Developing a Geospatial Model for Power Transmission Line Routing in Turkey

Volkan YILDIRIM, Recep NISANCI, Turkey

Key Words: Power Transmission Line, PTL, raster, GIS, Turkey

SUMMARY

Power Transmission Line (PTL) construction is one of the most complex engineering projects. Routing a transmission line is much more difficult than routing any other public infrastructure. Especially in developing countries like Turkey, the present PTL routing system used is time consuming and does not produce satisfactory results because PTL routing is done by manual methods using 1/25.000 standard topographic maps or smaller scale paper maps. Current route determination methods are considerably insufficient in transmitting the power to long distances. The optimum route for PTL in the majority of cases is not the shortest path between the start and end points. For the determination of the optimum one, many factors which affect the route should be considered all together. Some of these factors are (i) technical factors such as slope, landslide, earthquake/fault, road/railway/pipeline crossing, lightning strike, wind, snowfall, and thunderstorm; (ii) environmental factors such as national parks, archaeological areas, water resources, river crossing, wildlife, and forests; (iii) socio-economic factors such as agricultural areas, residential areas, cultural assets, temples, shrines, recreation areas, tourism, right of way, and relocation. Each of these factors basically corresponds to a spatial data set. Therefore, optimum PTL routing is a spatial problem. GIS is currently one of the most effective tools for resolving such complicated spatial problems. In GIS, raster data models which is used for storage and visualisation of spatial data sets provides important advantages especially in such projects which is to be constructed for long distances. This article presents a raster-based GIS model developed for PTL routing and lists the advantages of the model in a PTL implementation. Routes defined with network analysis techniques over raster-based GIS models minimize economic, environmental, and time costs, depending on the quality of data used.

Developing a Geospatial Model for Power Transmission Line Routing in Turkey

Volkan YILDIRIM, Recep NISANCI, Turkey

1- INTRODUCTION

PTL delivers and processes electrical power on its way from generating stations to distribution, which completes the processing and delivers it to consumers. Demand for electricity continuously also increases over time. In order to meet this demand new generators are built in Turkey in recent years. The power from these generators will overload existing lines, so new lines are needed. In the Turkey 10.600 km. line of transmission were planned for 2006 and 2007 (TEIAS, 2006 and TEIAS, 2007). These are in different stages of planning and construction. Some of these lines may be delayed or may not be constructed at all. The main reason for this is that it is very difficult, uncertain and expensive to route lines in Turkey.

PTL is one of essential infrastructures of the power supply system. In the site evaluation process for those facilities, it is necessary to carefully consider not only technical issues, but also the impact on natural environment, the influence on local communities, and various regulations. However, it is getting difficult to find the preferable site for a transmission line, because of the increasing cost of constructions, the increasing concern on environmental issues and the growing consciousness of land owners. In addition, the number of experienced planners and engineers engaged in the sitting process is decreasing with generational changes. (Murata, 1995).

PTL routing is an engineering task that optimizes the equipment installation and maintenance costs subject to geographic, environmental, social, and legal constraints. Thus, routing can be defined as the previous stage to the design of a new electric power line, where the planner decides the path and areas crossed by the line taking into account the existing constraints. (Monteiro et all, 2005).

PTL routing is a complex process which involves local, state and federal agencies. The route of the line is first approved by the state, usually a state commission, and then it goes to federal agencies like the Department of Energy and Federal Energy Regulatory Commission for approval in US. Depending upon the line route, approval may be required from several federal and state agencies. The transmission line routing process is highly complex, as transmission lines are not aesthetically pleasing, and people are concerned about health issues like Electro Magnetic Force. This may creates a high level of public opposition towards a line. Projects may face legal litigation from various stakeholders involved in the project if their concerns are not properly addressed. Such legal litigation further delays the project. This result in an increase in the budget of the project and a stage may come at which the utility finds the project to be financially unfeasible (Gill, 2005).

The spatial nature of some of the aspects involved in PTL routing leads to a compromise between a straight line from one point to another and path deviation to avoid costly terrain, obstacles, or other intolerance criteria. The automation of the routing process integrates a detailed geographic modelling of the problem with information and expert knowledge in order to reduce both the time consumed and the gap between planning and erection and, therefore, to reduce efforts in the revision of the project (Sumic et all, 1993)

Although the exact set of factors to be considered may change in different parts of the country, most PTL routing requires attention to environmental (e.g., wetlands and floodplains), community (e.g., existing neighborhoods and historic sites) and engineering (e.g.,slope and access) factors. GISs are explicitly designed to manage and combine large amounts of spatially distributed data. In fact, PTL siting can be thought of as a special case of land suitability analysis that drove much of GIS early development. (Glasgow et all, 2004).

GIS is already used in PTL routing as a technical tool. This research applies GIS to increase the public involvement in the routing process and which further results in reductions in time involved in approval of the line. This technique reduces the public resistance during the planning and design process and allows more people to participate in the complex infrastructure planning and design problems (Sumic et all, 1993).

This article presents a raster-based GIS model developed for PTL routing and lists the advantages of the model in a PTL implementation. The model is developed to assist engineers in selecting a suitable route to minimize economical, environmental and sociological issues and obstructions. For this, the model is mainly focused on route planning and design of a PTL. Moreover, using the same methodology with appropriate modifications, the model can be applied to a variety of different public utility (linear engineering structures) design and construction methods such as pipeline, highway, railway etc.

2- MATERIALS AND METHODS

2.1. Study Area and Current Pipeline (CR)

The study area is selected in Turkey which is situated in the Black Sea Region (Figure 1). In this area, existing PTL route is optimized. Source point is Giresun Province Tirebolu County, (in the western part) and target point is Artvin Province Borçka County (in the eastern part). Route length is approximately 268 km. The PTL was constructed by TEIAS (Turkish Electricity Transmission Company) by using conventional methods in the routing process. Problems such as the passing of the PTL over landslide areas, settlement areas, agricultural areas and protected areas resulting from exceeding the allocated budget, and the failure to complete the project according to the schedule, are all associated with routing problems. The PTL route is digitized on a 1/25000 standard topographic map, and the required coordinate transformations are made; thus it is entered into the system.

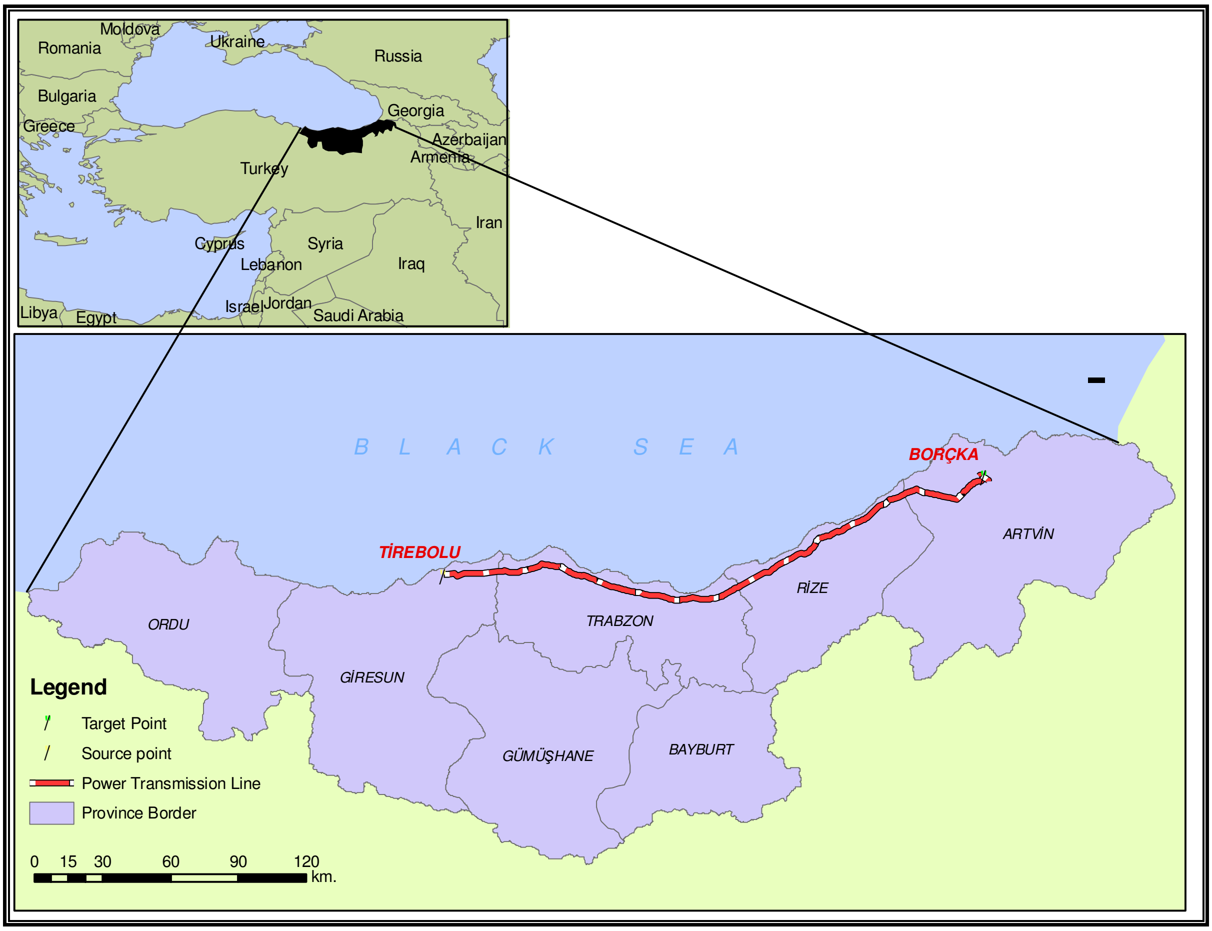

Figure 1. The Study area and current PTL route on the boundary map

2.2. System Development

A long distance PTL is a complex system. It relates closely to geographic location, environment, geological condition and many other factors as a geographic object with continuous distributive character. There will be many different data, diagrams, figures, files and other information, which are difficult to use and update them together and effective on each step of PTL route planning, construction, operation and management by manual method. So, there is a need to raster datasets for GIS based route determination. In this process, the most important step is database design. After this, optimum route are generated via intermediate processes and produced data. In this study, firstly a conceptual model is composed (figure 2).

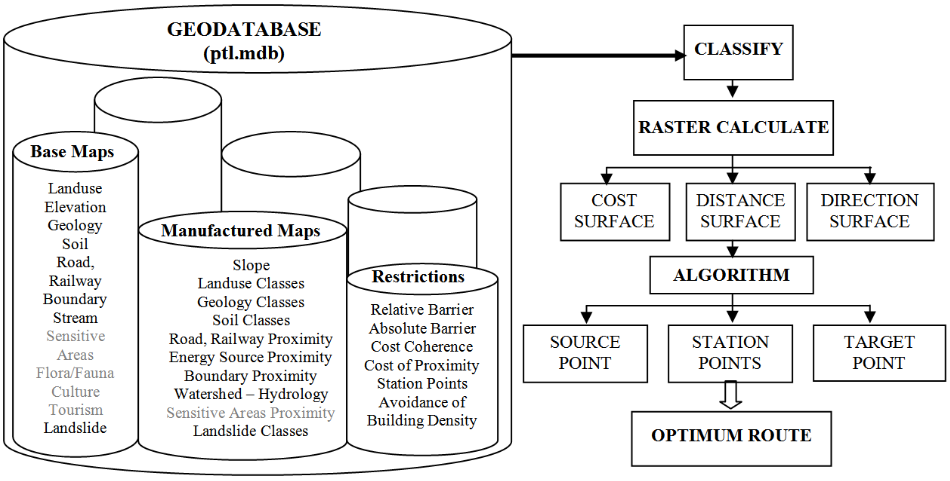

Figure 2. A conceptual model for optimum PTL route.

2.3. Data, Factor and Weighting

GIS data were acquired or derived based on the funneled approach of the analysis phase (figure 3). Prior to obtaining data, a preliminary generalized area of interest was created based on physical barriers and the known or assumed start and end location of the route.

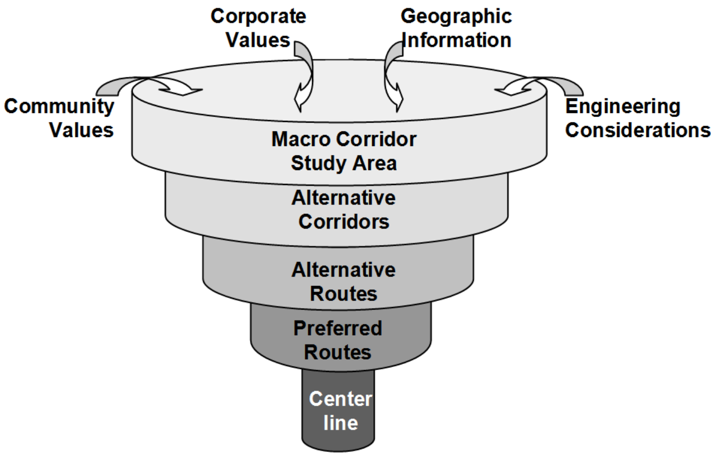

Figure 3. Funneled Approach (Glasgow et all, 2004)

In this routing model, firstly some datasets such as landuse, building density, landslide, soil, slope, linear infrastructures, flora/fauna, protected area and lakes are composed (Figure 4-7). After then, every dataset are converted to raster data format separately and raster based routing method is applied for PTL routing.

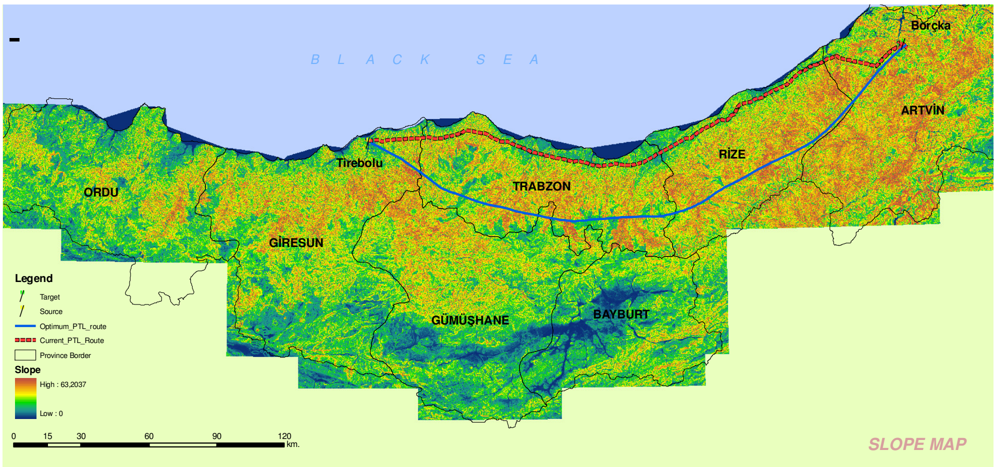

Figure 4. Slope Map

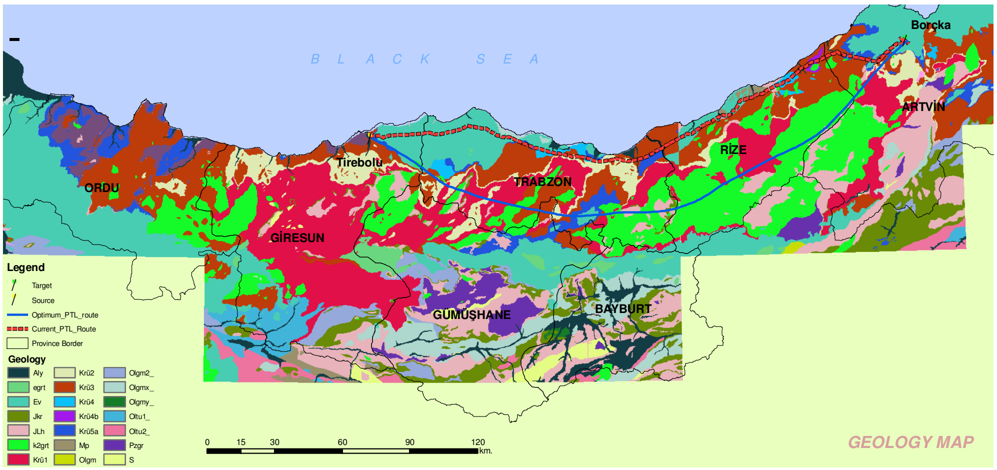

Figure 5. Geology Map

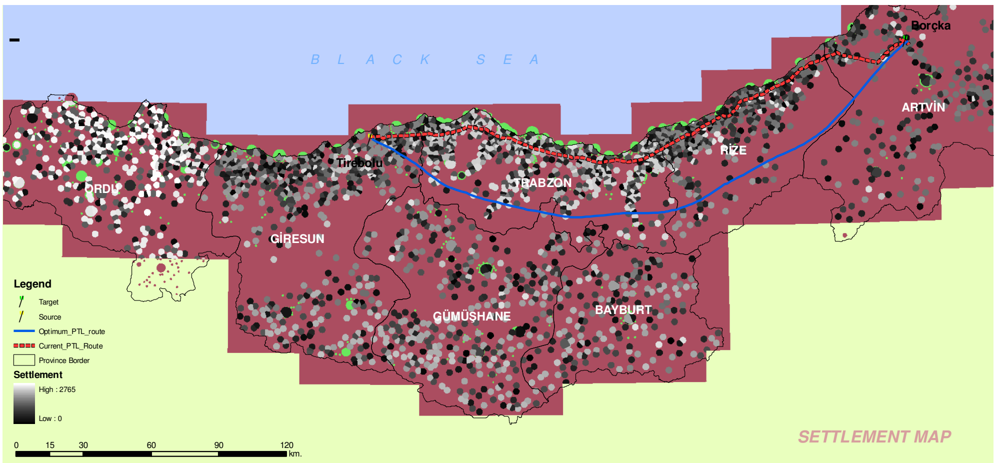

Figure 6. Settlement Map

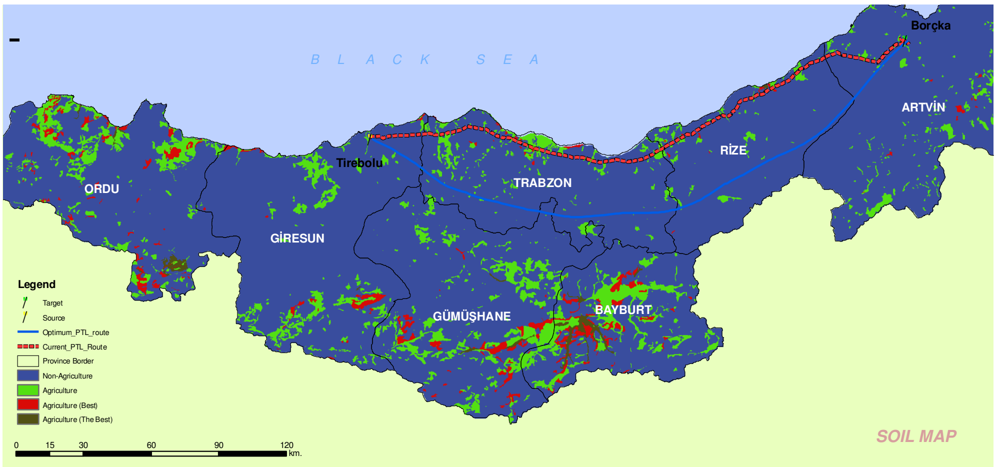

Figure 7. Soil Map

2.4. Least Cost Path Analysis

The study of the least-cost path problem predates the development of modern GIS. Some of the earliest work came from (Wrantz, 1957) who considered where a good must be transported over two broad regions, each with a different cost of transportation. There are a number of basic steps in finding a minimum cost path over a surface partitioned into regions of different resistances to movement (Collischonn and Pilar, 2000; Douglas 1994);

- A friction surface is created for each evaluation criterion, where each cell in the grid is assigned a value based on the relative cost of traversing that cell.
- Multiple friction surfaces are weighted and combined to create a cost-of-passage surface, representing the total cost associated with traversing each cell.
- A spreading function combines two separate grids representing source points and destination points are combined with the cost-of-passage grid to calculate an accumulated cost surface.
- The lowest cost line is traced down the accumulated-cost-surface from a departure point to a destination (Atkinson et all, 2005).

The model developed was tested with a case study by optimizing a current PTL. Process steps for the optimum PTL defined over the model are as follows;

<u>2.4.1. Factor selection and raster conversion:</u> The first process step is to define the factors and factor weights that affect the PTL route (table 1). Datasets to be used at this step can be organized by classifying it into a geo-database and data can be converted into raster data format. At this step, the required pixel dimension identification is adjusted according to the data scale (Pixel size in this implementation is 50 * 50 m).

Table 1. Factors and Sub-Factors Weights (Schmidt, 2009)

Land Use	**20%**	**Linear Infrastructure**	**10%**
Open Land, Pasture	1	Rebuild Existing Transmission Line	1
Rocky	3	Parallel Existing Transmission Line	1.4
Forest	4	Parallel Road ROW	3.6
Agriculture	7	Parallel Gas Pipelines	4.5
Residential/Settlement	9	Parallel Railroad ROW	5
Building Density	**15%**	Background	5.5
0-0.5 Buildings/Acre	1	Future Road Plans	7.5
0.5-0.2 Buildings/Acre	3	Parallel Expressways	8.1
0.2-1 Buildings/Acre	5	Road /Rail ROW	8.4
1-4 Buildings/Acre	7	Scenic Highway ROW	9
4-25 Buildings/Acre	9	**Stream**	**5%**
Landslide	**15%**	Branch	1
Potential	7	Brook	3
Old	8	Wide-Brook	5
Active	∞	Stream	7
Soil	**10%**	River	9
Non - Agriculture	1	**Flora - Fauna**	**5%**
Agriculture	3	Flora	∞
Agriculture (Best)	7	Fauna	∞
Agriculture (The Best)	9	**Protected Area**	**5%**
Slope	**10%**	Level III	5
0 – 10	1	Level II	7
10 – 20	5	Level I	∞
20 – 30	7	**Lakes and Pond**	**5%**
> 30	9	Background	1
		Lakes and Ponds	9

2.4.2. Pixel-based calculation and weighted surface: Pixel-based mathematical calculations are made using factor weights and classified raster data layers. This way, the weighted surface is obtained showing PTL routing costs on the surface (Figure 8).

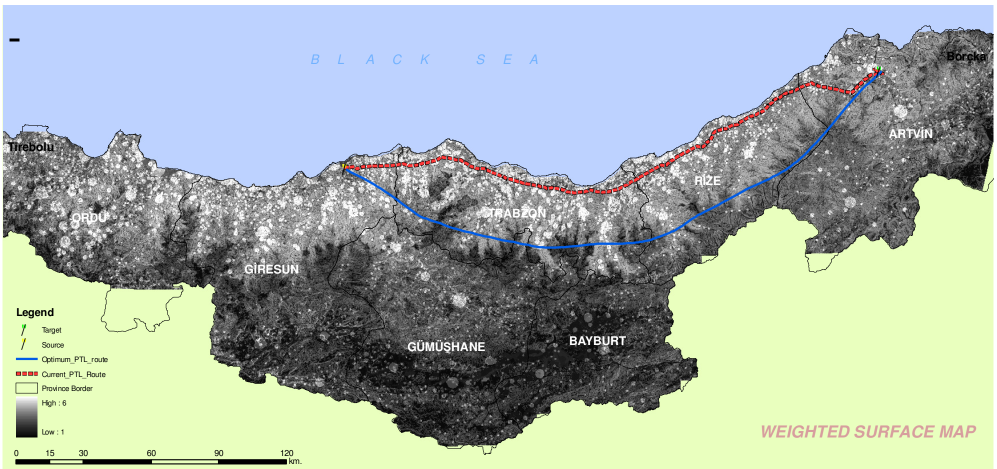

Figure 8. Weighted Surface Map

2.4.3. Absolute/Relative barriers: After the weighted surface is obtained, the areas absolutely impossible to be passed through, and the areas with high passage costs can be modelled as “barriers” on the surface. In this process step, ∞ value was used in sub-unit classification for absolute barriers (active landslide areas, flora fauna areas, protected areas, earthquake areas, etc). Algorithm prevents the route from passing over the pixels this value is assigned to. The value “9” was assigned to places with high passage cost (settlement areas, rvers and lakes), which means that a passage is quite difficult in sub-unit classification.

2.4.4. Source/Destination/Stops: Source and target points are marked “point” for this procedure and are recorded in the database as a separate file. Source point is Giresun Province Tirebolu County and target point is Artvin Province Borçka County

2.4.5. Optimal routing: After these interim procedures, direction and distance data is created through “Cost Distance Algorithm” which uses ArcGIS 9.2 software whereby the final route is obtained. These steps have been followed in the implementation and optimum PTL have been defined (Figure 6).

3- COMPUTATIONAL RESULTS

Finally, current PTL and optimum PTL are compared. The factors affecting the optimum PTL route were evaluated for the current route. Passage characteristics increasing the cost were examined on the basis of the cost data of the route (Table 2).

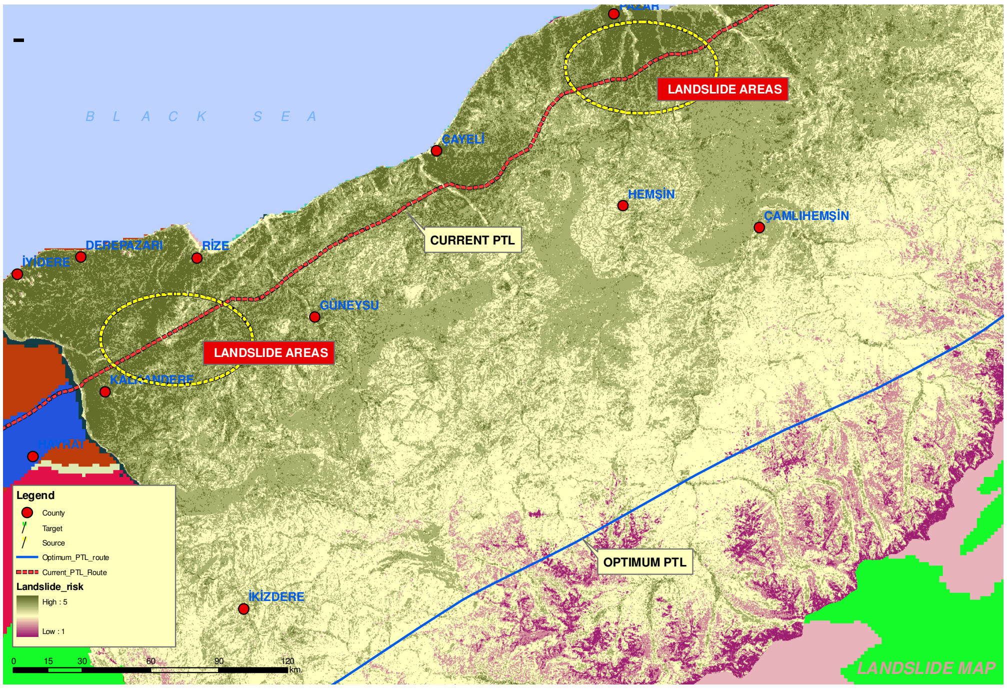

Figure 9. Landslide Map

Table 2- Evaluation for Current PTL and Optimum PTL

Examination Criteria	Current PTL	Optimum PTL
Length of The PTL (km.)	268,4	319,5
Size of The Effect Area (50 m.)	1342 hectare	1598 hectare
Road Passages (Highway and Expressway)	18	6
Stream Passages (Only River)	12	5
Passages Over Active Landslide Areas	573 hectare	70 hectare
Passages Over Open Land, Pasture Areas	200 hectare	975 hectare
Passages Over Forest Areas	682 hectare	606 hectare
Passages Over Agriculture Areas (Best and The Best)	70 hectare	14 hectare
Passages Over Residential/Settlement Area	1385 hectare	339 hectare
Settlement Areas Passages (inside 1000 m. buffer)	172	27
Average Distance to Settlement Areas (inside 1000 m. buffer)	310 m.	520 m.

Calculations on the 25 m either side of the optimum PTL route determined 606 hectares of forest, 14 hectares of agricultural field and 70 hectares of landslide field were passed. It crosses 6 passages over roads, and 5 passages over river.

4- CONCLUSION

In this study, a GIS-based application has been developed for PTL routing. It is shown that, PTL routing process can be made simpler and less time consuming by using the geographical information system. Landscape features are incorporated into ArcGIS software, and then it can be applied to any transmission routing project. The GIS data format used in the proposed methodology is the raster format for input values (associated costs: terrain, slopes, landuse, geology, obstacles, infrastructures, maintenance, etc.) as well as for computational results. The raster-based GIS model depends on collecting all factors that would affect routing on a single raster-based surface. Each pixel on this surface has a digital value representing cost of PTL works. These digital values and direction-distance data determine optimal PTL routing.

REFERENCES

TEIAS, 2006, Turkish Electricity Transmission Corporation Annual Report, Ankara.

TEIAS, 2007, Turkish Electricity Transmission Corporation Annual Report, Ankara.

Glasgow, J., French, S., Zwick, P., Kramer, L., Richardson, S., Berry and K., J., A Consensus Method Finds Preferred Routing, www.geoplace.com/gw/2004/0404/0404pwr.asp.

Murata, M., 1995, A GIS Application for Power Transmission Line Siting, ESRI User Conference Proceedings, US.

Monterio, C., Rosado, I., J., R., Santamaria, J., P. and Jimenez, P., J., 2005, GIS Spatial Analysis Applied to Electric Line Routing Optimization, IEEE Transactions On Power Delivery, Vol. 20, No. 2.

Gill, 2005, Electric Transmission Line Routing Using A Decision Landscape Based Methodology, MsC Thesis, Punjab Technical University.

Sumic, Z., Venkata, S., S. and Pistorese, T., 1993, Automated Underground Residential Distribution Design. Part I: Conceptual Design, IEEE Trans. Power Del., vol. 8, no. 2, pp. 637–643.

Hillier, F., S. and Liberman, G., J., 1989, Introduction to Operation Research. New York McGraw-Hill.

Wrantz, W., 1957, Transportation, Social Physics, and Law of Refraction, The Professional Geographer, Vol:9, No.4, p.2-7.

Collischonn, W., Pilar, J. V., 2000, A Directional Dependent Least-Cost Path algorithm for Roads and Canals, International Journal of Geographical Information Science, Vol:14, No.4, p.397-406.

Douglas, D. H., 1994, Least Cost Path in GIS Using an Accumulated Cost Surface and Slope Lines, Cartographica, Vol:31, No:3, p.37-51.

Atkinson, M. D., Deadman, P., Dudycha, D., Traynor, S., Multi-criteria Evaluation and Least Cost Path Analysis for an Arctic all-weather Road, Applied Geography, Vol:25, 2005, p.287-307.

Schmidt, A., J., 2009, Implementing a GIS Methodology for Siting High Voltage Electric Transmission Lines, Vol. 11, Papers in Resource Analysis. 17 pp.

BIOGRAPHICAL NOTES

Volkan YILDIRIM graduated from the Department of Geomatic Engineering at Karadeniz Technical University (KTU) in 1999. He received his MScE degree with thesis entitled "Address Information System Design and Application: Trabzon City Case Study" in August 2003. He received his PhD degree with thesis entitled "Development of a Raster Based Dynamic Model with Geographical Information System for the Determination of Natural Gas Transmission Pipelines" in August 2009. His research interests are networks in GIS and address information systems.

Recep NISANCI,

Recep Nisanci is a assistant professor at Karadeniz Technical University (KTU), Turkey. He graduated from the Department of Geodesy and Photogrammetry Engineering at KTU in 1992. He received his Phd degree with the thesis entitled "The Production of pixel based urban land value maps with nominal valuation method using GIS" in November 2005. His research interests are land valuation, land readjustment.

CONTACTS

Volkan YILDIRIM / Recep NISANCI
Karadeniz Technical University
Dept. of Geomatic Engineering
GISLab 61080
Trabzon
TURKEY
Tel: +90 (462)3772794
Fax: +90 (462)3280918
e-mail: yvolkan@ktu.edu.tr / rnisanci@ktu.edu.tr
web site: www.harita.ktu.edu.tr/volkan