as arc-node approximation for road networks by Pun-Cheng at al. (2006). Petrik et al. (2003) implemented another shortest path analysis for road networks with fuzzy logic into GIS.

Mesgari,S. et al.(2006) determined the suitable locations for power plants in Fars by using GIS and Remote Sensing technology by means of improving it with fuzzy logic. The role of GIS in planning the route of power transmission lines was examined by another application in India (URL3). Monterio et al. (2005) proposed a new method for identifying electric line economic corridors taking into consideration nongeographic, slope, terrain cross, and direction change costs by using dynamic programming based on GIS. Kaijuka (2006) have implemented a GIS application related to rural electricity planning for identifying energy needs and determining the energy quantities required in Uganda.

2.3 Multicriteria Analysis

Multicriteria Evaluation (MCE) may be considered as one of the most fundamental decision support operations in GIS. It is a process for combining data according to their importance and the basic aim of MCE technique is to investigate a number of alternatives in the light of predefined Multicriteria and to rank these alternatives according to predefined preferences (Heywood et al., 1995; Lin et al., 1997).

Chakhar (2003) stated that “One common definition of Multicriteria Analysis is a decision-aid and a mathematical tool allowing the comparison of different alternatives or scenarios according to many criteria, often contradictory, in order to guide decision makers towards a sensible choice”.

Malczewski points out that Multicriteria decision analysis is a set of systematic procedures for analyzing complex decision problems. These procedures include dividing the decision problems into small, understandable parts; analysis of each part; and integrating the parts in a logical manner to produce a meaningful solution (Malczewski,1999; Malczewski,1997).

The main, Multicriteria Decision Analysis problems involve some components (Keeney et al., 1976; Heywood et al., 1995). These are:

- The goal, the evaluation criteria and constrains definitions,
- The standardization of evaluation criteria,
- The generation of the cost map,
- Weights assignment according to a decision rule with respect to the preferences of the decision makers,
- The decision alternatives determination and the evaluation of the alternatives.

Multicriteria Decision Analysis can be used to distinguish suitable from unsuitable possibilities, to rank the alternatives, to list a limited number of options for subsequent detailed evaluation and to identify a single most preferred alternatives (Dodgson, 2000).

2.3.1 Evaluation Factors

The effective factors and constraints are determined to find the optimum path. Constraints limit the alternative routes and provide us consideration yes or no solution for electric transmission lines (Gomes et al., 2002; Idrisi, 2003).

The relative importance of input layers, which is defined according to factors and constraints affecting costs for the selection of the optimum route, can be expressed as a percent influence.

2.3.2 Standardization of Evaluation Criteria

The input layers can be in different measurement systems (slope is in degrees and road in meters.), so they cannot be compared relative to each other. The cost of traveling through a cell is represented to rank the cell values using a common scale.

The standardization of the input layers is an important step because the relative preferences should be characterized in the computer but it doesn’t have any idea of the importance of the layers for the study. The used scale for ranking the cell value might vary from 1 through 9. A ranking of 1 might indicate that the cost traveling through the cell is very low, while a ranking of 9 may indicate that the cost of traveling through the cell is very high.

2.3.3 Creating the Cost Map

Once a directed graph model for the movement through space is constructed, the cost of the movement through it is modeled. The costs are represented as the combination of factors that affect travel across a surface (Husdal, 2000).

The meaning of cost depends on if we want to find the shortest path, fastest path or least risky path, and etc. The combination of factors that affect the movement between a source cell and a destination cell is represented on a cost surface. For example, the slope of the terrain is taken into account for selecting the optimum route of electric transmission lines for decreasing the construction cost of the lines.

A cost value is assigned to every edge in the network. As mentioned in Graph Theory part, a path is a connected set of edges linking the source and destination nodes. For every cell traveled from the source node cost increases until the destination node is reached. The sum of the costs of all edges in the path forms the cost of a path. It guarantees the shortest path but accumulates many cells to do this.

2.3.4 Weighting the Evaluation Criteria

The least cost path between two electric transformer centers is acquired based on weighting the inputs to get the cost raster. Weights have been given to each evaluation factor (each criterion) to reflect its importance for the study. Weights must sum up to 1. Each site has been ranked on each of the criteria. The final product is used to get overall evaluation according to these criteria.

2.3.5 Finding the Least Cost Path:

A cumulative cost surface creates a new surface by assigning each cell a number that indicates the least cost direction to the ending point. This best-direction surface is used to draw the least cost path from the source transformer center node to the destination transformer center node (Iqbal, 2003).

2.4 The Use of Shortest Path Analysis in GIS

Zhan and Noon (1996) have carried out a broad study of shortest path algorithms on 21 real road networks in the US. The networks are ranged from 1600/500 to 93000/264000 nodes/arcs. They tested these real road networks on 15 of the 17 shortest path algorithms. Dijkstra- based algorithms, varying in data structure, surpass other algorithms for the single shortest paths problem. Pallottino's graph growth algorithm performed with two queues (TQQ) is the best solution for one-to-all shortest path problem according to Zhan and Noon.

They chose one implementation of two proposed Dijkstra's implementation, depends on the maximum network arc lengths. The approximate buckets implementation of the Dijkstra algorithm is used to compute one-to-some shortest paths over networks where the maximum arc length is more than 1500, the double buckets implementation of Dijkstra algorithm is used to solve the problem.

In Choi et al.'s (2004) study the alternate road selection was planned by considering the surrounding facilities, development plan and estimated amount of traffic. 3D simulation method was studied for the additional possibility of view analysis and environment effects of analysis elements. Firstly, geometric structure and facility standards, such as the minimum radius of horizontal curve, the minimum length of horizontal curve, the stop sight distance, the transition curve and the maximum eccentric grade are determined on account of design speed. Secondly, the route selection plan is established to take into consideration the harmony of the development plan and the smooth traffic on intersections, the traffic volume of the main route of perspective traffic that is efficiently connected to the main route.

Pun-Cheng and Li (2006) have introduced a new method of using an independent of any arc-node data model to find path for pedestrians. The arc-node data structure is the most common and suitable way to represent a network, such as road network. The nodes are used to depict road intersections while arcs are utilized to describe road segments between intersections but the road centerlines are defined as the road networks in many applications. The creation of the network arcs is tedious and time consuming process owing to the digitizing of the centerlines. An alternative method, using the map features directly for pedestrian walking, is provided to substitute the laborious creation of arc-node representation. A theoretical line linking the source and destination point is constructed; it involves the magnitude and direction information. The street blocks, are defined as the polygon geometric structure, are used to represent the necessary movement of pedestrians. The connection features between street blocks are considered, such as zebra-crossings, bridges and subways. The theoretical line is divided into several segments by removing intersection points between street blocks and link features. Each segment has the same direction information with the theoretical line. A Polygon Id list is obtained by overlaying the street block layer and the start and end points of acquired line segment. Then the polygon list is checked for removing any physical dividers or traffic islands and the links if there is more than one between two polygons. When the check process finishes, the result polygon list is displayed (Mandy et al., 2004).

Collischonn and Pilar (2000) have proposed the least cost path algorithm, depending on a direction, given topography, a function relating slope, distance and cost and the defined source and destination points for road and canals. The structure of the proposed algorithm is formed in 4 parts. The first part is the input data, contains DEM surface, source and destination points belonging to the path, the function relating cost and slope. The second one is the initialization process, creation of accumulated cost surface from the cost of passage grid surface that forms the cells and the values belonging to these cells are used to calculate the least cost path as weight value. The weights can be stated concerning cost, time, distance or risk. The accumulated cost surface is created for some iteration that is proportional to the path complexity until generation of the best direction surface or the least cost path between the source and destination points.

Zhan and Noon (1997) has introduced the fastest path algorithms for computing shortest paths on real road networks, the Pallottino's graph growth algorithm implemented with two queues (TQQ), the Dijkstra's algorithm implemented with approximate buckets (DKA) and the Dijkstra's algorithm implemented with double buckets (DKD). The Forward and Reverse Star representation is most convenient data structure for the networks according to the past research. The Forward Star representation is a data structure that can be used to determine efficiently the set of arcs outgoing from any node and the Reverse Star representation is a data structure that provides an efficient means to determine the set of incoming arcs for any node. A key operation in many shortest path algorithms is the labeling method. The labeling method employs a scanning operation to scan each node progressively until all nodes on a network are scanned. During the scanning process, the distance labels associated with nodes to which there exists an outgoing arc from the node being scanned is updated. The study evaluates the data structures and procedures related to the three proposed faster shortest path algorithms.

Lee and Stucky (1998) have determined least cost paths, which can be used for environmental planning, military and civil engineering by applying viewshed analysis. There were four types of viewpaths from a digital elevation model, called as hidden path, scenic path, strategic path and withdrawn path. The cost of movement from a departure point to its nearest neighboring pixels were calculated by using the visibility cost, surface distance and gradient. An iterative searching method formulated by Douglas (1994) was utilized for determining the least cost path between the departure and destination points. They evaluated this method by using a USGS DEM for hiking and pipeline design problems by taking into account the gradient, slope, distance and viewshed factors.

Stefanakis and Kavouras (1995) have built network using direct, indirect and remote neighbors pixels. They reviewed the existing solution to the optimum route determination, which forms three steps, generation of friction surface, generation of accumulated surface and the determination of the optimum path. The applicability of the approach to plane surface, the 3D space and spherical surface were examined.

Yu et al. (2003) have presented a new method of approach related to the least cost path finding for roadway planning. 5x 5 pixel window was used in describing the network neighbors cells, which were defined as the moves in a game of chess, the Rook’s (4 cells) , Queen’s (8 cells) and Knight’s (16 cells) patterns in Figure 2.7.

The Rook's pattern interests a calculation based on only direct neighboring cells and doesn't examine diagonal values during accumulation. The Queen's and Knight's patterns take more angular movement into consideration.

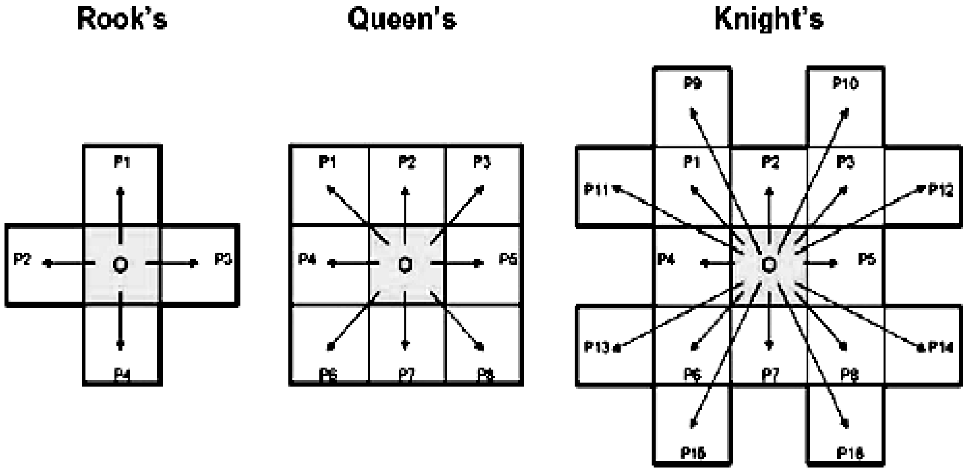

Figure 2.7. The Rook's, Queen's and Knight's patterns for O node. (Yu et al., 2003; Saha et al., 2005)

Using a pattern such as the consideration of these directions makes switchback possible. Yu et al. (2003) have stated the spatial distance formula in Queen's, Knight's directions as two parts, which are direct and diagonal neighbors as shown equation 1, equation 2 and equation 3.

$$D'_{(o,p_{ii})} = \sqrt{\mu^2 + (H_{p_i} - H_o)^2} \quad \text{where i=2,4,5, and 7} \qquad (2.1)$$

$$D'_{(o,p_{ii})} = \sqrt{2\mu^2 + (H_{p_i} - H_o)^2} \quad \text{where i=1,3,6, and 8} \qquad (2.2)$$

$$D'_{(o,p_{ii})} = \sqrt{5\mu^2 + (H_{p_i} - H_o)^2} \quad \text{where i=9,10,11,12,13,14,15, and 16} \qquad (2.2)$$

Landuse cost with distance and gradient cost were accumulated by getting a cost function. The least cost path between the source and destination points were found by applying Dijkstra algorithm but the smart terrain algorithm was proposed to compare the products of two methods.

The result of ST algorithm showed more realistic than that of Dijkstra algorithm, because of taking into account spatial distance instead of Euclidian distance.

Saha et al. (2005) has presented a study for determining the optimum path. There are four fundamental steps for route planning. The first step is to create thematic cost map, which is formed according to geo-environmental factors belonging to the study area. The used cost for creating the grid-based map is related to landslide distribution, landslide hazard zonation, landuse/lancover, lithology, and drainage orders layers. The ordinal number from 0 to 9 is given to these layers as a weight. The result of cost map varies between 30 and 220 values; the values express suitable pixels for the route planning. The second step is to select linking neighbors. The thematic cost map doesn't involve distance and gradient cost values.

Evaluating of these two factors is performed at this step; the movement from a source pixel to its neighborhood by using 3x3 or 7x7 pixel windows is assimilated as Rook, Bishop, Queen, and Knight elements in a game of chess. The distance and gradient in neighborhood patterns are calculated by applying some formulas. Then, the neighborhood movement cost is calculated from neighbor distance, gradient cost and thematic cost. The last one is to select the least cost route between the source and destination points. Dijkstra's Algorithm is used to select the least cost route. The route planning is applied for the major landslide and adjacent minor landslide case and the significant regional variation in thematic cost case. The results of found paths are represented on the same map for selecting the optimum route. The computer-assisted methodology and the conventional method for the route planning are compared according to cost, working time, the used parameters, and finding alternative route possibility.

CHAPTER 3

MATERIALS AND METHODOLOGY

The study area, the applied methodology and the acquired input datasets for the determination of optimum route between two transformer centers owned by General Directorate of TEİAŞ are presented in this chapter. The study area and the required data are specified after the user requirement survey in General Directorate of TEİAŞ was performed.

The energy produced by power plants is transmitted through available or scheduled transformer stations. These transformer stations are planned by Department of Research, Planning and Coordination in TEİAŞ while the route between these scheduled transformers stations are determined by Directorate of Investigation and Planning.

The first part of planning process of the route are realized by using the embossing map at 1/250000 scale and topographic map at 1/100000 scale taking into account bird-eye distance. Then, some criteria are evaluated for the route according to the regulation and expert's opinion by using topographic maps at 1/25000 scale but most of criteria should be determined during the land survey. Preliminary work for the route determination is realized by using these maps. The maps that are used for Gölbaşı-Temelli electric transmission route are depicted in Figure 3.1.

Gölbaşı-Temelli electric transmission line route was constructed in 1967. The way of choosing the criteria for locating the route were chosen is not known clearly, it is understood that the slope factor was only taken into account with prior investigations. Currently, Gölbaşı-Temelli electric transmission line is being reconstructed. The pole utility locations coincide with the road during this reconstruction, as seen in the zone plan, the route was changed twice.

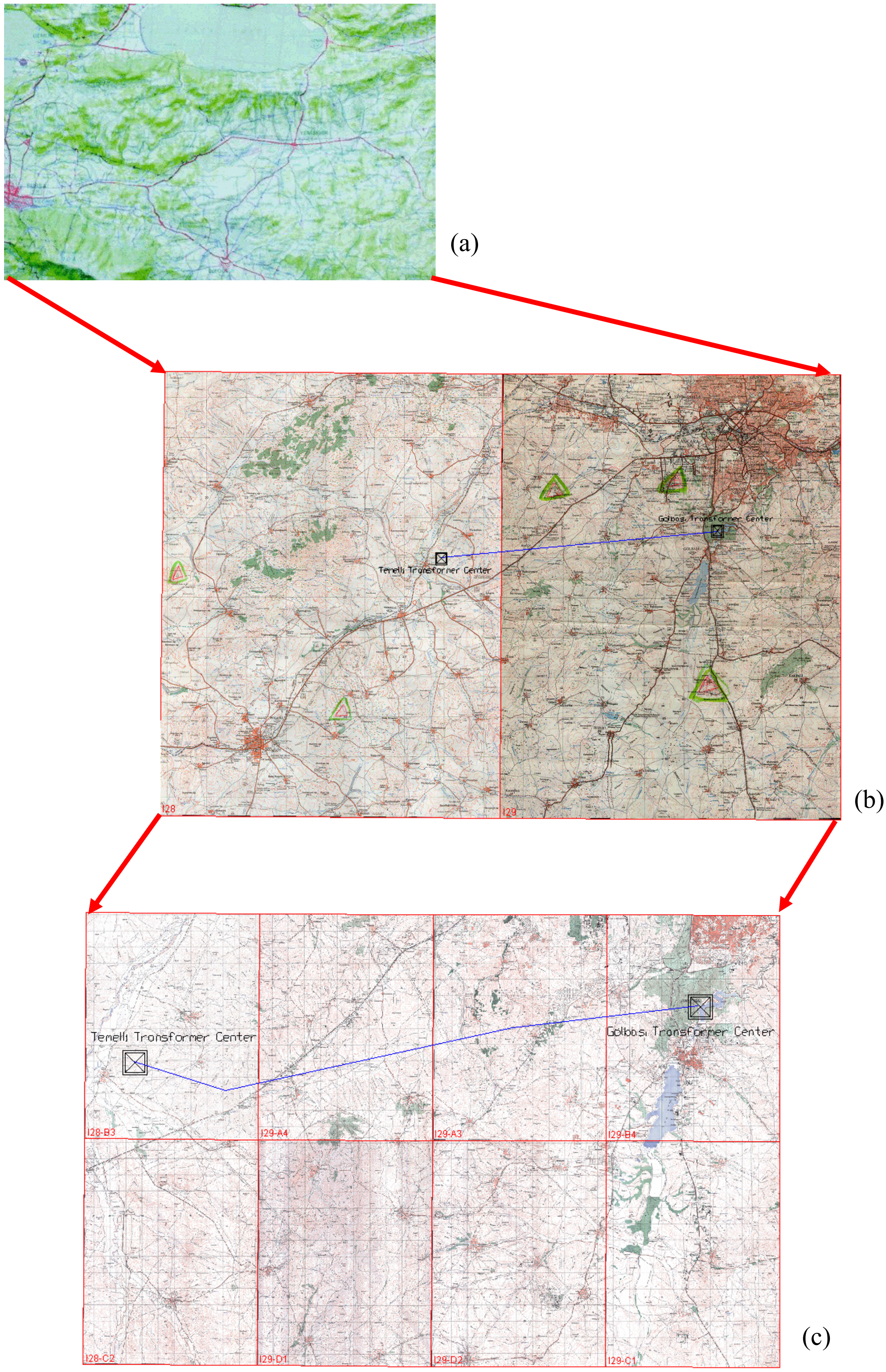

Figure 3.1 The used maps for the route determination in the available system at (a) 1/250000, (b) 1/100000 and (c) 1/25000 scales.

The electric transmission line route should be designed with respect to optimum time, cost and labor where optimum cost is the most significant factor among these. The route cost can be analyzed under two main headlines; expropriation and construction costs. The factors which affect the route's construction cost are as follows geology, topography, land use and road information. The factors that cause high or low expropriation cost by affecting the real estate value are zone plan, topography, landuse, and landuse capability.

The required criteria for the route determination according to the technical regulations in TEİAŞ can be listed as follows:

- The route should be the least cost path as far as possible,
- The elevations through the route should be kept as minimum as possible,
- The high transmission line route should be passed near roads for simplifying transportation and decreasing the maintenance of the electric transmission lines,
- The route should not be passed from the built-up area in order to decrease damage probability for people,
- Landuse is very important for choosing location of the utility pole. For example, marsh area is not suitable for the transmission line route because passing the route from these areas requires more foundation work for construction of utility poles. Rank land is not suitable because passing the route from these areas increases the expropriation cost,
- Land stability is the crucial factor which has effect on construction of the transmission lines,
- The route should not be passed through valuable lands which increase expropriation cost and also through troops area except of mandatory situations,
- The route should not be passed through areas belonging to Agricultural Research Institute.

The required data and passing allowance during the electric transmission line route planning are acquired from related associations such as General Directorate of State Hydraulic Works, General Directorate of Forestry in Turkey, General Directorate of Highways, General Directorate of Forestation, General Directorate of National Parks and Hunt-Wildlife, Province Housing Authority, Municipalities and Military Authorities after completion of planning process by using topographic maps at 1/25000 scale.

The other criteria can not be evaluated such as the impact on natural environment and technical regulation rules for the foundation of the transmission line because the necessary data such as geological constitution, land use, zone plan, etc. are not provided before land survey. In addition, the comparison and analysis of the alternative routes are not appreciated before the ground survey working since the hardcopy data are only used for the route planning and determination processes. This traditional method in route planning increases the cost and processing time.

3.1 The Study Area:

The experimental study area is located in southern Ankara (Figure 3.2). It covers approximately 1187,43 km^2. The area is selected in order to compare the proposed transmission line and the existing transmission line belonging to TEİAŞ. Two transformer centers are placed in the study area, in Gölbaşı and Temelli. The data required for performing the analyses within the methodological frame were available, and that is the main reason of selecting this area for this study.

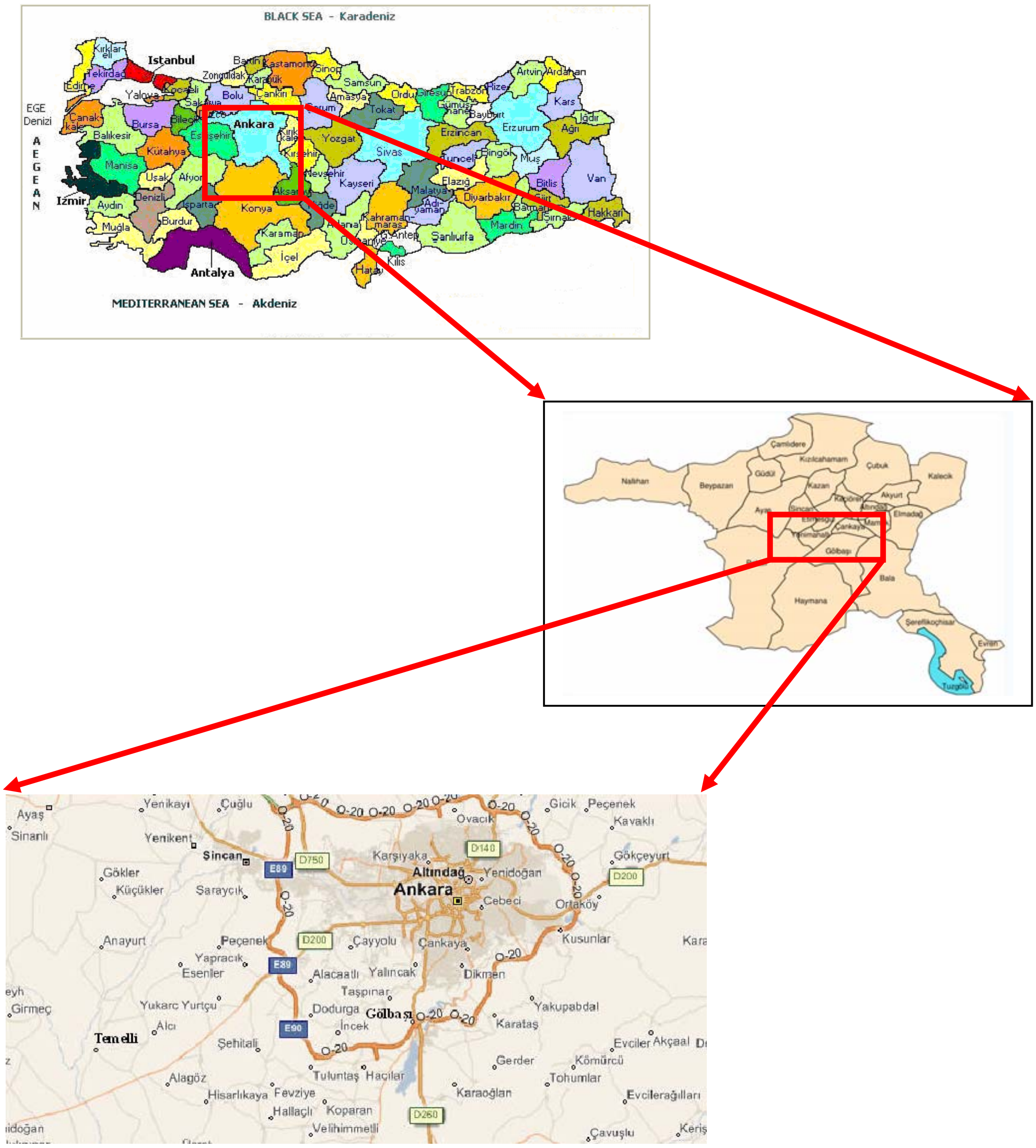

Figure 3.2. The location of the study area

3.2 Data

The data input process is the most important and time consuming stage for the GIS applications due to labor intensive, tedious, error-prone and cost. The data sources and characteristics of the data used in the study are described in this chapter.

The real world is defined as three basic forms, which are spatial data, attribute data and image data. Landuse map, landuse capability map, geological map, digital elevation model, present map and zone plan were used as spatial data, which are in different formats, projections and scales.

The difference stem from formats and projections were eliminated and the analyses were performed by using GIS and CAD softwares, such as NetCAD, Matlab, Erdas Imagine, ARCGIS Desktop and PCI Geomatica.

3.2.1. Digital Elevation Model:

Elevation data plays an important role for determining which areas may be suitable according to the specified elevation factor on the technical regulation related to the optimum route design. Elevation data provides us information about terrain. These data include the elevation of land surfaces, which are continuous phenomena rather than discrete objects; in order to fully model the land surface. Any digital representation of the continuous variation of the land surface is known as a digital elevation model (DEM). The DEM, which consists of a regular raster matrix of elevation values, is the simplest form of digital representation of topography. The distance between adjacent grid points, called the resolution, is a crucial factor.

The DEM can be derived from contour lines that are in vector form. Contour lines are defined as lines linking points on a map that are the same height above sea level.

DEM was generated from the contours and it is given in Figure 3.3. The present map of study area was taken from MNG Bilgisayar A.Ş. The scale of the present map is 1/5000. The projection belonging to the present map is UTM 3 degree and the datum information of the present map is ED50. This map contains lots of information about the study area in CAD format, such as building, road layers. The contour map has ± 20 cm in x,y error as stated by MNG Bilgisayar A.Ş., the DEM having 10 m spatial resolution was generated by using PCI Geomatica software.

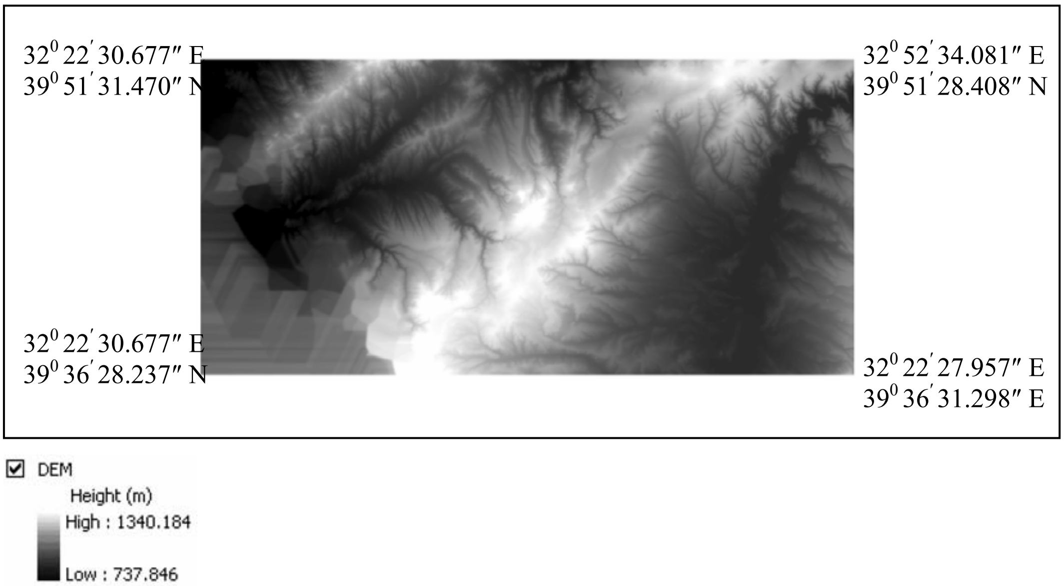

Figure 3.3. The Digital Elevation Model (10m.) of the study area

The other DEM data layer, SRTM DEM 90 m data was obtained from URL6 as shown in Figure 3.4. The projection and datum information are presented in Table 3.1. The elevation values of the study area range from 458 m. to 1944 m.

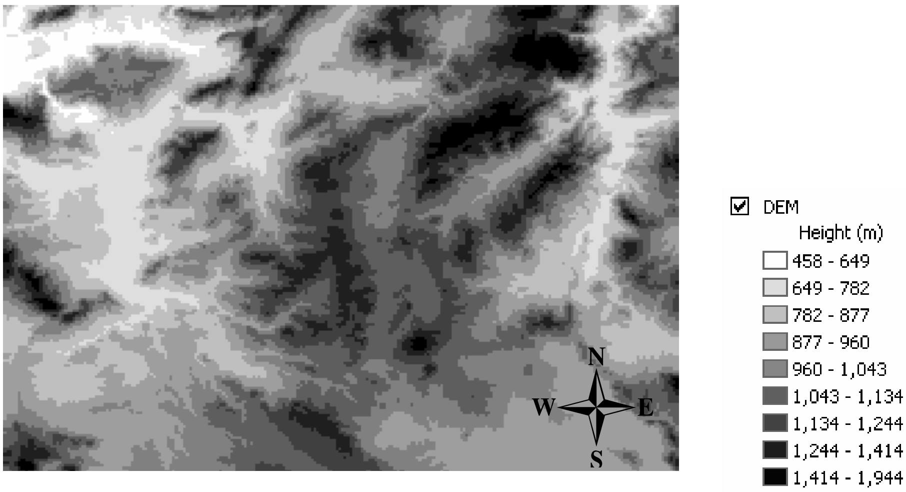

Figure 3.4. The Digital Elevation Model (90m.) of the study area

Table 3.1 Data projection and datum properties of the data used in this study

Data	Scale	Projection	Datum
SRTM DEM	1:100000	UTM 6^0	European Datum (1950)
DEM	1:5000	UTM 3^0	European Datum (1950)
The Land Use Map	1:100000	Lambert Conformal	European Datum (1950)
The Land Use Capability Map	1:100000	Lambert Conformal	European Datum (1950)
The Geology Map	1:500000	UTM 6^0	European Datum (1950)
The Zone Plan	1:100000	UTM 6^0	European Datum (1950)
The Zone Plan	1:1000	UTM 3^0	European Datum (1950)
The Road Map	1:25000	UTM 6^0	European Datum (1950)
The Existing Transmission Line	1:5000	UTM 3^0	European Datum (1950)

3.2.2 Land Use Map:

Land use information being one of the most significant information is available on soil maps. The land is described by several soil polygons according to land use information. Each polygon depicts a land use class, 13 different classes, grounds (dry and watery), vegetation (fruits) (dry and watery), brake, dry agricultural land, dry agricultural land (fallowing land), watery agricultural land (adequate and inadequate), feeding grounds, forest, abandoned land, meadow as seen in Figure 3.5.

The other spatial properties are depicted in Table 3.1. The transformations from available projection and datum information to UTM 3^0 and ED50 were implemented.

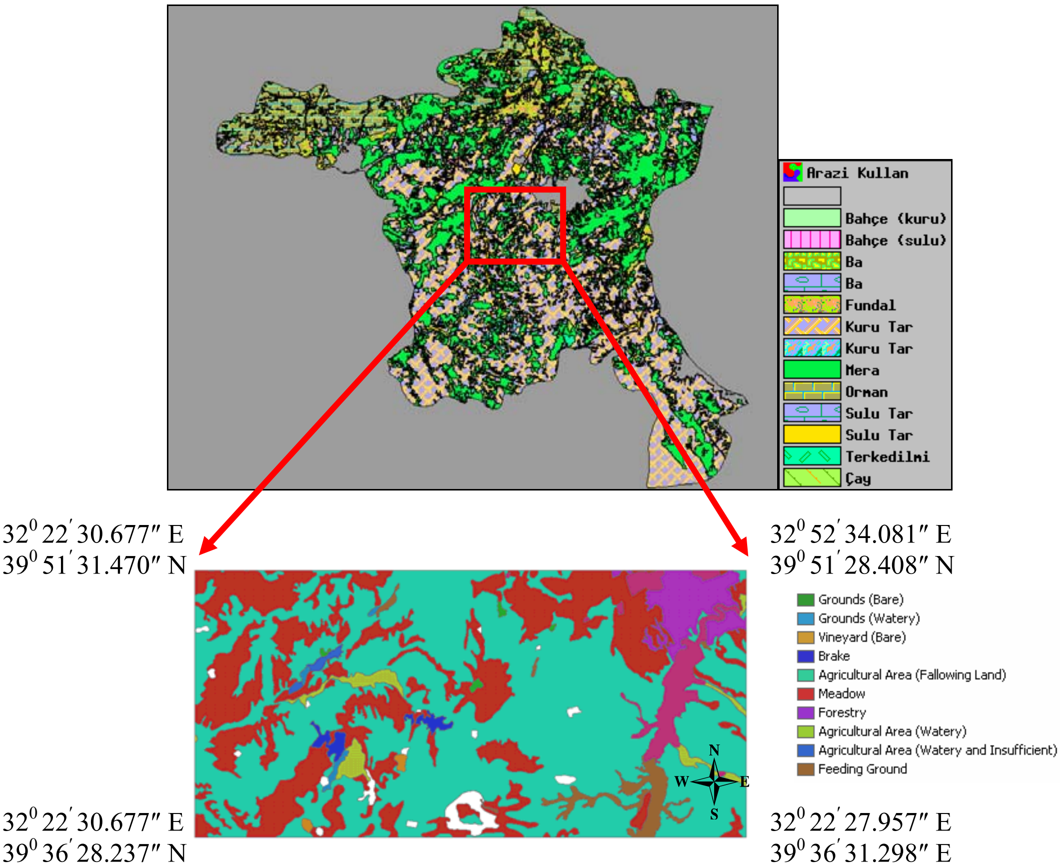

Figure 3.5. The landuse map of the study area

3.2.3. Land Use Capability Map:

Land use capability class information, which is one of the most significant information indicating the suitability of the land for agricultural crop growth, is available on soil maps. The land is described by several soil polygons according to land fertility.

Under the land use capability classification, land is classified into one of eight classes, namely class I to class VIII. There are three categories according to this classification. First category is class I to IV, which are suitable for cultivation and animal husbandry. This category has few limitations; it requires special conservation practices except class IV, which requires very carefully management because of its severe limitations. Second category class V to VII, which are unsuitable for cultivation but only perennial plants with intensive conservation and development practices. It is suitable for under controlled grazing and forestry. This category has very severe limitations that make the land unsuitable for economic and sustainable agricultural usage. Third category is class VIII which is suitable only for wild life, sports and turistics activities. This land is not covered with soil for commercial crop productions (Özden et al., 2000). The classes are depicted in Figure 3.6.

The spatial properties relating to this layer are denoted in Table 3.1. The available projection and datum information are transformed to UTM 3^0 and ED50.

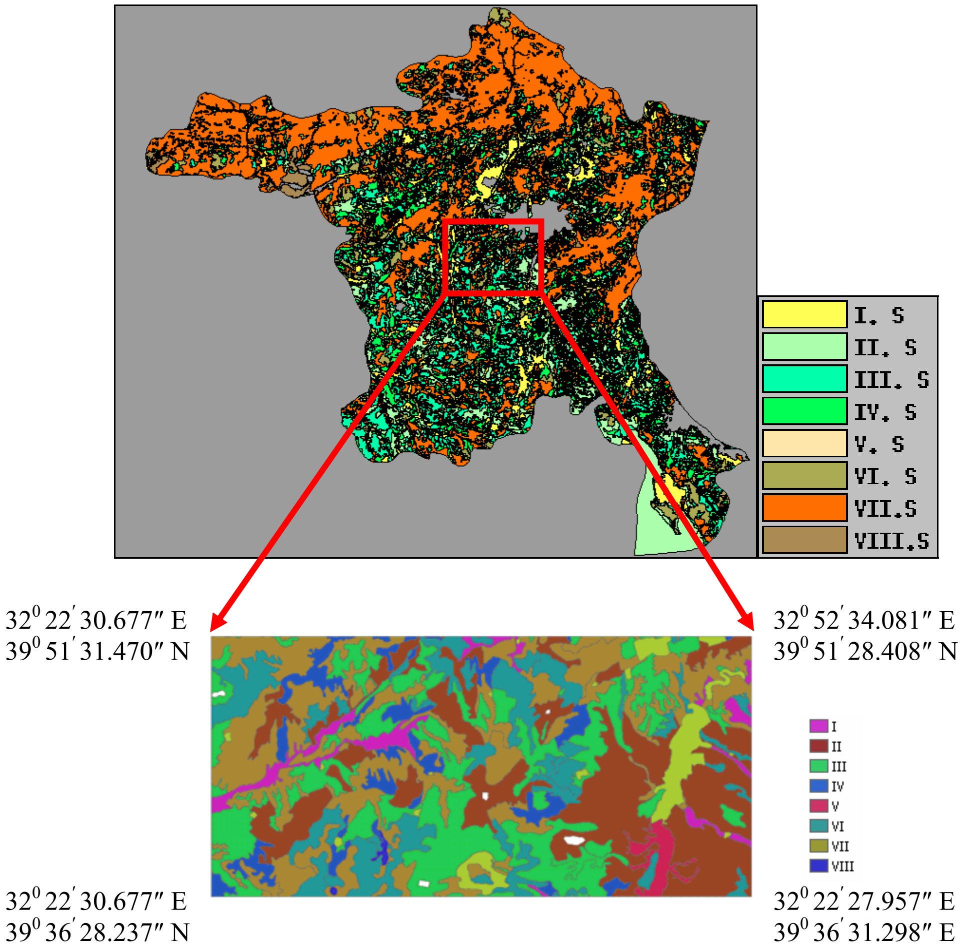

Figure 3.6. The landuse capability map of the study area

3.2.4. Geology Map:

Geology is an Earth science which covers interactions between the earth materials and the structure of those materials (URL8). The foundation of a utility pole is affected by the geological formation of terrain surface. The geology map at 1/500000 scale was acquired from MTA.

The foundation of a utility pole is affected by the geological formation of terrain surface because of the stability property. The geology map at 1/500000 scale are acquired from MTA.

The project area is depicted by several polygons in accordance with the geological structure. Each polygon has a geologic class value varying from 1 to 9, jurassic (undifferentiated), paleozoic (ophiolitic), permian-mesozoic, pliocene, continental, flish, holocene, recent, middle eocene, permian, volcanic as seen in Figure 3.7.

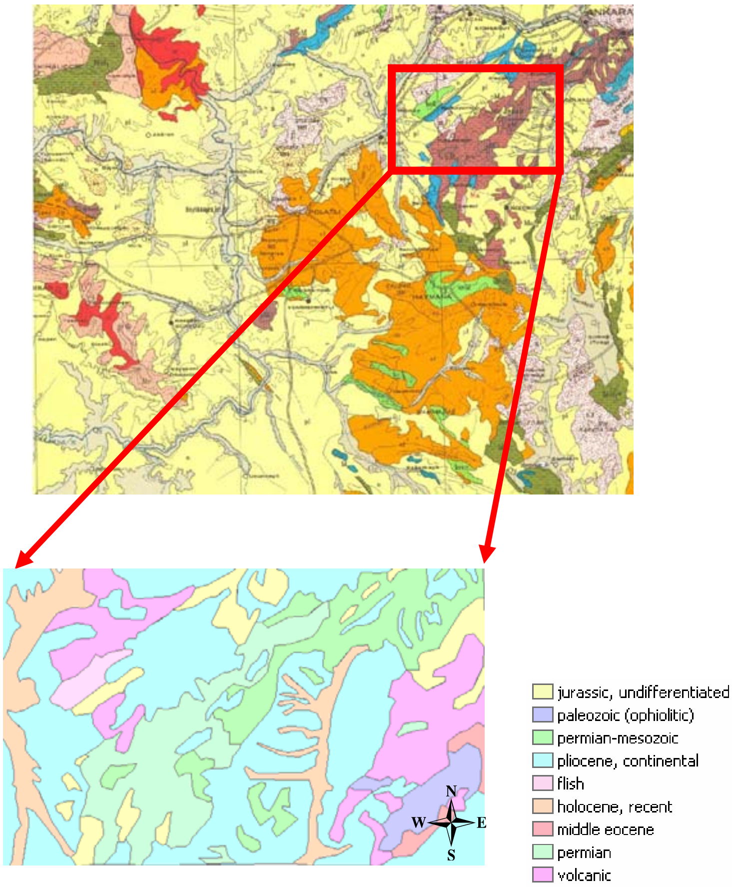

Figure 3.7. The geology map of the study area

3.2.5. Zone Plan:

The zone plan involves zoning and cadastral status. The cadastral status is the other important factor for determining the route. The selection of the transmission line route is affected by zoning status because of the expropriation cost. The zoning plans belonging to the study area were acquired from TEİAŞ and ASKI as presented in Figure 3.8. The datum and projection information belonging to zone plan layer are summarized in Table 3.1.

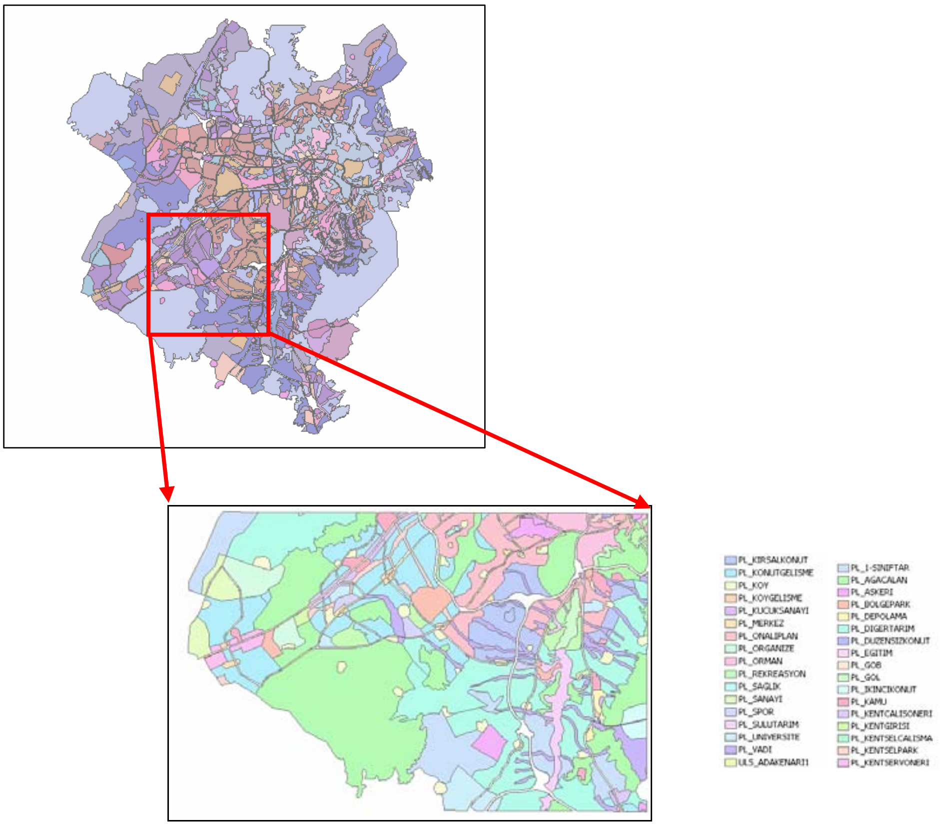

Figure 3.8. The zone plan of the study area at 1/100000 scale

3.2.5.1. The Built-up Area

The built up area of the zone plan was clipped separately considering the areas which have high expropriation cost. The clip operation was performed for zone plans belonging to two different data precisions. The built-up area layer is depicted in Figure 3.9.

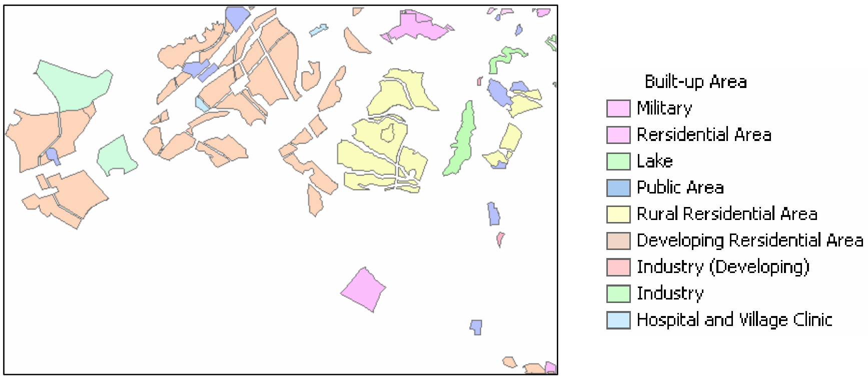

Figure 3.9. The built-up area in the zone plan

3.2.6. Road Map:

One of the evaluated criteria for the transmission line route determination according to the regulation is the road data. It is an important factor because of simplifying transportation and decreasing the maintenance of the electric transmission lines for selecting the route. The road data were digitized from topographic maps at 1/25000 scale as shown in Figure 3.10 (a) and (b). The spatial properties of the road map are described in Table 3.1.

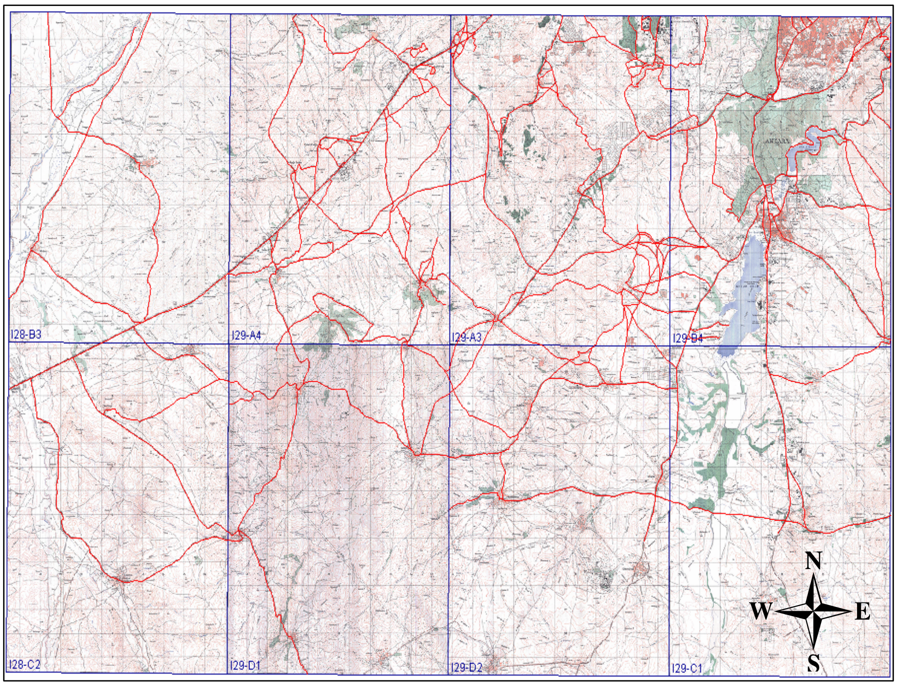

Figure 3.10 (a) The road map of the study area on the topographic maps

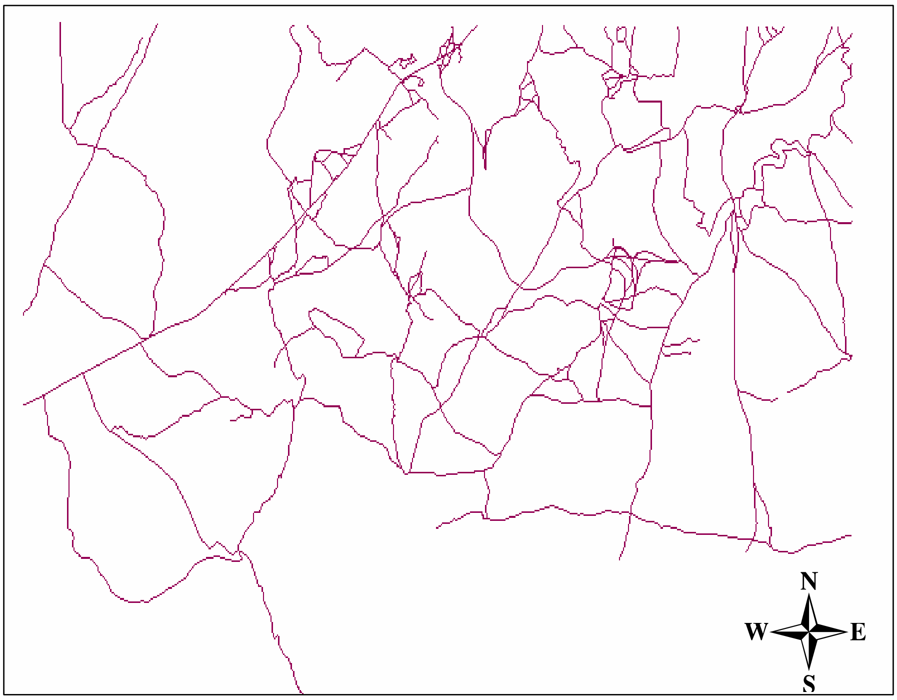

Figure 3.10 (b) The digitized road map of the study area

3.2.7. Existing Transmission Line:

The existing electric transmission line has two ends, at Gölbaşı and Temelli Transformer Centers. The length of the 154 KV Gölbaşı-Temelli Energy Transmission Line is approximately 38 km, involves 112 utility poles and 12 break points. The existing transmission line is represented in Figure 3.11.

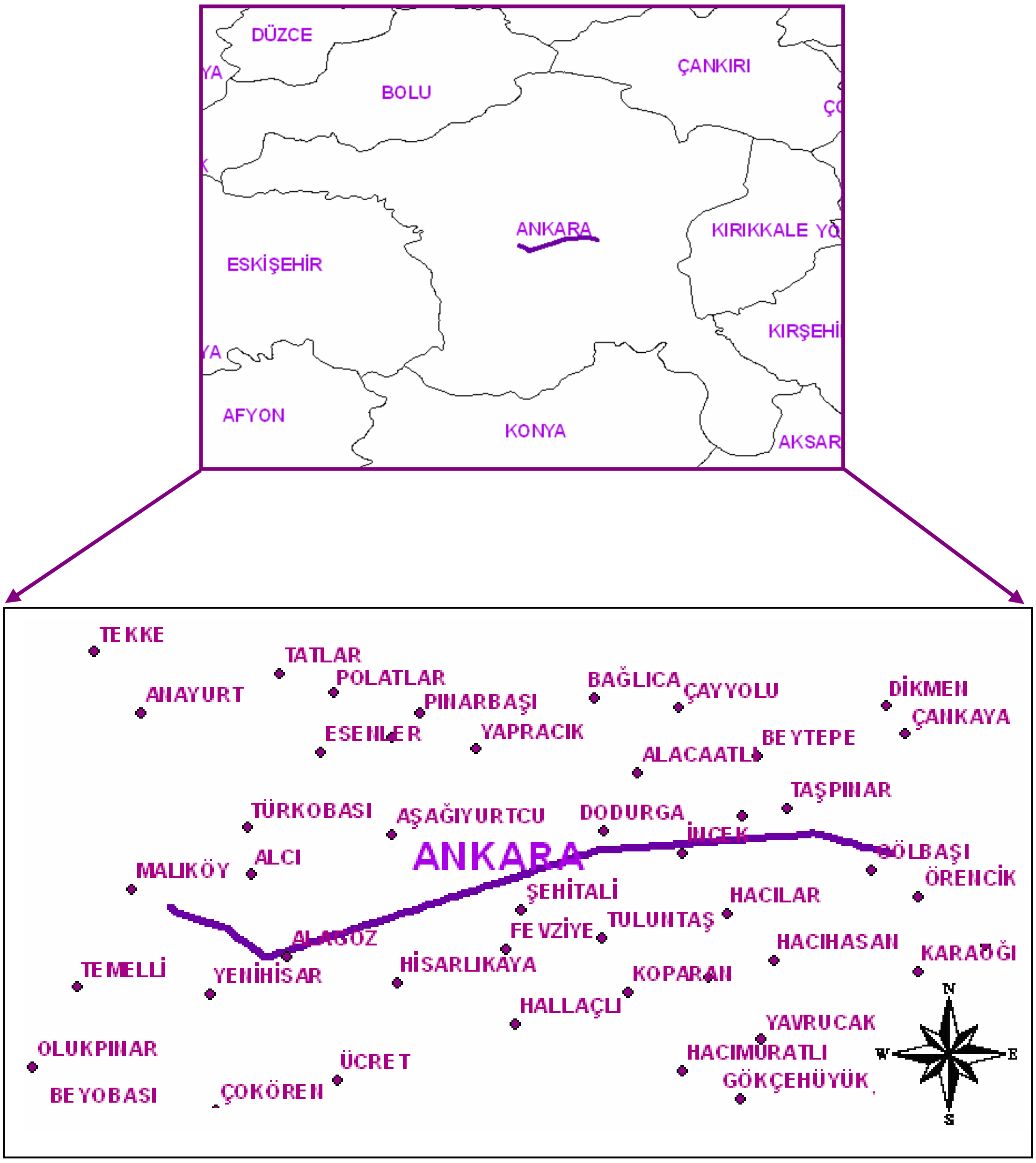

Figure 3.11. 154 kV Gölbaşı-Temelli energy transmission line

3.3. Methodology

The optimum path finding application for electric transmission line is performed within GIS. The input datasets according to the defined criteria by the expert and technical regulations are converted to raster format and the projection and datum information of these datasets are transformed to UTM 3^0 and ED50.

The goal of this application is to acquire more accurate route between these transformer centers by using the actual (spatial) distance within GIS instead of the used bird-eye distance in the available system. The alternative routes could be detected and compared very precisely and rapidly within GIS. Determining the optimum route from Temelli to Gölbaşı transformer centers processes are summarized as follows and also the flowchart of the proposed methodology is given in Figure 3.12.

- Input datasets are converted to raster format, slope and distance information are derived,
- The standardization of datasets for characterizing the relative preferences of these data in the application is performed,
- The integration of MCE and GIS is reviewed as the definition of evaluation criteria and constraints. The creation of the cost map is performed according to the described criteria with different data precision. The proposed system for the electric transmission line route determination between Gölbaşı and Temelli transformer centers are designed by considering two scenarios by varying the weights of the criteria used in the proposed approach. The weights for the criteria for scenario 1 (slope: 0.24, built-up area: 0.23, landuse: 0.1, landuse capability: 0.1, geology: 0.1, road: 0.23) and scenario 2 (slope: 0.1666, built-up area: 0.1666, landuse: 0.1666, landuse capability: 0.1666, geology: 0.1666, road: 0.1666) were determined depending on the expert's knowledge. The importance of each layers is emphasized by the given weight percentages,
- Finally, the optimum route for the electric transmission line is determined by using Euclidian distance and spatial distance. The spatial distance takes into

account 16 directions around the source cell during the distance calculation between two cells.

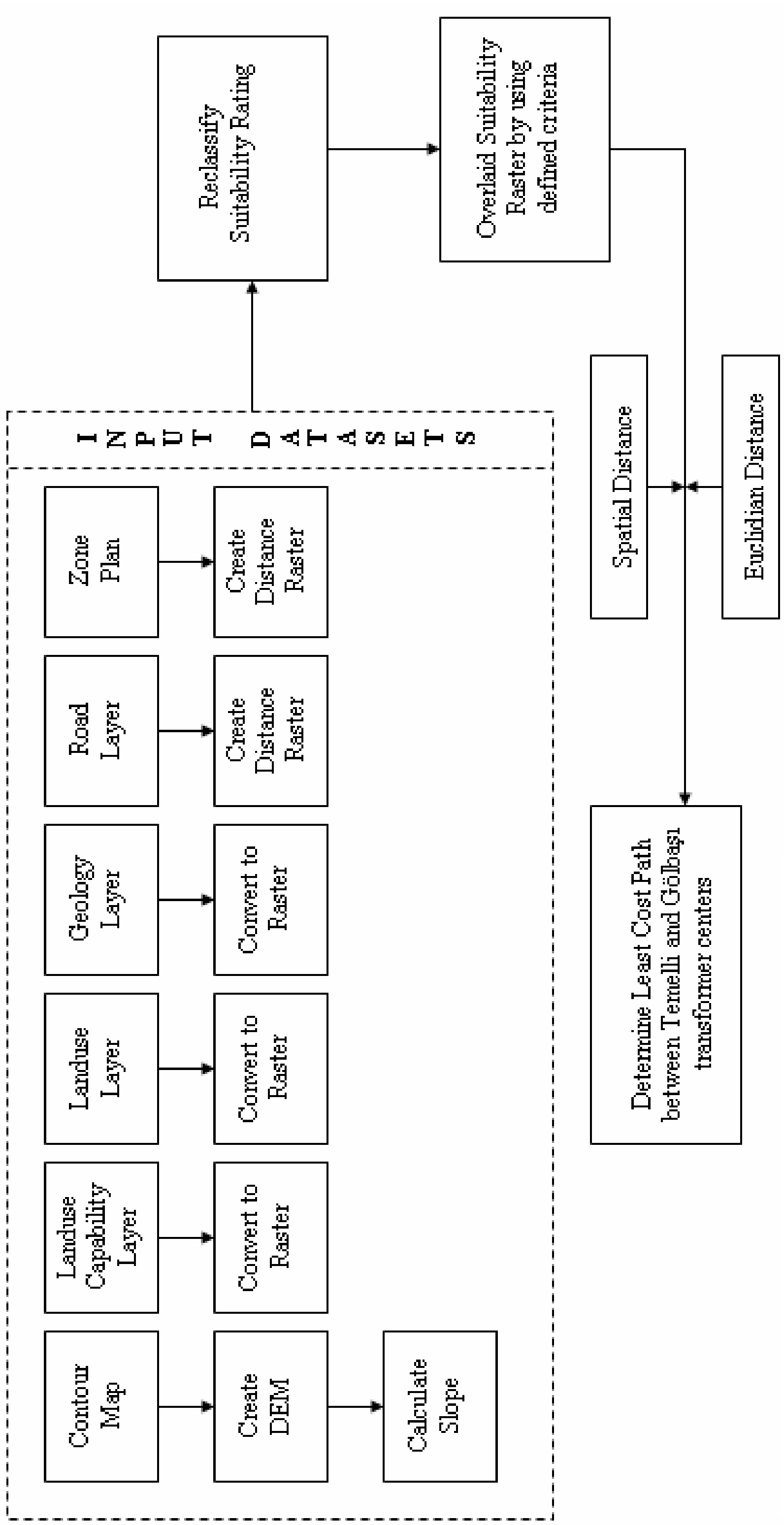

Figure 3.12. The outline of the used methodology

CHAPTER 4

ANALYSIS

The electric transmission between two transformer centers must be designed very accurately in order to save time, cost and productive effort. It is also important in terms of the negative effects of high voltage electricity on the environment and human.

The approach of the available system depending on the process on hardcopy maps causes loss of labor, money and time. In the proposed system, having considered different data layers in digital format can cause saving time, labor and money.

Besides these shortages in the available system, the route planning on the computer provides preventing the high damage of electric transmission lines on environment and human. For instance, a number of helicopters belonging to HGK fell down due to the magnetic area effect of electric transmission lines. The cost of a helicopter is approximately 1 million dollars and there were at least 3 people in this helicopter. TEİAŞ was responsible for loosing of cost and human life.

Optimum route planning can be done by using GIS-based Multicriteria Analysis in a timely, reliable, and cost-effective way. In this implementation, the least cost path is found between the Gölbaşı Transformer Center and Temelli Transformer Center by using two distance calculation methods. First of all, the optimum route is performed by using multicriteria decision analysis in classical GIS application. Secondly, the spatial distance approach related to least cost path calculation is applied for the study. 16 directions around a cell on the raster representation of the terrain are used for describing the network neighbors cells, which are defined as the Rook's, Queen's and Knight's patterns in a game of chess.

4.1. I. Method

As mentioned in Chapter 2, GIS-based Multicriteria decision analysis is used to design the optimum route for evaluating all factors affecting the route determination process according to the expert's knowledge and technical rules.

In order to fulfill the first objective of the study, Temelli-Gölbaşı transmission line is designed by applying the declared steps in Chapter 2. The route is described by minimizing the subjectivity of the expert. The following steps are followed in the application.

- Creation of Grid Layers for all the data used in this application,
- Reclassification of the layers according to the evaluation criteria,
- Generation of source, destination and cost datasets,
- Creation of a thematic cost map,
- Generation of direction datasets
- Performing the shortest path with distance and direction datasets.

4.1.1. Creation of Grid Layers

Raster model is preferred rather than vector model for the optimum route determination for electric transmission lines because of taking into account the movement from the cell to cell not through a finite line. All of the data layers are in vector format but the data are converted into raster to perform the least cost path analysis. Geology map, Landuse map, Landuse capability map, Road map, Contour map and Zone plan are converted from vector to raster as presented in Figures 4.3- 4.6.

The analysis is performed using 10 m. resolution cells. The choice of cell size is important, and the network density, maximum travel cost and processing time should also be considered. The larger the cell size, the greater the boundary errors in every direction. The more accurate route is produced owing to smaller cells.

The elevation layer of the study area that has 90 m and 10 m spatial resolution is shown in Figure 4.1 and Figure 4.2 respectively. The boundary representation of the same region in two layers is indicated for recognizing the differentiation between them.

In addition to cell size, the other special considerations are encountered during the spatial decision analysis process. Data, which is used in the study, should be in the same projection, datum and coordinate systems.

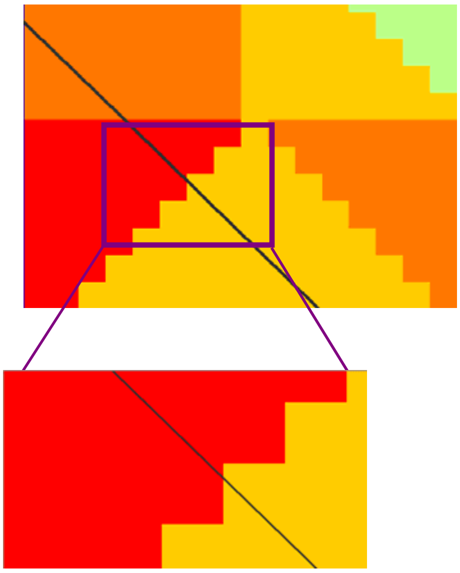

Figure 4.1. The representation of data precision effects on DEM layer (90 m)

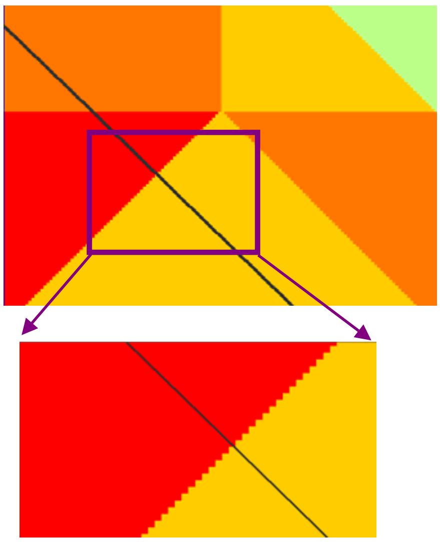

Figure 4.2. The representation of data precision effects on DEM layer (10 m)

4.1.2. Derived Maps:

Spatial analyses are used to derive distance to road map, distance to zone plan map and slope map. Proximity Analysis is a spatial analysis based on analyzing locations of a geographic feature by measuring the distance between the feature and other features in the area. The distance from feature A to feature B may be measured as a straight line.

4.1.2.1. Distance to Road Map:

It is preferable to establish an electric transmission line close to roads for simplifying transportation and decreasing the maintenance of the line. A map is required to display the distance to roads to find the line in areas close to them. The straight line distance can be calculated by Euclidian distance in Spatial tool of ArcMap as shown in Figure 4.3. As moving away from the suitable area for the optimum route, values of the distance to road map increases.

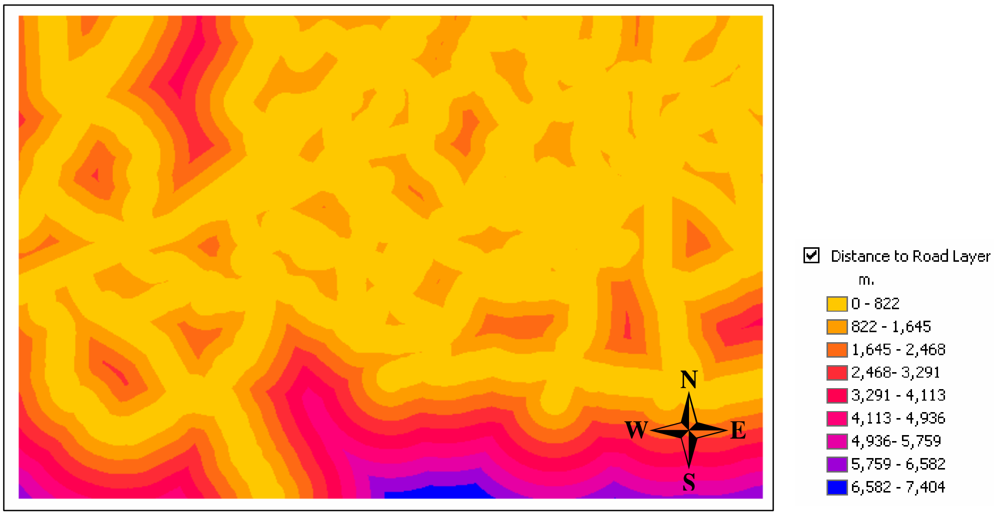

Figure 4.3. Distances to road map

4.1.2.2. Distance to Built-up Area Map:

The site away from existing zone plan is preferable to decrease expropriation cost. The data precision effect is examined by using two different zone plans at different scales. The areas that increase the expropriation cost are clipped according to the expert opinions as seen in Figure 4.4. The high value of the distance to the built-up area map that is created by moving away from the built-up area indicates the most suitable areas for the optimum route. The red areas in Figure 4.5 depict the most suitable area for the electric transmission route in terms of built-up criteria.

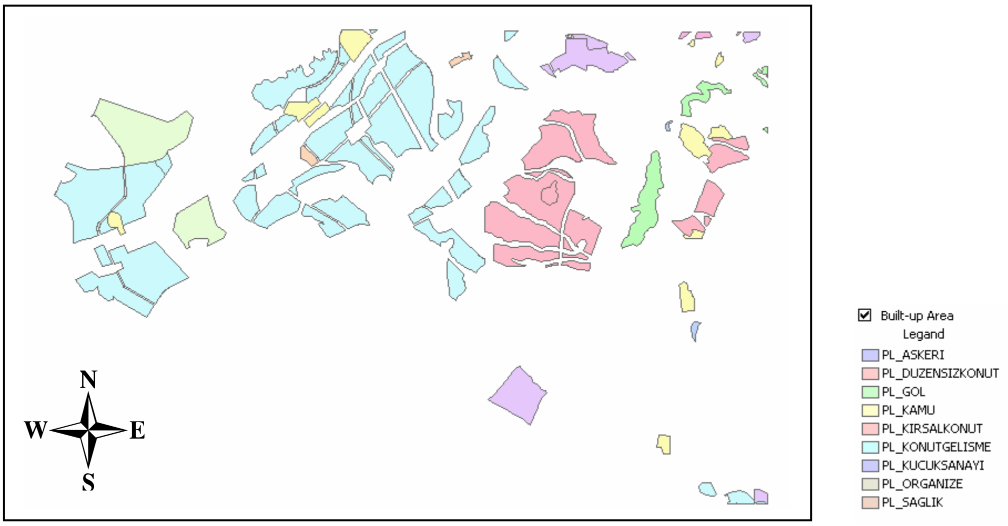

Figure 4.4. Built-up area layer

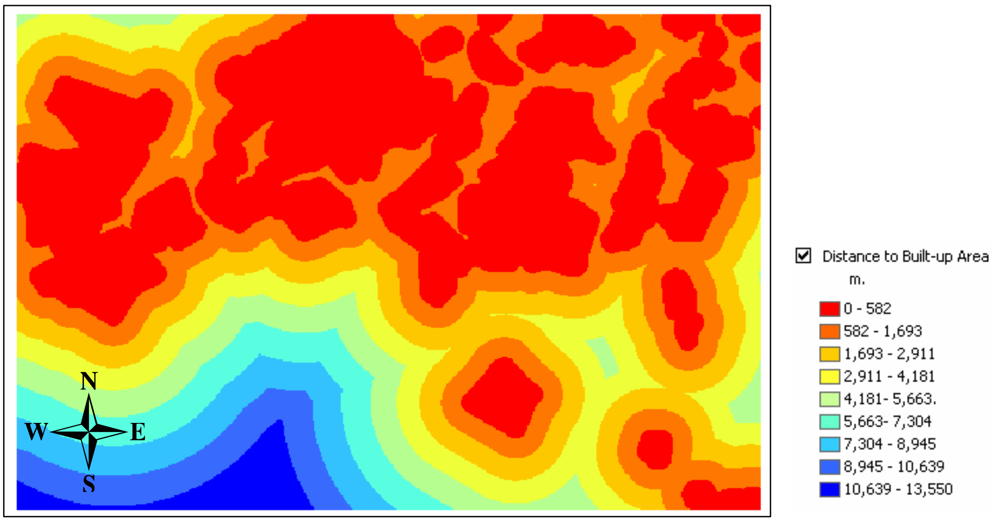

Figure 4.5. Distance to Built-up area map

4.1.2.3. Slope Map:

The flat land is suitable to simplify transportation and decrease maintenance cost for determining the electric transmission line. The established break point on the line depends on this criterion. The slope of the land is taken into consideration to find the suitable areas because of this reason. Two digital elevation models are used to compare the result of two different data precision for this study. The slope maps are acquired from digital elevation model by using PCI Geomatica and ARCGIS software. The slope maps derived from 90 m. DEM and 10 m. DEM are represented in Figure 4.6 and Figure 4.7.

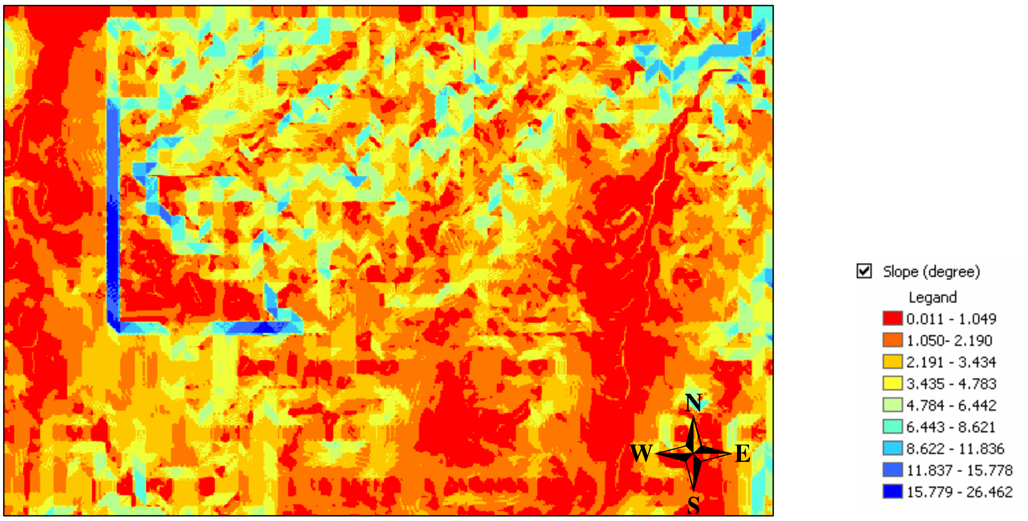

Figure 4.6. Slope layer derived from 10 m DEM

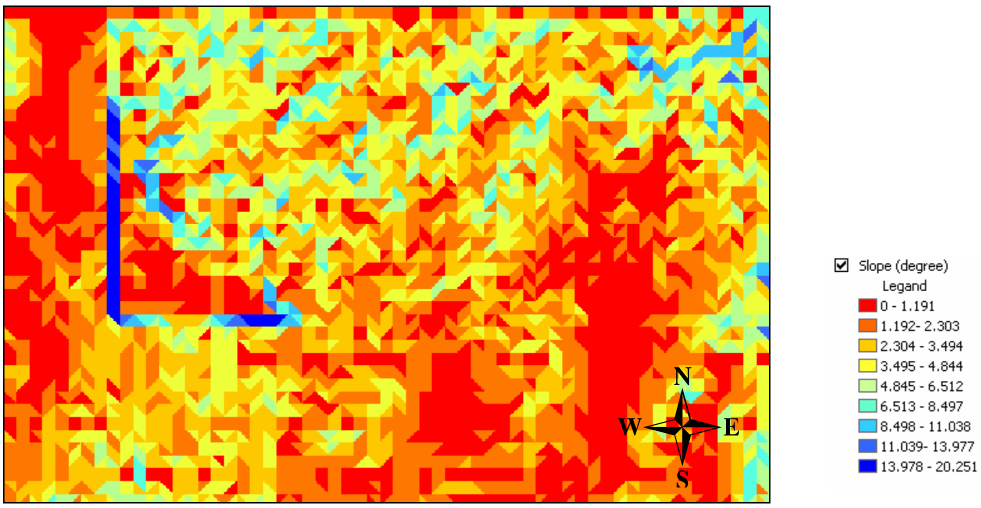

Figure 4.7. Slope layer derived from 90 m DEM

4.1.3 Reclassification of Grid Layers

The reclassification of the input layers is an important step because the relative preferences should be characterized in the computer but it doesn't have any idea of the importance of the layers for the study. It is used to re-assign values in an input layer to create a new raster layer (Esri, 2002). A common scale is used to standardize input datasets. The scale ranges from 1 to 9 values in this application, where 1 indicates high cost and 9 indicates the opposite of 1 for movement. The comparative importance of criteria is evaluated by the expert, in TEİAŞ relative to previous route determination processes in the available system.

4.1.3.1 Reclassification of Slope Layer

In this study, the slope layer is reclassified by standardized values, where 1 expresses the least suitable land and 9 expresses the most suitable land for the electric transmission line route. The reclassification values relating to slope layers are defined according to the expert's opinion in Table 4.1 and Table 4.2. The result of reclassification process concerning the slope layers derived from 90 m. DEM and 10 m. DEM are presented in Figure 4.8 and Figure 4.9.

Table 4.1. Reclassification values for the slope layer (90 m.)

Slope Values	N.V.
0–1.191	9
1.192– 2.303	8
2.304–3.494	7
3.495–4.844	6
4.845–6.512	5
6.513–8.497	4
8.498–11.038	3
11.039–13.977	2
13.978–20.251	1

Table 4.2. Reclassification values for the slope layer (10 m.)

Slope Values	N.V.
0.011–1.049	9
1.050– 2.190	8
2.191–3.434	7
3.435–4.783	6
4.784–6.442	5
6.443–8.621	4
8.622–11.836	3
11.837–15.778	2
15.779–26.462	1

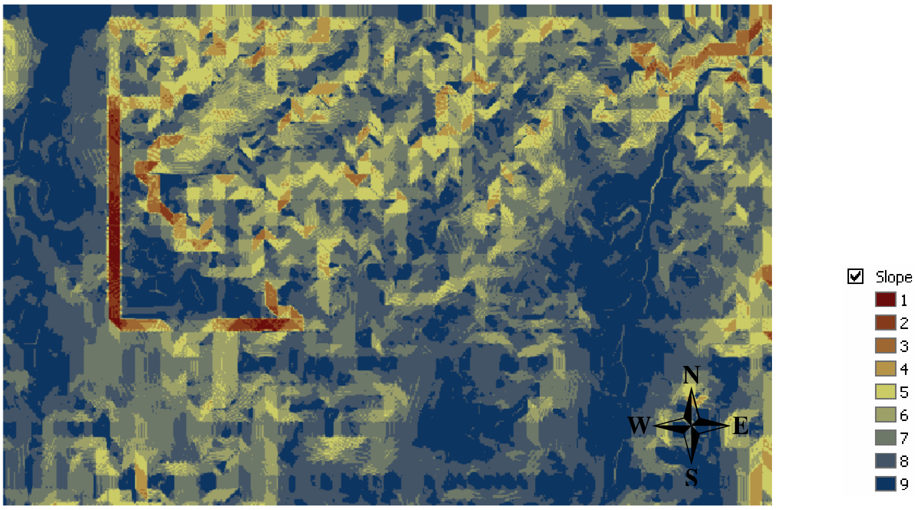

Figure 4.8. Reclassification of the slope layer (10 m.)

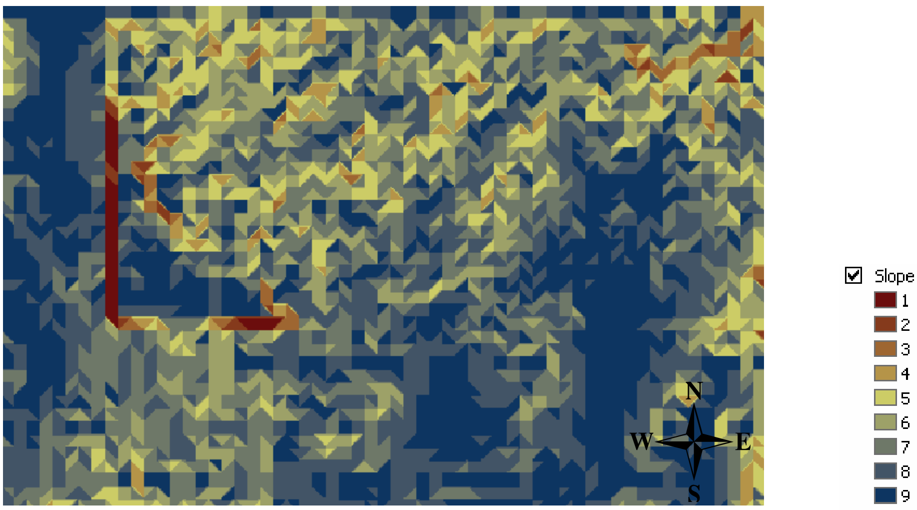

Figure 4.9. Reclassification of the slope layer (90 m.)

4.1.3.2 Reclassification of Distance to Roads Layer

The route should be passed near roads in the study area. The layer is reclassified, giving a value of 1 to areas far from the roads and that of 9 to areas closest to roads. The least suitable areas in terms of the distance to road criterion are reclassified as purple in Figure 4.10. Table 4.3 gives details about assigned new values to distance to roads.

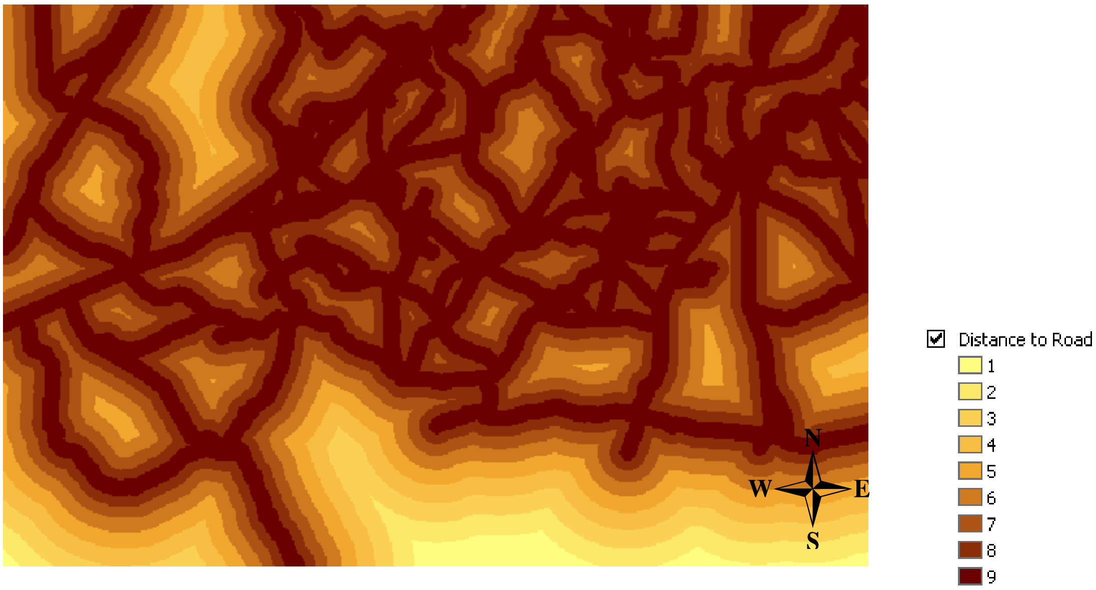

Figure 4.10. Reclassification of distance to road layer

Table 4.3. Reclassification values for the distance to road layer

Distance Values	New Values
0–882	9
883–1.645	8
1.646–2.468	7
2.469–3.291	6
3.292–4.113	5
4.114–4.936	4
4.937–5.759	3
5.760–6.582	2
6.583–7.404	1

4.1.3.3 Reclassification of Distance to the Built-up area Layer

As the distance from the built-up area increases, the most preferable area can be selected for the electric transmission line because of decreasing the expropriation cost. The assigned values are summarized in Table 4.4. The reclassification maps of distance to the built-up area layer in small and large scales are depicted in Figure 4.11 and Figure 4.12.

Table 4.4. Reclassification values for the distance to built-up area layer

Distance Values	New Values
0–582	1
582–1.693	2
1.693–2.911	3
2.911–4.181	4
4.181–5.663	5
5.663–7.304	6
7.304–8.945	7
8.945–10.639	8
10.639–13.550	9

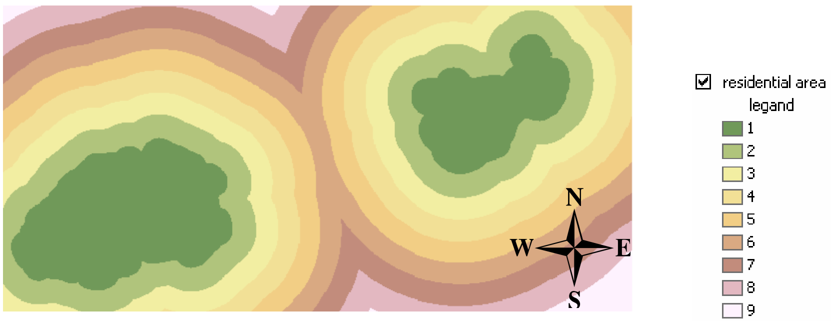

Figure 4.11. Reclassification of distance to built-up area layer at 1/100000 scale.

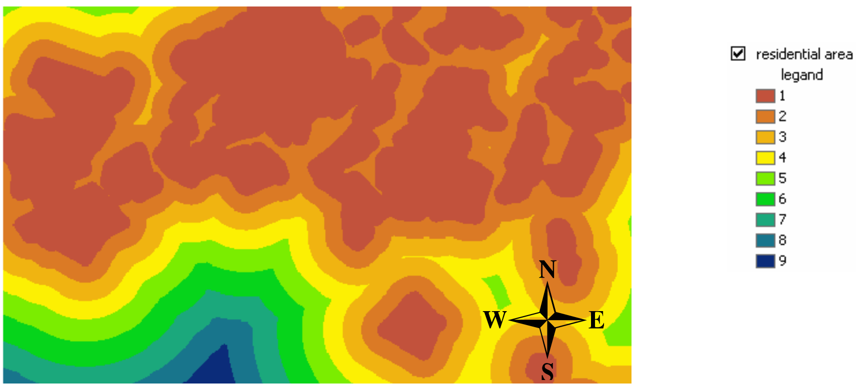

Figure 4.12. Reclassification of distance to built-up area layer at 1/5000 scale.

4.1.3.4 Reclassification of Geology Layer

The optimum route should be designed considering the landslide effect. There are two important factors that affect landslide; geology and slope. The poles belonging to a transmission line may be collapsed due to landslide; the geologic formation affects the maintenance and foundation of electric transmission line. The flish and holocene (recent) classes are masked because these geological formations are younger formations and have less possibility of landslide. The result map is seen in Figure 4.13.

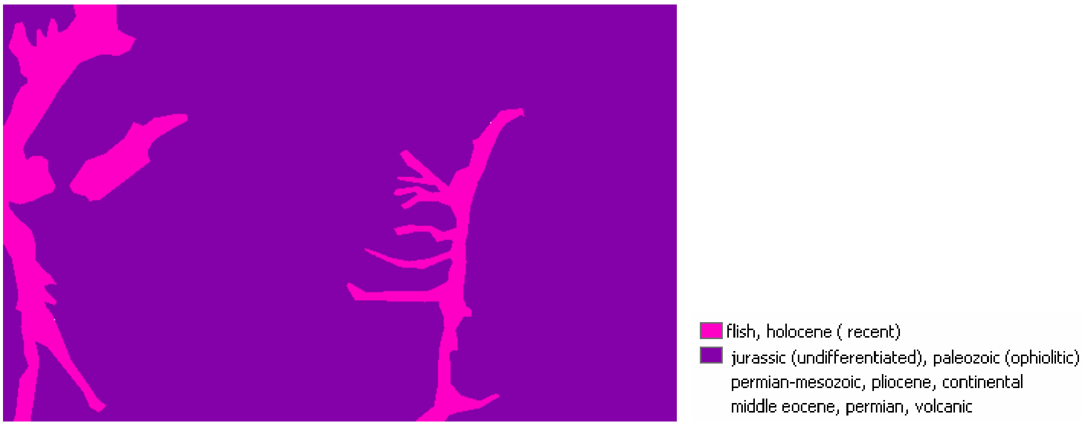

Figure 4.13. Reclassification of geology layer

4.1.3.5 Reclassification of Landuse Layer

The expert is forced to rank the Landuse classes because there isn't any standard in the available system for the route determination between two transformer centers. There are 13 classes for this layer. The layer is standardized by using the expert opinions It is reclassified into 9 classes , where 9 indicates least difficult classes and 1 indicates most difficult areas in terms of expropriation issue for establishing the route. The reclassification values according to the expert are shown in Table 4.5. and the result of the process for this layer is seen in Figure 4.14.

Table 4.5. Reclassification values for landuse layer

Landuse Levels	New Values
Grounds (Bare)	9
Grounds (Watery)	8
Vineyard (Bare)	7
Brake	6
Agricultural Area (Fallowing land)	5
Meadow	4
Forestry	3
Agricultural Area (Watery)	2
Agricultural Area (Watery and Insufficient)	1
Feeding Ground	1

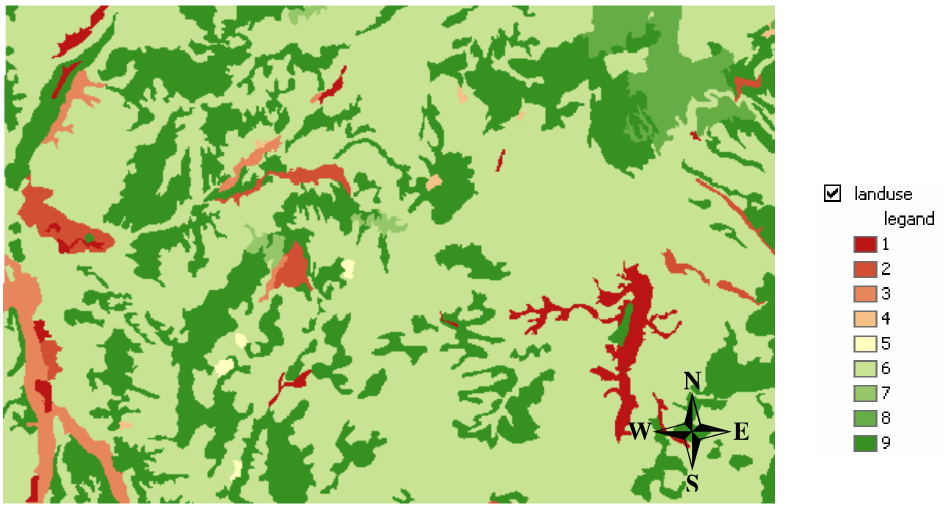

Figure 4.14. Reclassification of landuse layer

4.1.3.6 Reclassification of Landuse Capability Layer

The values between 1 and 9 are given in order to standardize the layer, where 9 indicates higher vulnerability and 1 indicates low vulnerability depending on the layer's class values. Table 4.6 presents the standardization values relating to landuse capability criteria. The most suitable sites are denoted by pink in Figure 4.15.

Table 4.6. Reclassification values for landuse capability layer

Landuse Capability Classess	New Values
I	1
II	2
III	3
IV	4
V	5
VI	6
VII	7
VIII	8

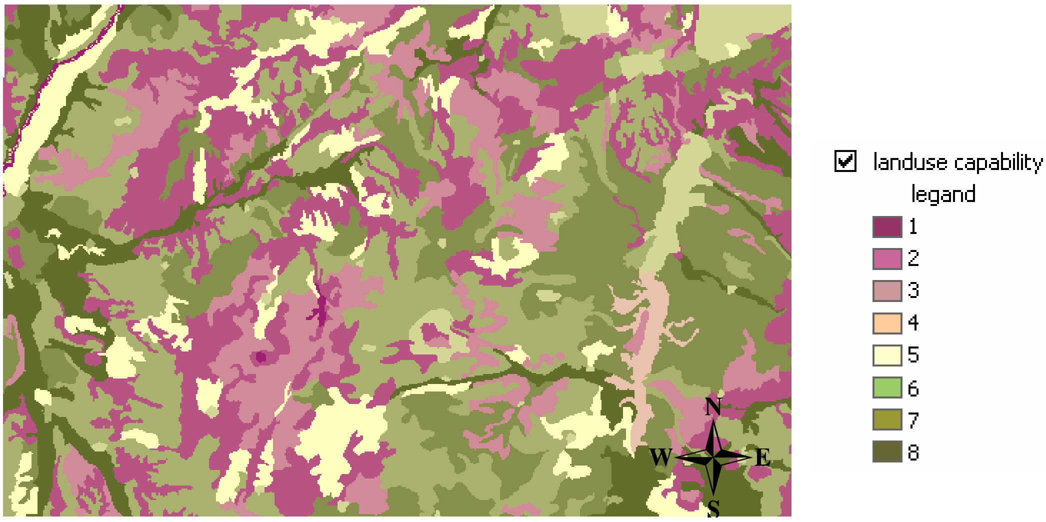

Figure 4.15. Reclassification of landuse capability layer

4.1.4. Generation of Source and Destination Datasets

Two transformer centers in Gölbaşı and Temelli are placed in the study area. Temelli transformer center is determined as the departure point of this electric transmission line and Gölbaşı transformer center is decided as the destination point of the line. Two point layers are created as departure and destination for these transformer centers as presented in Figure 4.16.

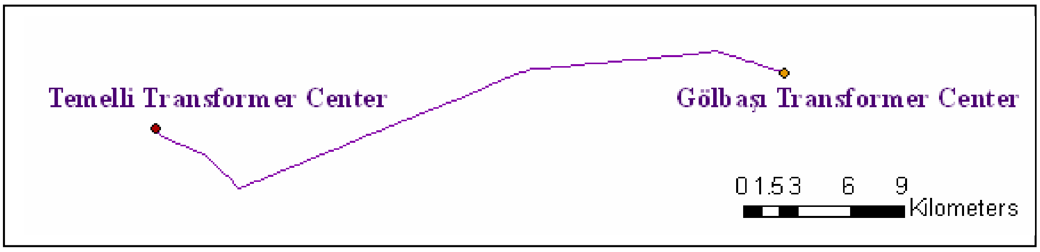

Figure 4.16. The departure and destination points layer

4.1.5. Generation of Cost Dataset

GIS based Multicriteria Decision Analysis is used to choose the most ideal alternative. Each determined criterion is assessed by using Ranking Method that is one of the Weighted Linear Combination method. Fundamentally, the optimum route is analyzed by applying the main rules in terms of decreasing environmental and social effects besides economical effect of the electric transmission line in this study, such as expropriation, foundation and maintenance costs.

In order to find the optimum route, all data sets must be combined after standardizing all input and derived datasets in a common scale. Higher values in standardized datasets are considered as the suitable locations for designing the route. The reclassified datasets are weighted to reflect the importance of the criteria according to each other for this application. They must sum up to 1. Higher the influence, more weight percentage is used for the optimum route determination. The final product is used to get overall evaluation according to these criteria.

There are two different weight ratios that demonstrate the comparison of the influences of criteria by determining the costs in the study. Weight values are selected by considering the previous applications performed by the experts. Every step in the study is performed for two different weighting approximations.

Scenario 1

The most important issue is to decrease costs associated with an electric transmission line. All the criteria affect expropriation, foundation and maintenance costs, but some of them, slope, road and built-up area, are more effective in determining these costs. The scenario is intended to determine the optimum route for the electric transmission line as performed in the available system. Weight percentages are selected by considering the previous study applications performed by the experts as defined in Table 4.8. Cost maps are created one by one for the slope and built-up area layers that have different precisions concerning required spatial resolution and scale as seen in Figure 4.17.

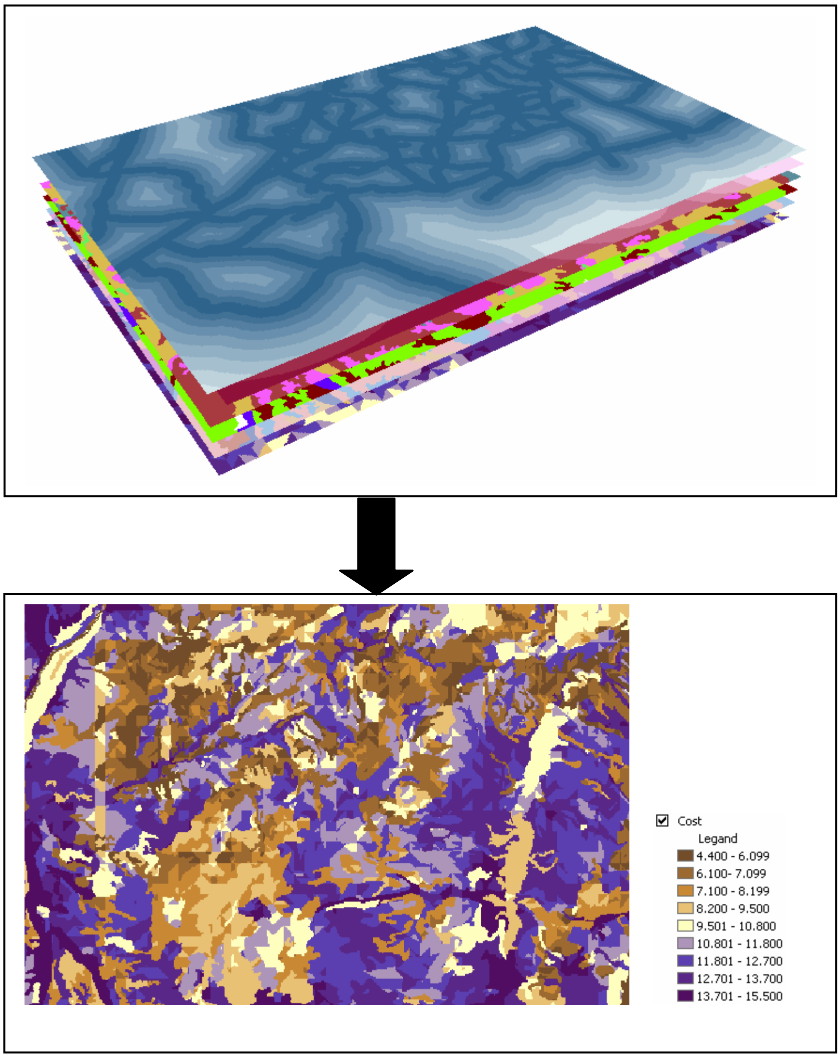

Figure 4.17. The cost map for scenario 1

Table 4.7. Weighting percentages for scenario 1

Criterion	Weighting Percentage
Slope	0.24
Built-up Area	0.23
Landuse	0.1
Landuse Capability	0.1
Geology	0.1
Road	0.23

Scenario 2

The second scenario is designed to compare the results of two different weighting approximations and the influences of criteria on determination of the optimum route for electric transmission lines in terms of expropriation, foundation and maintenance costs. Weighting percentages are selected as the same value, which makes the sum equal to 1 presented in Table 4.8. Cost maps are created separately for the slope layers that have 10 m and 90 m spatial resolution and the built-up area layers that are at 1/100000 and 1/1000 scales. The cost map that is generated by using the slope layer with low spatial resolution and built-up area in small scale is presented in Figure 4.18.

Table 4.8. Weighting percentages for scenario 2

Criterion	Weighting Percentage
Slope	0.1666
Built-up Area	0.1666
Landuse	0.1666
Landuse Capability	0.1666
Geology	0.1666
Road	0.1666

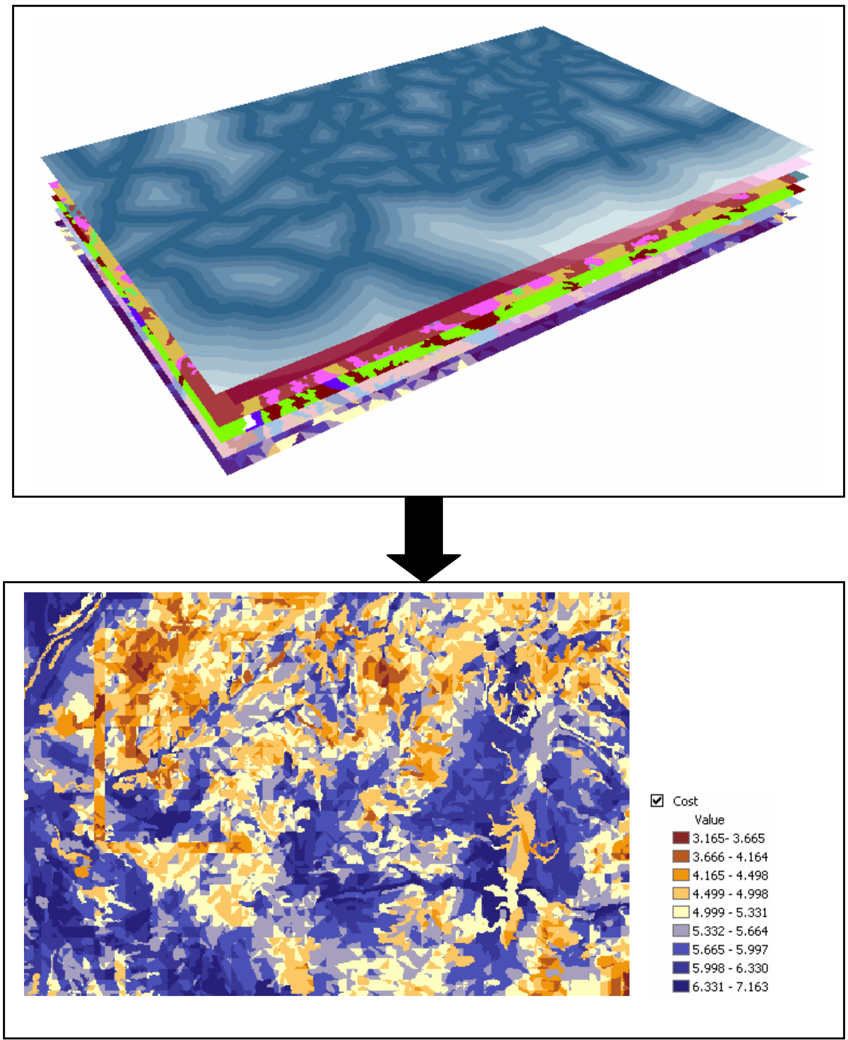

Figure 4.18. The cost map for scenario 2

4.1.6. Generation of Direction and Distance Datasets

Cost distance is used to estimate the minimum cost for designing the optimum electric transmission route. The distance finds the least accumulated cost from each cell to the nearest one (Esri, 2002). The distance to the source point is represented as every cell value in the created distance map. The generated distance map by using built-up area layer in small scale and slope layer that derived from 90 m. DEM is depicted in Figure 4.19.

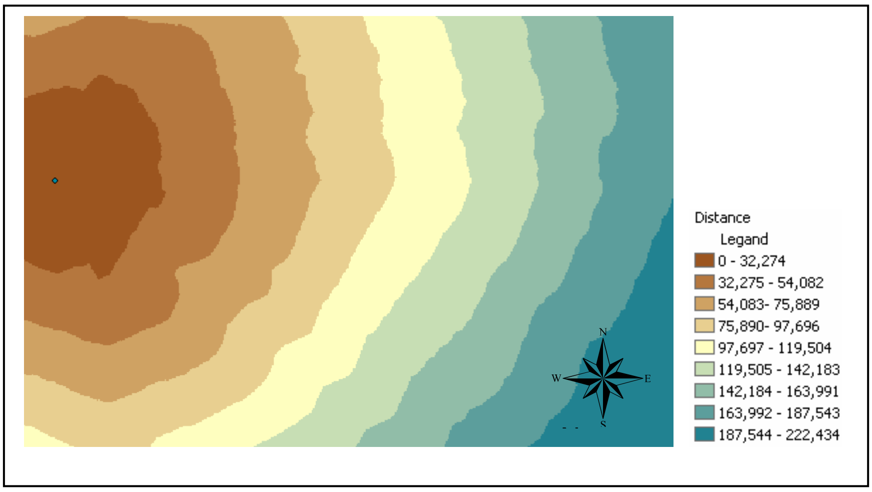

Figure 4.19. The distance map for scenario 1

Every cell in the direction map is expressed with a code that represents the direction of the nearest source point (Esri, 2002). The codes are defined in Table 4.10. The directions of all cells in the map are calculated in relation to the source point. The directions of the source cell that are used in ArcMap are presented in Figure 4.20. These directions are the same as Queen's pattern in a game of chess as mentioned in Chapter 2. The created direction map regarding the percentages in Table 4.10 is shown in Figure 4.21.

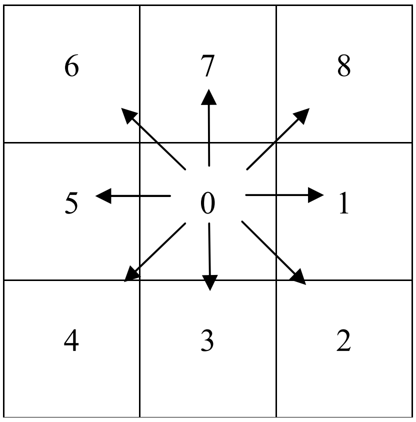

Figure 4.20. Direction codes in ArcMap

Table 4.9. Direction codes in ArcMap

Direction Code	Direction
1	East
2	Southeast
3	South
4	Southwest
5	West
6	Northwest
7	North
8	Northeast

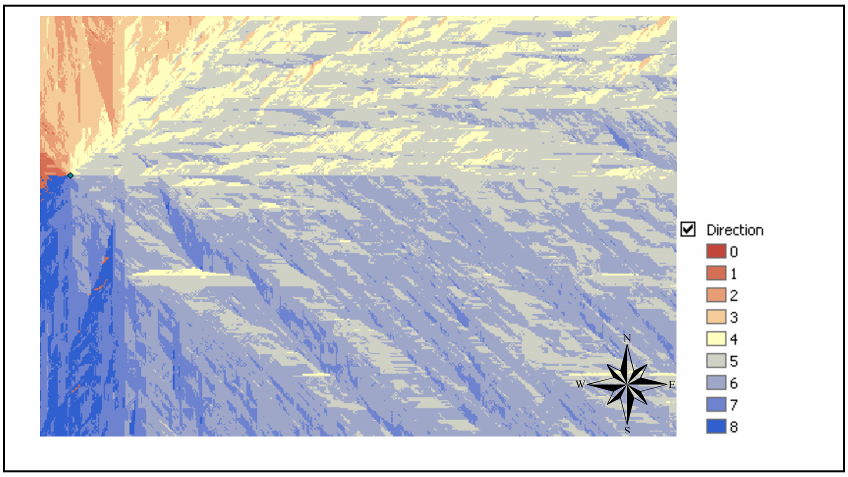

Figure 4.21. The direction map for scenario 1

4.1.6. Generation of Alternative Routes

The proposed transmission line is affected by topographic structure, productive power of the soil, land use, geologic formation, easement of access and built up area for this application. The route should be the least cost path as far as possible taking into account the impact on natural environment, the influence on local communities, and the technical regulations.

The distance and direction maps are utilized to find the least cost path between two transformer centers, Gölbaşı and Temelli. Data that have different precision are used to evaluate the influences of used data for proposing the new routes in this study. The comparison is realized by utilizing the slope and built-up area layers.

Scenario 1

First of all, the optimum route is specified by the slope and built-up area that have less precision as shown in Figure 4.22. The main factors are topographic structure, road and built up area for this scenario given in Table 4.9.

The existing transmission line is denoted by purple line and red line indicates the alternative route between these transformer centers. The length of the alternative route is 36.238 km. There are definite differences between two lines in terms of length, break points and direction. The alternative route has a number of break points but the alternative route is designed for improving the preliminary work in the available system. A corridor that is 500 m. width around the alternative route should be defined for acquiring the final route between two transformer centers. Thereby, the break points on the alternative route as presented by red line in Figure 4.22 can be designed according to the defined corridor around the routes

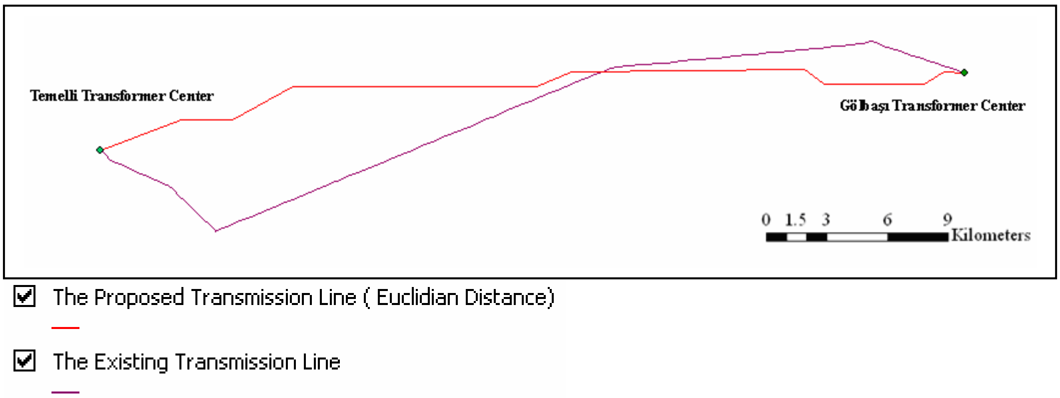

Figure 4.22. The alternative route for scenario1 by Euclidian distance computation (Built-up area layer at 1/100000 scale and slope layer that derived from 90 m. DEM)

Secondly, the alternative route is identified by using the slope layer that is derived from 10 m. DEM and built-up area in large scale as presented in Figure 4.29.

The influence of data precision to the route determination is examined by using these data. There is not much more difference concerning the direction and length of the routes that is proposed, but break points on the second route for scenario 1 are less than the first determined route.

The proposed and existing transmission lines are denoted by the same color lines, red and purple in Figure 4.23. The length of the alternative route is 35.759 km.

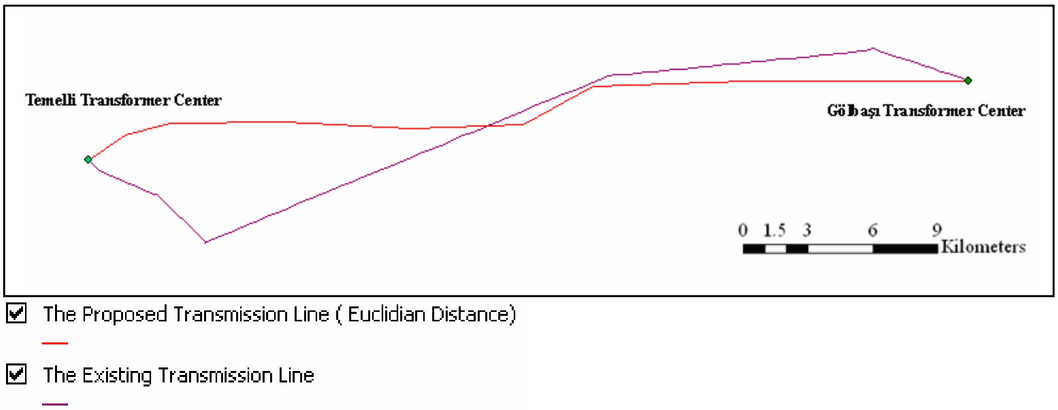

Figure 4.23. The alternative route for scenario 1 by Euclidian distance computation (Built-up area layer at 1/100000 scale and slope layer that derived from 10 m. DEM)

Scenario 2

In order to compare the results of routes that are found by using different weighting values, the impact of all specified criteria on the route determination is selected equal to each other for this scenario.

The proposed and existing transmission lines are denoted by the same colors, red and purple as in case of scenario 1 in Figure 4.24. There are dissimilarities on the beginning part of the new route concerning break points. The length of the route is 36.307 km.

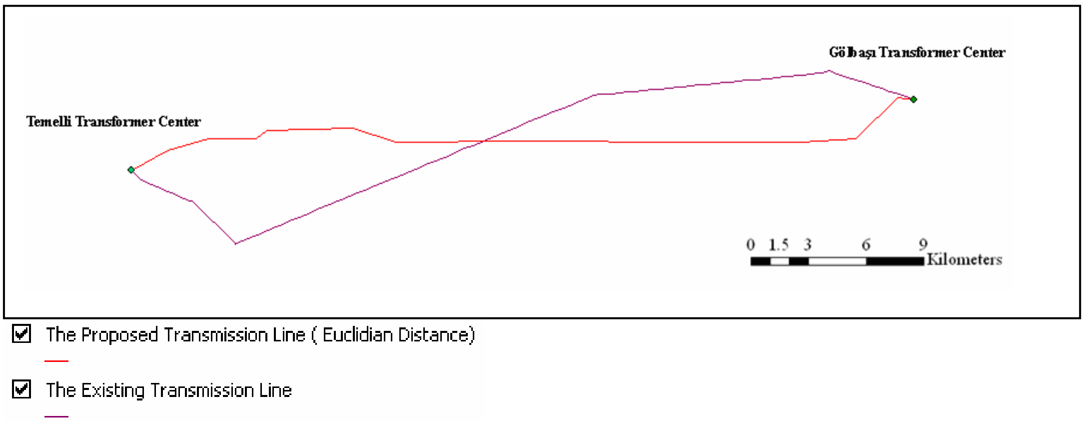

Figure 4.24. The alternative route for scenario 2 by Euclidian distance computation (Built-up area layer at 1/100000 scale and slope layer that derived from 90 m. DEM)

The second route is proposed by considering the same weight as it was done in scenario 1. The length of the proposed transmission line is less than the prior route for this scenario, 36.575 km but the difference is not much as in scenario 1 as shown in Figure 4.25.

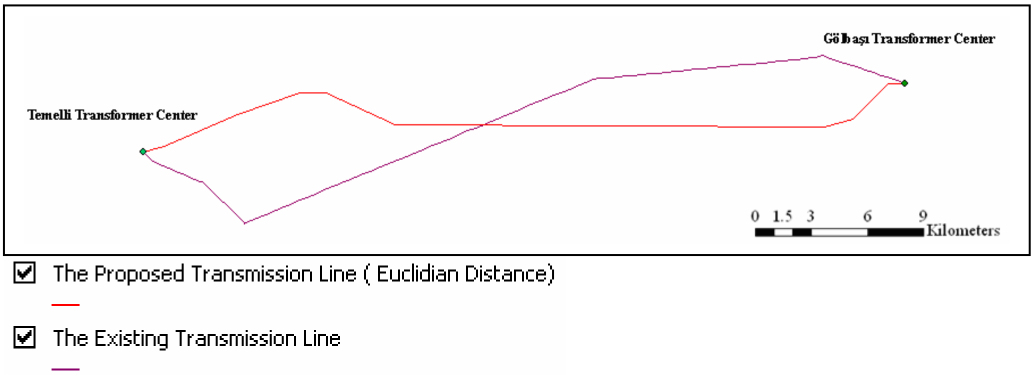

Figure 4.25. The least cost path for scenario 2 by Euclidian distance computation (Built-up area layer at 1/1000 scale and slope layer that have 10 m. spatial resolution)

The optimum route results are obtained to improve the available system by using defined criteria, weighting percentage (scenario 1 and scenario 2), and data that are in different data precision. The alternative routes are compared concerning the length of the routes as summarized in Table 4.10.

Table 4.10. The comparison of alternative routes in terms of their lengths (computed by Euclidian distance)

Scenarios	Routes	Length
Scenario 1	Proposed Transmission Line 1	36.238 km
	Proposed Transmission Line 2	35.759 km
Scenario 2	Proposed Transmission Line 1	36.307 km
	Proposed Transmission Line 2	36.575 km
	Existing Transmission Line	38.093 km

4.2. II. Method

The alternative route is determined using the spatial distance between cells on the raster representation of the study area. The calculation of path travel distances by the Euclidian distance computation is presented in Figure 4.26. The distance between two given cells is called the spatial distance, which is defined as the distance between the centers of these two cells on the terrain surface, to calculate the anisotropic accumulated costs from one cell to another.

The route from Temelli transformer center to Gölbaşı transformer center is also determined by using the spatial distance between these point features. The spatial distance approximation uses 5x5 pixel window Rook's, Queen's and Knight's patterns as described in Chapter 2 and it is presented in Figure 4.27. The spatial distance do not always equal to cell width, which is the case in Euclidean distance computation. It varies with changing direction and slope. The accuracy of the route from a source node to a destination node is better obtained by the spatial distance, and it can be called as actual distance taking into account small slope angle changes between cells.

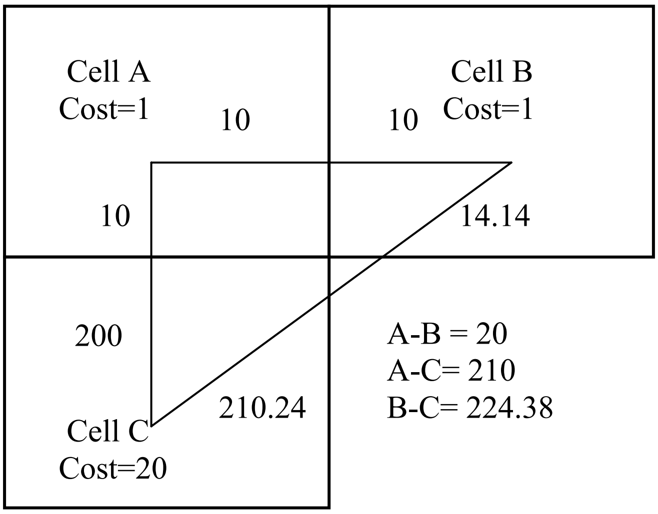

Figure 4.26. The distance calculation between cells in ARCGIS software.

	P_{13} 1000		P_{14} 1002	
P_9 1018	P_1 1000	P_2 998	P_3 1012	P_{10} 1100
	P_4 1013	0 1000	P_5 1020	
P_{11} 1022	P_6 999	P_7 1010	P_8 1011	P_{12} 999
	P_{15} 1008		P_{16} 1006	

Rook's pattern : 2,4,5,7

Queen's pattern : 1,3,6,8

Knight's pattern : 9,10,11,12,13,14,15,16

Figure 4.27. The 5x5 pixel window of DEM layer

The difference between the spatial distance and Euclidean distance are denoted in Table 4.11 and Table 4.12. It is seen from these tables that the spatial resolution of DEM data is the effective factor for the computation methods.

Table 4.11. The spatial distances between the pixels where the elevations are given in Figure 3.3 (10 m)

Source Pixel	Destination Pixel	Spatial Distance	Euclidian Distance	Formula
P_2	P_1	10.19 m.	10 m.	1
P_2	P_8	30.74 m.	22,36 m.	3
P_2	P_6	22.38 m.	22,36 m.	3
P_2	P_{14}	14.69 m.	14.14 m.	2

Table 4.12. The spatial distances between where the elevations are given in Figure 3.4 (90 m)

Source Pixel	Destination Pixel	Spatial Distance	Euclidian Distance	Formula
P_2	P_1	90.02 m.	127.28 m.	1
P_2	P_8	201.66 m.	201.25 m.	3
P_2	P_6	201.25 m.	201.25 m.	3
P_2	P_{14}	127.34 m.	127.28 m.	2

The processes of this application are performed by the spatial distance code that is written with Matlab. The code is given in Appendix and the steps of this part of the study are summarized in following sections.

4.2.1 Input Data Step:

DEM and the acquired cost raster map by landuse, landuse capability, erosion, road and built-up area layers are input datasets. The cost raster map is carried out for scenario 1 and scenario 2, the slope layer with high and low spatial resolutions and built-up area in large and small scales. In this study, data layers are prepared in ArcGIS in order to acquire the cost maps as mentioned before.

The results of spatial analysis by ARCGIS are in 32-bit. They are converted into 16-bit for performing in Matlab.

4.2.2. Programming in Matlab Step:

The least cost path between Gölbaşı and Temelli transformer centers by using the spatial distance formula is found according to defined criteria and constraints. The least cost path program by using spatial distance is written in Matlab.

As the algorithm proceeds, the least cost path is calculated from the start node to the end node. The distances associated with the start node cell in the raster grid are computed along 16 directions, Rock's, Queen's, and Knight's patterns. The computed distances are kept in an array. The node which has the minimum distance in the array is marked as an element of the proposed shortest path. The algorithm starts searching for determining nodes, the elements of the route from the start node to the end node, which has the minimum distance according to the neighborhood cells.

The least cost path algorithm considering the spatial distance must be optimized by using distance and direction arrays. The optimum route determination by the actual distance is executed by order of 2 times for each array.

The result layers that are acquired by the least cost path finding program taking into account the spatial distance are converted into 32 bit for comparing the results that are carried out by Euclidian distance computation. The least cost paths between two transformer centers by spatial distance are imported to ARCGIS for displaying the differences between two methods.

As the program runs, the cells that have the minimum spatial distance are written as an element of the least cost path from the source cell to the destination cell. The elements of the proposed path by using the spatial distances from a source point to a destination point on DEM layer are presented as straw colored cell in Figure 4.28.

16 directions around s node are taken into account for finding the optimum route between s and d nodes in Figure 4.28.

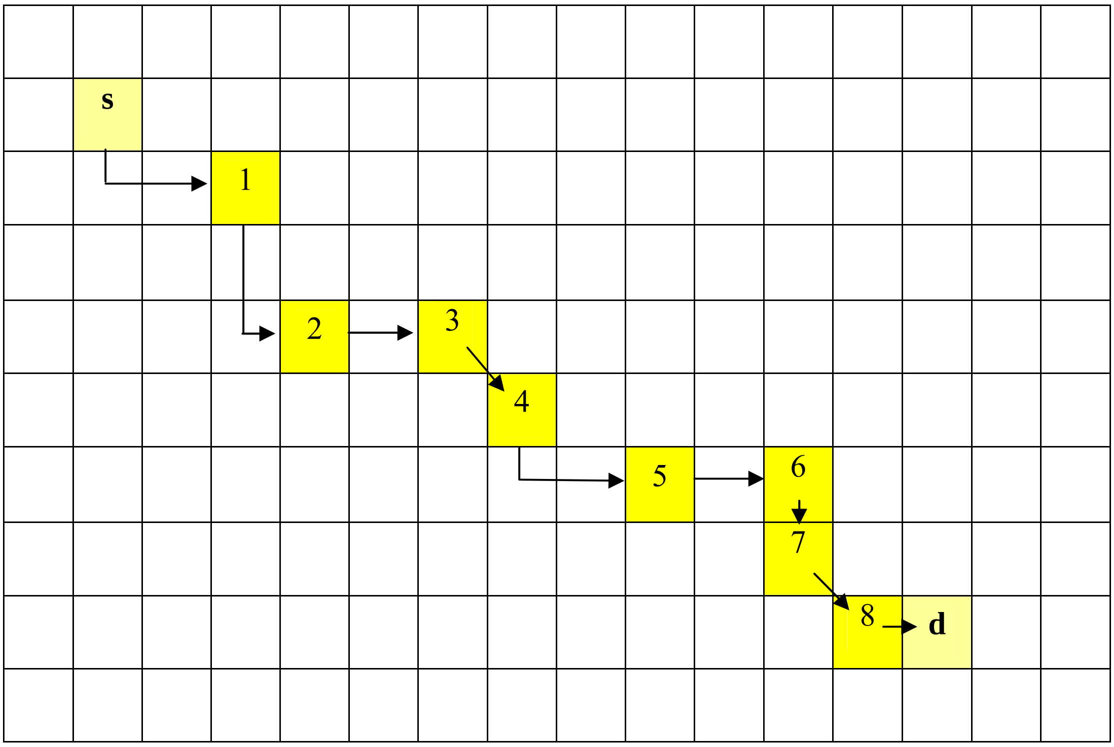

Figure 4.28. The proposed path that is found by using spatial distances from a source node to a destination node on DEM layer.

Scenario 1

The path between two transformer centers for electric transmission line is planned as the optimum route that is close to roads and far from built up and hilly areas. It is also passed through the suitable locations on the basis of landuse, landslide and landuse capability. In Scenario 1, the topographic structure, road and built-up area factor are considered as the main criteria for the route determination from Temelli transformer center to Gölbaşı transformer center.

The red and purple lines in Figure 4.29 are used to represent the alternative route and the existing transmission line between the transformer centers. The length of the alternative route is shorter than that of the existing transmission line. However there are more break points than the existing transmission line.

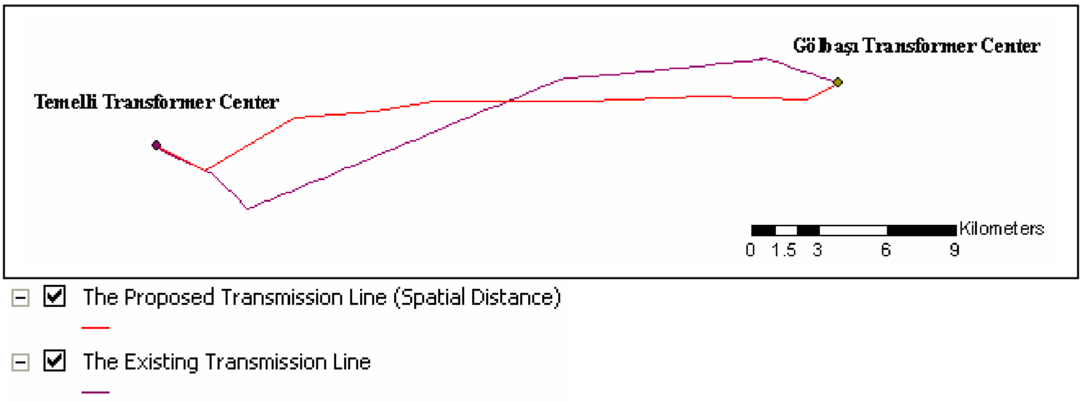

Figure 4.29. The alternative route for scenario 1 by the spatial distance computation (Built-up area layer in large scale and slope layer that derived from 90 m. SRTM DEM)

Secondly, the alternative route is identified by increasing data precision for the slope and built-up area layers. The proposed and existing transmission lines are denoted by the same color lines, red and purple in Figure 4.30. There are much more differences regarding the direction, the number of break points and the length of the routes between two routes. If the alternative routes in Scenario 1 and Scenario 2 are compared, break points on the second scenario are less than the first one because of the pixel size of the layers.

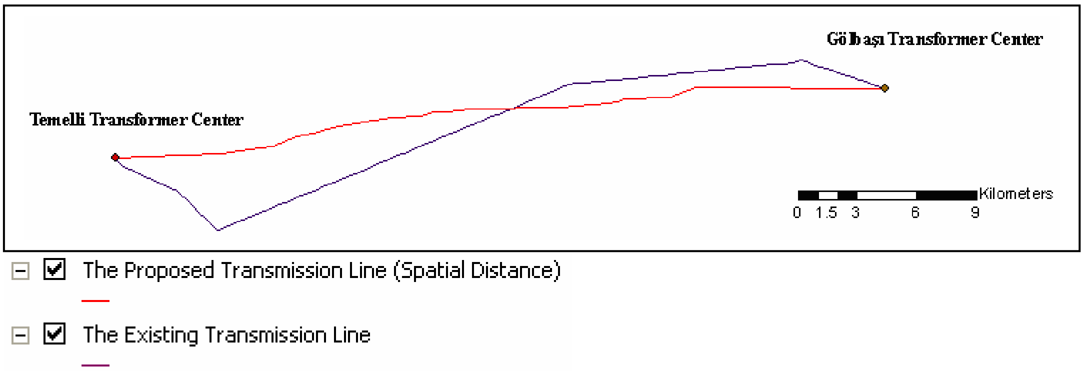

Figure 4.30. The alternative route for scenario 1 by the spatial distance computation (Built-up area layer in small scale and slope layer that derived from 10 m. DEM)

Scenario 2

In order to compare the results of routes that are found by using different weighting values, the impact of all specified criteria on the route determination is selected as equal to each other for this scenario.

The proposed and existing transmission lines are denoted by the same color lines as is in the case with scenario 1 and scenario 2 in Figure 4.31 and Figure 4.32. The influence of data precision in this study is perceived clearly by using the spatial distance approximation in Scenario 2. The lengths of the routes are summarized in Table 4.15.

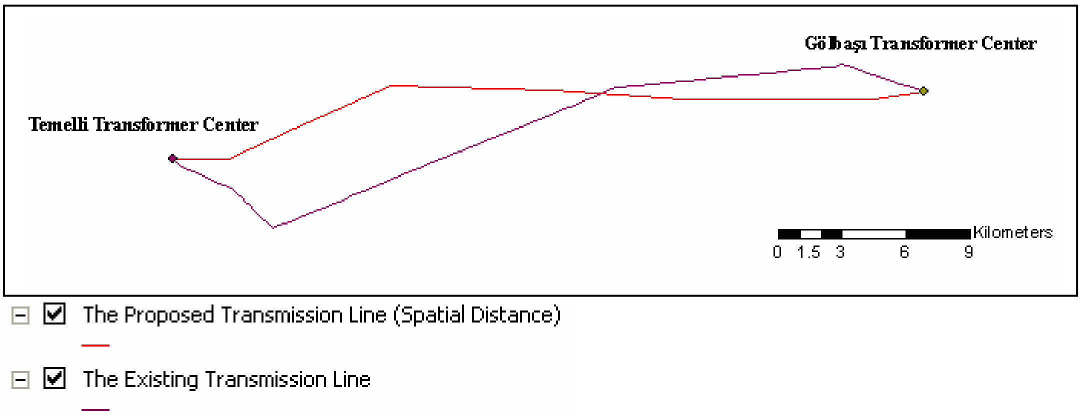

Figure 4.31. The alternative route for scenario 2 by the spatial distance computation (Built-up area layer in large scale and slope layer that derived from 10 m. DEM)

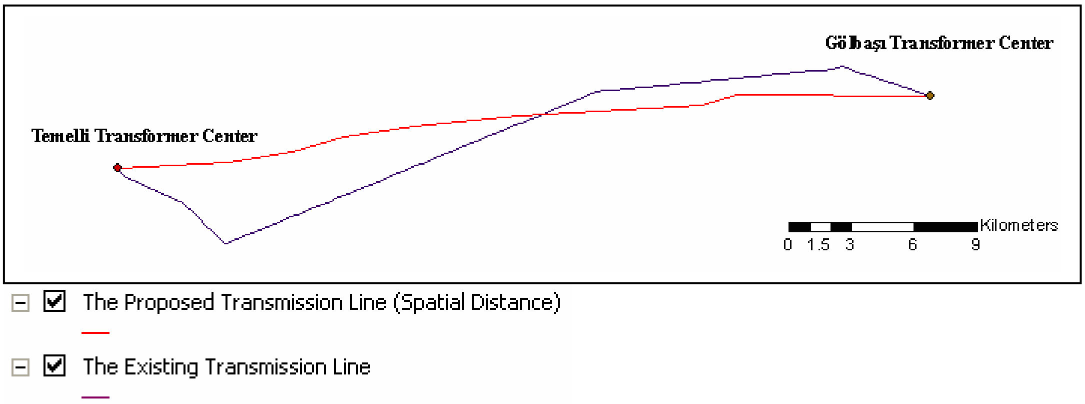

Figure 4.32. The alternative route for scenario 2 by the spatial distance computation (Built-up area layer in small scale and slope layer that derived from 10 m. DEM)

Table 4.13. The comparison of alternative routes in terms of their lengths (computed by the spatial distance)

Scenarios	Routes	Length
Scenario 1	Proposed Transmission Line 1	36.490 km
	Proposed Transmission Line 2	35.520 km
Scenario 2	Proposed Transmission Line 1	35.950 km
	Proposed Transmission Line 2	35.360 km
	Existing Transmission Line	38.093 km

CHAPTER 5

THE RESULTS AND DISCUSSIONS

The determination of least cost path is one of the oldest problems in network analysis. The shortest path finding between two transformer centers is the crucial for electric energy sector like other utility sectors in a timely, reliable, and cost-effective.

Raster-based or vector-based GIS can be used to identify the optimum route between two point features on the terrain. It depends on the preference of users but there are some advantages and disadvantages for both of them. The raster-based GIS is used in this study. Every cell in a raster map layer represents an attribute being owned by this cell on the terrain.

In general, the path from one cell to another is determined by Euclidian distance in raster-based GIS. The influence of distance calculation method on the route between two transformer centers is investigated in this study. The actual or spatial distance between these transformer centers is compared with the Euclidian distances.

The used criteria and constraints for the available route determination method for electric transmission line are evaluated by the experts from TEİAŞ. The requirements associated with the optimum route determination process are described according to the results of the user requirement survey and technical regulation in TEİAŞ. The data layers used in this study are defined by considering topographic structure, productive power of the soil, land use, soil erosion, easement of access and built up area for this application.

The raster-based data layers are constructed for both of the spatial distance and the used Euclidian distance in Spatial Tool of ArcMap. The layers can be in different measurement systems (slope is in degrees and road in meters.) so they cannot be compared relative to the others. The standardization values of the raster-based data layers are assessed by expert for characterizing the relative preferences in the application.

The combination of identified criteria that affect the route determination according to the expert and technical regulation is realized by two approaches by weighting method. In the first approach, the effective constraints and criteria weight percentage are given considering the available system. The effective constraints and criteria weight percentage in the proposed system are identified as if these criteria have the same affect on the route determination.

In addition to the distance calculation method comparison of two distance calculation methods, the effectiveness of data precision on the route from Temelli to Gölbaşı transformer centers is explored by using the zone plan layers that are in small and large scales (1/100000 and 1/5000) and DEM layers that have high and low spatial resolution (10 m. and 90 m.).

The route should be the least cost path as far as possible taking into account the impact on natural environment, the influence on local communities, and the technical regulation considering the productive effort, time and money factors. Based on determined criteria and constraints, the least cost path that is found by two distance calculation methods are compared by means of the lengths of routes, the cost for each route and the data precision.

5.1 Comparison of Results

The main objective of this study is to investigate the influence of the spatial distance method on the optimum route for electric transmission line, based on Multicriteria Decision Analysis and GIS. The comparison of the spatial and Euclidian distances is realized to emphasize the difference between them. The proposed routes by using the spatial and the Euclidian distances for scenario 1 are presented in Figure 5.1 and Figure 5.2. The comparisons of two methods for scenario 2 are shown in Figure 5.3 and Figure 5.4.

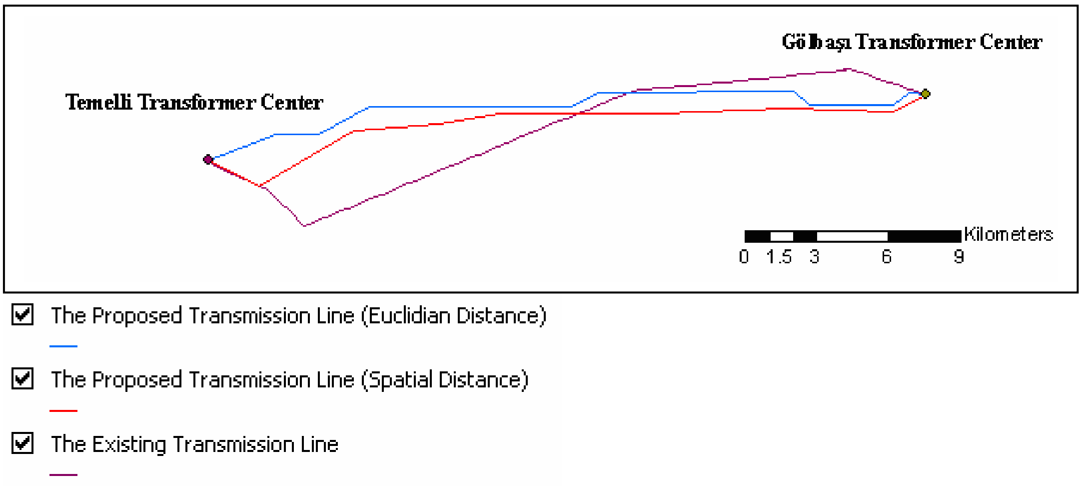

Figure 5.1. Proposed transmission line by using Spatial and Euclidian distance computation and the existing transmission line routes for scenario 1 (Built-up area layer in large scale and slope layer that derived from 90 m. SRTM DEM)

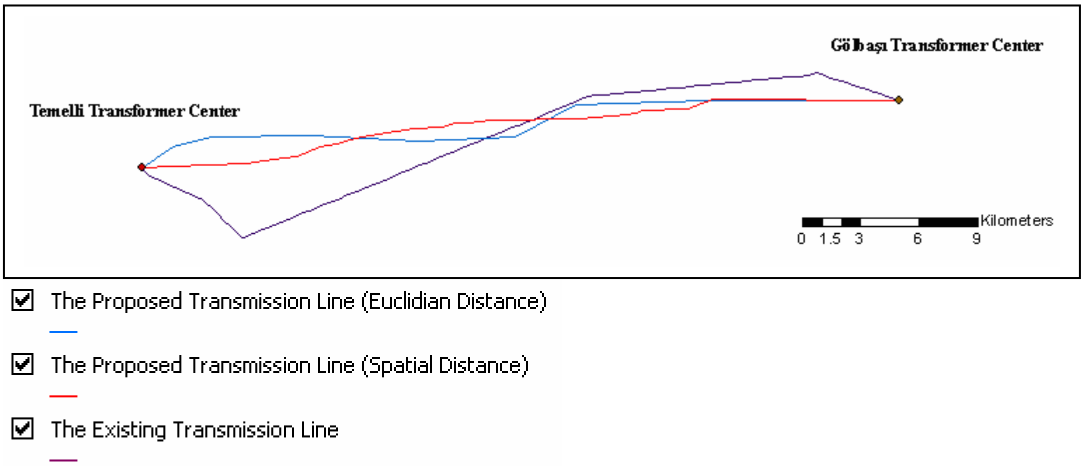

Figure 5.2. Proposed transmission line by using Spatial and Euclidian distance computation and the existing transmission line routes for scenario 1 (Bulit-up area layer in small scale and slope layer that derived from 10 m. DEM)

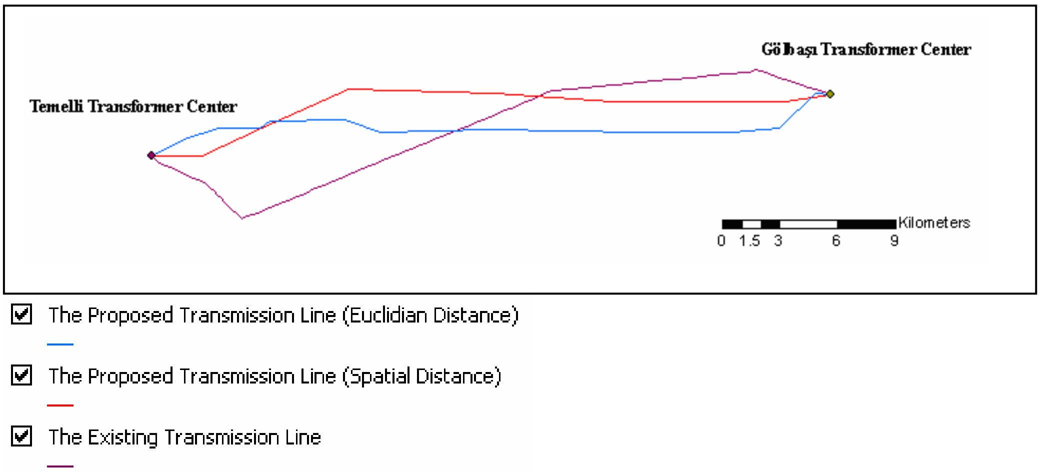

Figure 5.3. Proposed transmission line by using Spatial and Euclidian distance computation and the existing transmission line routes for scenario 2 (Built-up area layer in large scale and slope layer that derived from 90 m. SRTM DEM)

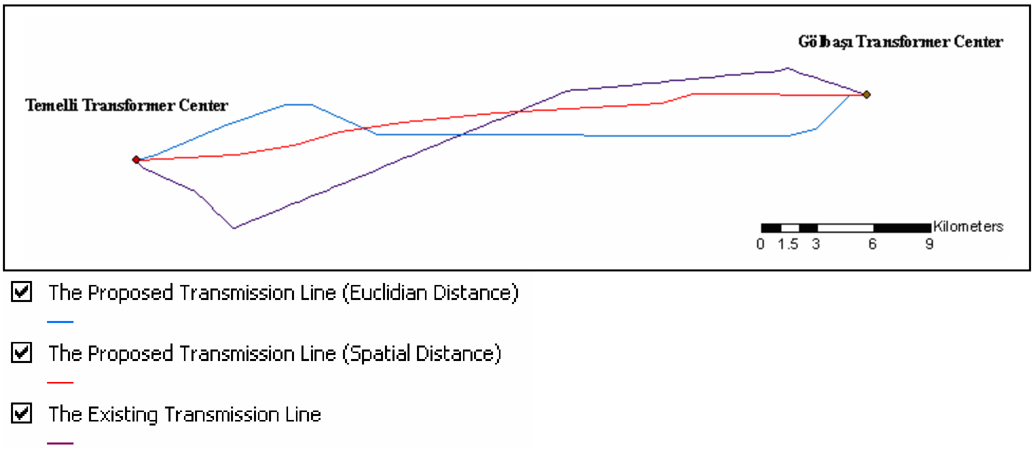

Figure 5.4. Proposed transmission line by using Spatial and Euclidian distance computation and the existing transmission line routes for scenario 2 (Built-up area layer in small scale and slope layer that derived from 10 m. DEM)

The comparison in terms of the electric transmission line length is given Table 5.1. The results of two methods are shorter than the existing transmission line that was obtained by the available system in TEİAŞ.

The proposed method by using the spatial distance provides us the results that are shorter than the method that have used the Euclidian distance in GIS environment.

The results are not only the shortest path between Temelli and Gölbaşı transformer centers, they are also the least cost path for the electric transmission line.

The accuracy of the route from Temelli transformer center to Gölbaşı transformer center is increased by the spatial distance. It can be called as actual distance taking into account small slope angle changes between cells that are elements of the representation of terrain in the raster form. The spatial distance approximation uses 5x5 pixel window 16 directions around a cell unlike the Euclidian distance. The spatial distance between two cells can be larger than the calculated straight line distance, Euclidean distance, because of slope angle between the cells. However the obtained results from this method must be converted into vector format for comparing with the existing transmission line and the proposed transmission line by Spatial tool of ArcMap. In addition to the weakness, the spatial distance function must be optimized very accurately for finding the optimum results. The distance and direction arrays are used to optimize the function. The optimum route determination by spatial distance program is executed by order of 2 times for each one.

Table 5.1 The comparison of alternative routes in terms of their lengths

	Routes	**Length (Euclidian Distance)**	**Length (Spatial Distance)**
Scenario 1	Proposed Transmission Line 1	36.238 km	36.490 km
	Proposed Transmission Line 2	35.759 km	35.520 km
Scenario 2	Proposed Transmission Line 1	36.307 km	35.950 km
	Proposed Transmission Line 2	36.575 km	35.360 km
Existing Transmission Line		38.093 km	

Existing transmission line is the final route which was determined after a detailed field survey. However proposed transmission lines are the routes which are determined by the preliminary analysis before the field study. Since the preliminary analysis of the existing transmission line in this study was not available, the proposed routes, obtained as preliminary analysis were compared with the existing transmission line. This may be one of the reasons to have a big difference in the lengths of the proposed and existing routes (Table 5.1). However the differences in the routes found can be due to the distance calculation methods (Euclidian and spatial distance).

5.2 Cost Analysis

The effective factors and constraints are determined to find the optimum path in terms of minimizing cost, to maximizing profit for TEİAŞ and minimizing environmental impact between two transformer centers. The least cost path is defined according to the classical approach and proposed approach.

The costs for the existing route in TEİAŞ are calculated by using zone values on the weight of ice map for each high voltage, such as 66 kV, 154 kV, 220 kV, and 380 kV. Temelli-Gölbaşı Transmission Line is in the second zone on the the weight of ice map and the cost related to this transmission line are computed according to 154 kV voltage as shown in Figure 5.7.

The conductors are weighted other burdens in horizontal and vertical direction except from its own heaviness. The additional burdens should be determined related to the climate conditions according to the region where the route passes through. Consequently, the ice condition should be examined along the electric transmission line route to establish the route very accurately. The additional weight of the ice on a line can cause it to fall. The weight of ice per kilometer for electric transmission lines can be calculated by using Equation 5.1.

$$g_b = k \times d \qquad (5.1)$$

g_b = The weight of ice

d = the diameter of the conductor

k = the determined value according to region

Table 5.2 The weight of ice parameters according to the zones in Turkey

k	The Region
0	I.
0,2	II.
0,3	III.
0,5	IV.
1,2	V.

The cost calculation criteria for 1 km electric transmission line are summarized in Table 5.4. It involves expense type that affect the cost, the quantity of the expenses, the unit prices corresponding to these expenses and the cumulative cost for 1 km electric transmission line as TL. The investigation and planning cost have affected the cumulative cost about in 4/1000 rate. Although it seems to the small rate in the cumulative cost, this rate affects all the expenses for a definite electric transmission line route. It has been emanated from the dependency processes of this part such as the procedures Directorates of Foundation, Real Estate, Expropriation and Map, Environment, and Progress Payment.

Finally, the profits have been evaluated by using Table 5.4 and the weight of ice map for Temelli-Gölbaşı transmission line. The differences of the existing and proposed transmission line lengths ranges from 1.2 km. to 2.5 km. If the length differences are generalized considering the sum length of electric transmission lines that have been scheduled in 2007 is 4668 km, the profits of TEİAŞ will be found as 28 992 427 808 493 TL.

The Keban high voltage utility pole was collapsed due to the weight of ice in January 1981 (Figure 5.5 and Figure 5.6).

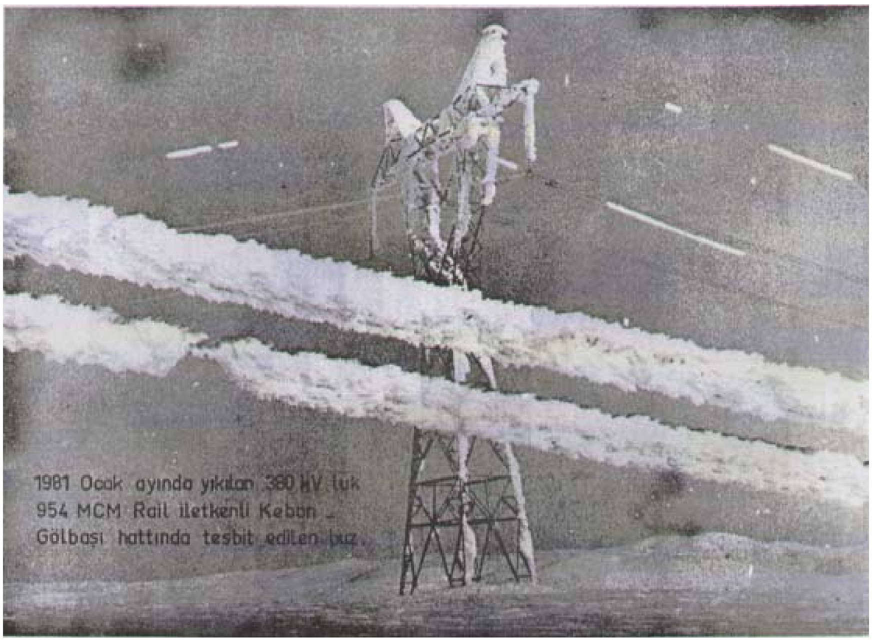

Figure 5.5 The photograph of Keban high voltage utility pole

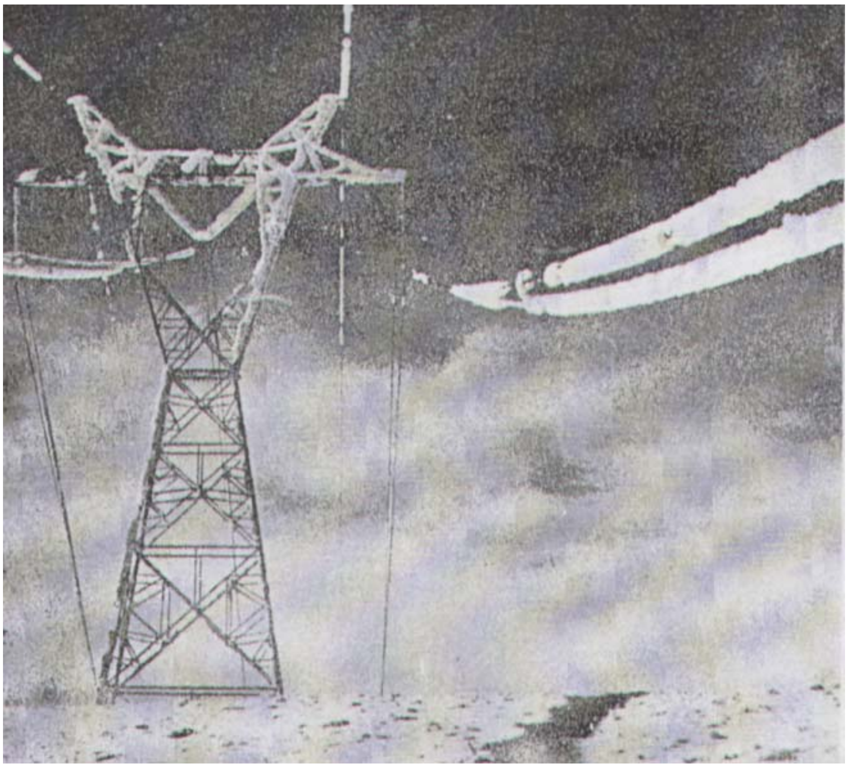

Figure 5.6 The other photograph of Keban high voltage utility pole

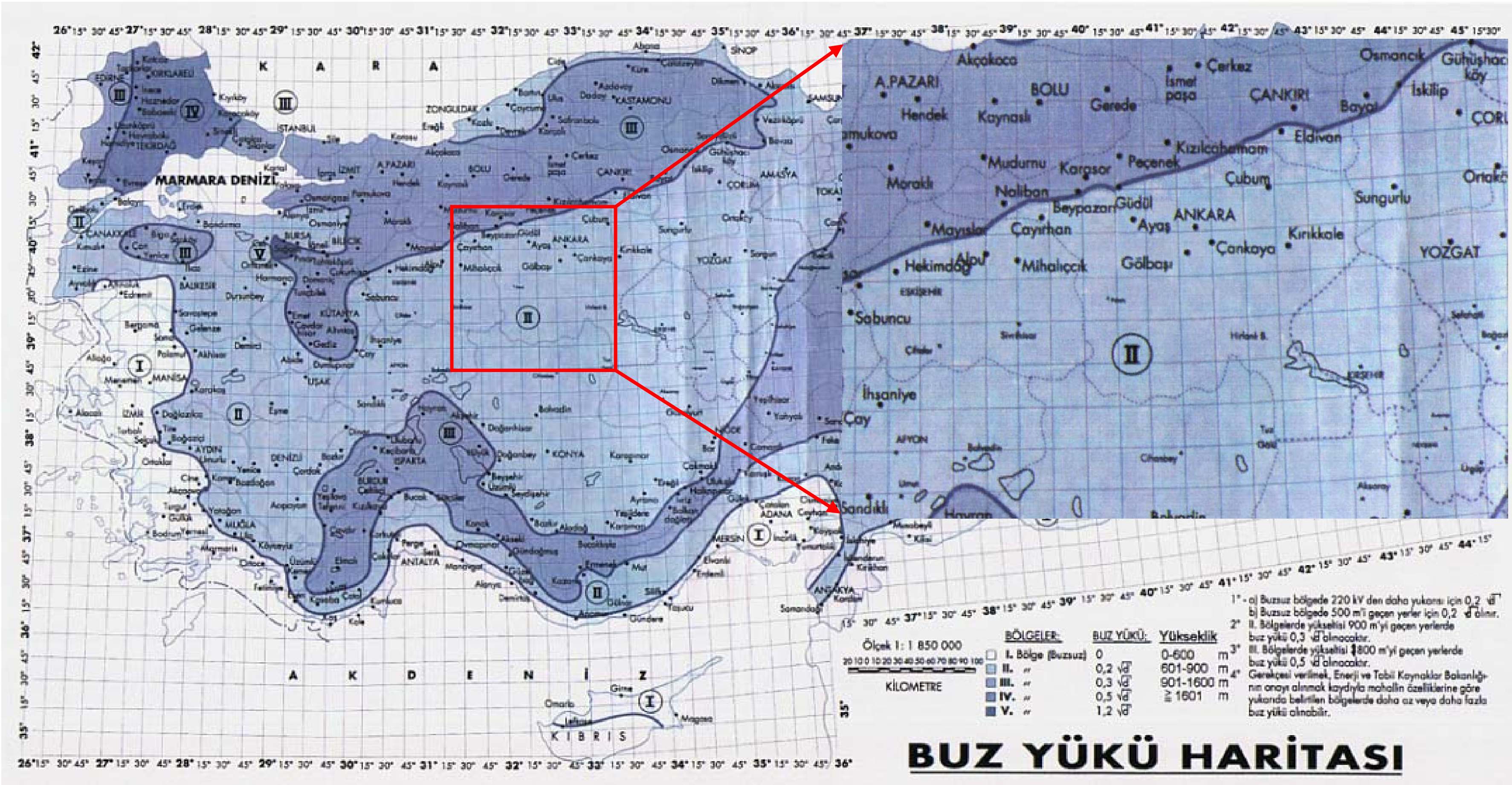

Figure 5.7. The weight of ice map for Turkey

Table 5.3. Cost table for I. and II. zones according to the weight of ice map for Turkey

Expenses Type	Quantity	Unit Price	Cumulative (TL/km)
Iron	38 000 kg	2 520. 000 TL/kg	95 760 000.000
Insulator	480 numbers	21 900. 000TL/kg	10 080 000.000
Narrow goods	48 Askı Tk.	196.000.000 TL/Askı Tk.	9 408 000.000
Conductive	14.889 kg	3 336.000 TL/kg	50 027 544.000
Production Conductive	592 kg	1 610.000 TL/kg	952 486.000
Conductive Gravity	14.889 kg	980.000 TL/kg	14 591 367.000
Production Conductive Gravity	592 kg.	1 050.000 TL/kg	621 180.000
Study and Preparing the Project	1 km.	840 000.000 TL/km	840 000.000
Nationalization Cost	1 km.	1 680 000.000 TL/km	1 680 000.000
State of the Environment Report Preparation	1km.	5 670 000.000 TL/km	5 670 000.000
Total Cumulative (1km.)			189 630 567.330

Table 5.4. The Costs between the existing and proposed transmission lines

Scenarios	Routes	Length (Euclidian)	Length (Spatial)	The Difference Length (Euclidian)	The Difference Length (Spatial)	Cost (TL) (Euclidian Distance)	Cost (TL) (Spatial Distance)
Scenario 1	Proposed Route 1	36.238 km	36.490 km	1.603	1.855	351 764 702.397	303 977 799.430
	Proposed Route 2	35.759 km	35.520 km	2.573	2.334	442 597 744.148	487 919 449.740
Scenario 2	Proposed Route 1	36.307 km	35.950 km	2.143	1.786	338 680 193.251	406 378 305.788
	Proposed Route 2	36.575 km	35.360 km	2.733	1.518	287 859 201.207	518 260 340.513
Existing Transmission Line		38.093 km					

Compared to the traditional algorithms the proposed algorithm produces more realistic least-cost paths by using spatial distances, anisotropic accumulated cost surfaces both Queen's and Knight's patterns have been used to calculate the accumulated costs of neighboring cells.

In the most of the commercial GIS softwares, the spatial distances, anisotropic costs have not been fully considered for functions of finding least-cost paths. Spatial distance algorithm improved the route finding on more realistic terrains.

This study has shown that the spatial resolution of DEM influences the results of least-cost path. The weights of the effective factors considered in this study also change the results. In this study, the various methods for weighting difficult parameters have not been fully explored, expert's knowledge was considered to be the ideal approach in selecting the effective factors.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

The least cost path finding is one of the oldest problems in GIS based network analysis since the last decade. A number of applications have been performed in this area, such as road planning, pipeline and electric transmission line route designing, etc.

Raster-based or vector-based GIS can be used to determine the least cost path lies between two define point features on the terrain. It depends on the user's preferences because there are some advantages and disadvantages for these representations of the terrain. In this study, raster-based GIS is selected to solve the least cost path finding problem across terrain data.

It is essential to carefully consider the impact on the natural environment and human during designing an electric transmission line route. The most suitable site for the electric transmission line route should be selected by evaluating time, cost and productive efforts.

This study aimed to design the optimum route from Temelli transformer center to Gölbaşı transformer center by Multicriteria Decision Analysis based on GIS. In order to achieve this aim, the optimum route determination for the electric transmission line is performed by using the spatial and Euclidian distance among cells on the terrain. The least cost path algorithm that uses spatial distance is compared with the Spatial tool of ArcMap. It is seen that, usage of the spatial distance among cells gives us the shortest path between the transformer centers besides the least cost path from one to another.

The impact of criteria that is defined by the expert on the route determination is evaluated by varying weights of the criteria in two cases, where the traditional approach considering slope, built-up area and road proximity have larger effects in the route determination and equal weights for each criterion were used. Data precision affects the least cost path. As more accurate data are used, more optimum route for the electric transmission line is determined.

During the route design implementation, a number of impediments are detected. Several data layers can be imported to increase the quality of route, such as water projects belonging to General Directorate of State Hydraulic Works and BOTAŞ Petroleum Pipeline Corporation, forestry maps that is provided from General Directorate of Forestation, protected areas that are provided from General Directorate of National Parks and Hunt-Wildlife.

3D display of topographic structure can help to design the number and locations of break points on the electric transmission line. The poles and break points on a transmission line are shown in Figure 6.1. The position of the electric poles and the breaking points of the transmission line can be designed as a preliminary study by visual interpretation. Certainly these designed electric poles and the breaking points are going to be in the final location after the field study.

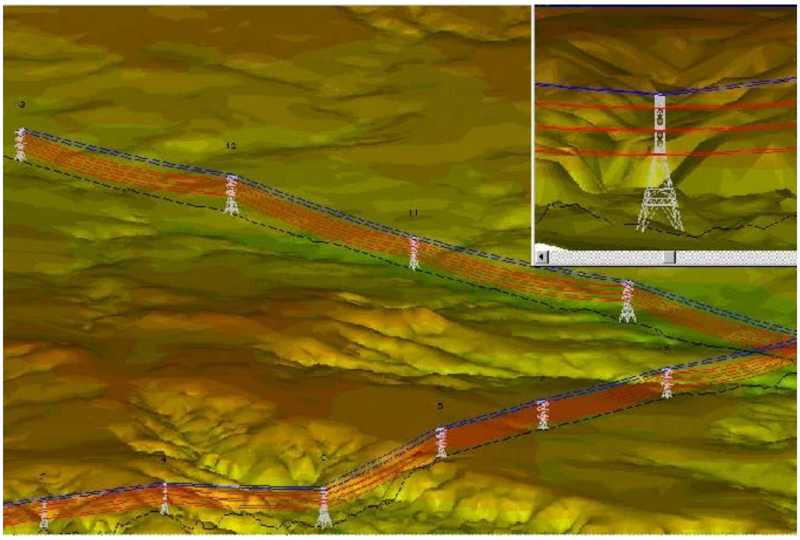

Figure 6.1. 3D Display of utility poles on the topographic structure

Aerial photographs can be used to gain the knowledge about the study area and assess the results by overlaying the real situation of terrain. Optimum route that will be designed according to the weight criteria concerning the electric transmission line and data that will be used in planning can be used more accurately in the design by overlaying with current aerial photographs.

Proposed optimum route finding system can be used in preliminary route determination of the electric transmission line in TEİAŞ. This new system can save time, labor and cost. By this way, in optimum time, person and cost, electric transmission lines can be designed comparatively accurate by providing much data integration.

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URL6:Earth Science Data Interface, http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

URL7: Role of GIS as a decision support system in power transmission (http://www.gisdevelopment.net/application/utility/power/utilityp0020.htm)

URL8: http://geology.com/articles/what-is-geology.shtml

APPENDIX

Algorithm/Code For Shortest Path Between Two Cell By Using Spatial Distance

```
I=imread('dem.tif');
[m n] =size(I);
a=m+4;
b=n+4;

DM=zeros(a,b);

K=zeros(a,b);

 for x=3:(m+2)
     for y=3:(n+2)
         K(x,y)=I(x-2,y-2);
     end
 end
ilki=902;
ilkj=288;
bitisi=589;
bitisj=3782;
basi=ilki+2;
basj=ilkj+2;
soni=bitisi+2;
sonj=bitisj+2;

while basi<soni | basj<sonj

donmin=1;

while donmin<5
 donmin=donmin+1;

 pikdist=zeros(1,9);
 mydeger=K(basi,basj);

  % 1alt, 2üst, 3sağ, 4sol
 altpik=K(basi+1,basj);
 pikdist(1,1)=spatialdistance(mydeger,altpik);
 ustpik=K(basi-1,basj);
 pikdist(1,2)=spatialdistance(mydeger,ustpik);
 sagpik=K(basi,basj+1);
 pikdist(1,3)=spatialdistance(mydeger,sagpik);

  % çaprazlar 5solalt,6sağalt,7sağüst,8solüst

 sagaltpik=K(basi+1,basj+1);
 pikdist(1,4)=spatialdiagonal(mydeger,sagaltpik);
```

```
sagustpik=K(basi-1,basj+1);
pikdist(1,5)=spatialdiagonal(mydeger,sagustpik);
% horse pikseller 1 satır farklı olanlar
% 9solalthorse,10sağalthorse,11sağüsthorse,12solüsthorse

sagalth1=K(basi+1,basj+2);
pikdist(1,6)=spatialhorse(mydeger,sagalth1);
sagusth1=K(basi-1,basj+2);
pikdist(1,7)=spatialhorse(mydeger,sagusth1);

 % horse pikseller 2 satır farklı olanlar
% 13solalthorse,14sağalthorse,15sağüsthorse,16solüsthorse

sagalth2=K(basi+2,basj+1);
pikdist(1,8)=spatialhorse(mydeger,sagalth2);
sagusth2=K(basi-2,basj+1);
pikdist(1,9)=spatialhorse(mydeger,sagusth2);

% şimdi I matrisinde min değerin hangi elemana denk geldiği bulunmalı

[mn yr]=min(pikdist);

if yr==1
   DM(basi+1,basj)=mn;
   sat=basi+1;
   sut=basj;
end

if yr==2
   DM(basi-1,basj)=mn;
   sat=basi-1;
   sut=basj;
end

 if yr==3
   DM(basi,basj+1)=mn;
   sat=basi;
   sut=basj+1;
end


 if yr==4
   DM(basi+1,basj+1)=mn;
   sat=basi+1;
   sut=basj+1;
end

if yr==5
   DM(basi-1,basj+1)=mn;
   sat=basi-1;
   sut=basj+1;
end
```

```
 if yr==6
    DM(basi+1,basj+2)=mn;
    sat=basi+1;
    sut=basj+2;
 end

if yr==7
    DM(basi-1,basj+2)=mn;
    sat=basi-1;
    sut=basj+2;
end

if yr==8
    DM(basi+2,basj+1)=mn;
    sat=basi+2;
    sut=basj+1;
end

if yr==9
    DM(basi-2,basj+1)=mn;
    sat=basi-2;
    sut=basj+1;
end

 basi=sat;
 basj=sut;

end %while min

dondir=1;

   while dondir<5
      dondir=dondir+1;
      pikdist=zeros(1,9);
      pikdir=zeros(1,9);

 mydeger=K(basi,basj);


 % 1alt, 2üst, 3sağ, 4sol

 altpik=K(basi+1,basj);
 pikdist(1,1)=spatialdistance(mydeger,altpik);
 pikdir(1,1)=uzakliki((basi+1),soni,basj,sonj);
 ustpik=K(basi-1,basj);
 pikdist(1,2)=spatialdistance(mydeger,ustpik);
 pikdir(1,2)=uzakliki((basi-1),soni,basj,sonj);
 sagpik=K(basi,basj+1);
 pikdist(1,3)=spatialdistance(mydeger,sagpik);
 pikdir(1,3)=uzakliki(basi,soni,(basj+1),sonj);
```

```
% çaprazlar 5solalt,6sağalt,7sağüst,8solüst

sagaltpik=K(basi+1,basj+1);
pikdist(1,4)=spatialdiagonal(mydeger,sagaltpik);
pikdir(1,4)=uzakliki((basi+1),soni,(basj+1),sonj);
sagustpik=K(basi-1,basj+1);
pikdist(1,5)=spatialdiagonal(mydeger,sagustpik);
pikdir(1,5)=uzakliki((basi-1),soni,(basj+1),sonj);

% horse pikseller 1 satır farklı olanlar
% 9solalthorse,10sağalthorse,11sağüsthorse,12solüsthorse

sagalth1=K(basi+1,basj+2);
pikdist(1,6)=spatialhorse(mydeger,sagalth1);
pikdir(1,6)=uzakliki((basi+1),soni,(basj+2),sonj);
sagusth1=K(basi-1,basj+2);
pikdist(1,7)=spatialhorse(mydeger,sagusth1);
pikdir(1,7)=uzakliki((basi-1),soni,(basj+2),sonj);

 % horse pikseller 2 satır farklı olanlar
% 13solalthorse,14sağalthorse,15sağüsthorse,16solüsthorse

sagalth2=K(basi+2,basj+1);
pikdist(1,8)=spatialhorse(mydeger,sagalth2);
pikdir(1,8)=uzakliki((basi+2),soni,(basj+1),sonj);
sagusth2=K(basi-2,basj+1);
pikdist(1,9)=spatialhorse(mydeger,sagusth2);
pikdir(1,9)=uzakliki((basi-2),soni,(basj+1),sonj);

 [mn2 yr2]=min(pikdir);

if yr2==1
   DM(basi+1,basj)=min(pikdist(1,yr2));
   sat=basi+1;
   sut=basj;
end

if yr2==2
   DM(basi-1,basj)=min(pikdist(1,yr2));
   sat=basi-1;
   sut=basj;
end


if yr2==3
   DM(basi,basj+1)=min(pikdist(1,yr2));
   sat=basi;
   sut=basj+1;
end


if yr2==4
```

```
    DM(basi+1,basj+1)=min(pikdist(1,yr2));
    sat=basi+1;
    sut=basj+1;
 end

 if yr2==5
    DM(basi-1,basj+1)=min(pikdist(1,yr2));
    sat=basi-1;
    sut=basj+1;
 end


 if yr2==6
    DM(basi+1,basj+2)=min(pikdist(1,yr2));
    sat=basi+1;
    sut=basj+2;
 end

if yr2==7
    DM(basi-1,basj+2)=min(pikdist(1,yr2));
    sat=basi-1;
    sut=basj+2;
end

if yr2==8
    DM(basi+2,basj+1)=min(pikdist(1,yr2));
    sat=basi+2;
    sut=basj+1;
end

if yr2==9
    DM(basi-2,basj+1)=min(pikdist(1,yr2));
    sat=basi-2;
    sut=basj+1;
end


 basi=sat;
 basj=sut;

   end %while dir
basi=sat;
basj=sut;
end % while

for i=3:(m+2)
   for j=3:(n+2)
    DMS(i-2,j-2)=DM(i,j);
   end
end
```