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ABSTRACT
In accordance with current demands, the natural gas transmission pipeline (NGTP) is one of the most appropriate methods used in the distribution of existing reserves. Construction of long-distance pipelines requires large expenditures. Decreasing the time and cost of such construction and minimising environmental damage depend upon identifying the optimum routes from the onset of the project. Route determination is one of the most important steps in NGTP projects. The route determination process requires obtaining the existing graphic and non-graphic data from different institutions and organisations, as well as gathering, storing, querying and analysing non-existing data in an appropriate and efficient manner. Accessing the correct results rapidly by analysing such large data-sets can be achieved with spatial multicriteria decision-making technologies based on the geographic information system as an effective decision support tool. In this study, three methods were implemented for two NGTP projects of 103.60 and 60.89 km in length. At the end of this study, it was concluded that Spatial technique for order preference by similarity to ideal solution was the most effective of the three pipeline routing methods and that it could reduce project costs by approximately 21%.

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Spatial analysis; geographic information systems; multicriteria decision-making; natural gas pipelines; routing

1. Introduction

Multicriteria decision-making (MCDM) problems have becoming increasingly complicated over the years. These problems can easily become overwhelming due to the many alternatives and criteria which must be considered. Methods to support decision-making are now essential and great effort has been made in the past few decades to advance the field (Kabir, Sadiq, & Tesfamariam, 2014; Taha, 2011). Decision-making can be complex and multifaceted as a result of the inherent trade-offs among socio-political, environmental, ecological and economic factors. Moreover, decisions may involve many different stakeholders with diverse priorities or objectives. Considerable research in the area of MCDM has made practical methods available for applying scientific decision theory approaches to complex multicriteria problems (Kiker, Bridges, Varghese, Seager, & Linkov, 2005). These MCDM approaches have been classified in a number of ways. One of the first classifications makes a distinction between multi-objective decision-making and multi-attribute decision-making.

The main distinction between the two is based on the number of alternatives under evaluation. The multi-attribute decision-making methods are designed for selecting discrete alternatives, while the multi-objective decision-making methods are more adequate in dealing with multi-objective planning problems when a theoretically infinite number of continuous alternatives are defined by a set of constraints on a vector of decision variables (Tang, Boyer, Pedram, Yusuff, & Zulkifli, 2013). Different techniques have been introduced to deal with multi-attribute decision-making problems, including elimination and choice expressing reality (ELECTRE) (Coutinho-Rodrigues, Simão, & Antunes, 2011; Sánchez-Lozano, Antunes, García-Cascales, & Dias, 2014), simple additive weighting (SAW) (Coutinho-Rodrigues et al., 2011), the analytic hierarchy process (AHP) (Chen, Yu, & Khan, 2010; Erden & Karaman, 2012; Feizizadeh & Blaschke, 2011; Sánchez-Lozano, Teruel-Solano, Soto-Elvira, & Socorro García-Cascales, 2013; Sani, Kafaky, Pukkala, Mataji, & Abdulkarimi, 2012), and the technique for order preference by similarity to ideal solution (TOPSIS) (Chen, Li, & Liu, 2011; Coutinho-Rodrigues et al., 2011; Sánchez-Lozano et al., 2013).

The most important step in planning activities for natural gas transmission pipeline (NGTP) projects is an applicable route selection. However, obtaining the optimum route over a surface is a very complex process. Many factors must be considered simultaneously with NGTP projects. At every stage, the defined route has economic, environmental, sociological and temporal influences on the project. The aim is to reduce unfavourable effects in terms of flora, fauna and the environment as much as possible and to complete the project at the least cost base with the most efficient route. Determining the best route depends on examination and inquiry together with the analysis of a great

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deal of complex data. Route determination requires spatial data from different organisations and state institutions, and it also needs to be carefully selected, saved, investigated and analysed.

Nowadays, this type of analysis with rapid results is made possible using a geographic information system (GIS) as an effective engineering tool for systematically organising factors affecting route determination. Once these factors are identified, based on the length of the project, a GIS should be used to evaluate these factors simultaneously. Additionally, the GIS-based visualisation technologies and cartographic abilities are generally adequate to determine the effective routes (Chand & Gloven, 2009; Wang, Wu, Wang, & Wang, 2009; Yomralioglu, 2009). In the construction of long-distance pipelines, depending on land use, there are a number of factors that affect the route determination process. With GIS technologies, it is possible to analyse and examine these types of intensive spatial data-sets and to produce an effective interpretation of the results; thus, GIS technology is an effective engineering tool for route selection (Yomralioglu, 2009).

The GIS-based spatial multicriteria decision-making (S-MCDM) methods have been developed for dealing with information and supporting complex decision-making with multiple objectives. Sadeghi-Niaraki, Varshosaz, Kim, and Jung (2011) addressed a methodology for an impedance model using the AHP method to properly represent a road network in GIS for network analysis. Filis, Sabrakos, Yialouris, Sideridis, and Mahaman (2003) presented an integrated geographic expert database system taking advantage of relational database methodology combined with a GIS and an expert system. Rahman, Rusteberg, Gogu, Lobo Ferreira, and Sauter (2012) introduced a new S-MCDM software tool for selecting suitable sites for managed aquifer recharge systems. Joshua, Anyanwu, and Ahmed (2013) developed a model to determine the suitability of an area for agricultural production using soils, slope, water bodies and geological maps of the area to support decision-making for sustainable agricultural production using MCDM and GIS integration. Charabi and Gastli (2011) proposed a GIS-based spatial multicriteria approach to assess land suitability for photovoltaic farms in Oman. Huang, Keisler, and Linkov (2011) reviewed environmental applications of MCDM. A series of queries in the Web of Science database identified over 300 papers reporting MCDM applications in the environmental field published between 2000 and 2009. Furthermore, Rahman et al. (2013) examined the use of MCDM in aquifer area management. A number of studies (San Cristóbal, 2011; Sánchez-Lozano et al., 2013, 2014; Uyan, 2013; van Haaren & Fthenakis, 2011) have dealt with renewable energy site selection periods using GIS and MCDM. In addition, the use of GIS and MCDM in the landfill site selection process has been the subject of many recent investigations (Alanbari, Al-Ansari, & Jasim, 2014; Donevska, Gorsevski, Jovanovski, & Peševski, 2012; Huang et al., 2011; Nazari, Salarirad, & Aghajani Bazzazi, 2012; Şener, Sener, & Karagüzel, 2011). Finally, many other studies have covered additional site selection processes employing GIS and MCDM (Behzadi & Alesheikh, 2013; Rikalovic, Cosic, & Lazarevic, 2014).

The integration of S-MCDM and GIS has been used to solve many spatial problems. In this study, the spatial problem of NGTP routing has been solved in the same way. In addition, this study has determined the optimum S-MCDM method by evaluating and comparing the SAW, AHP and TOPSIS techniques.

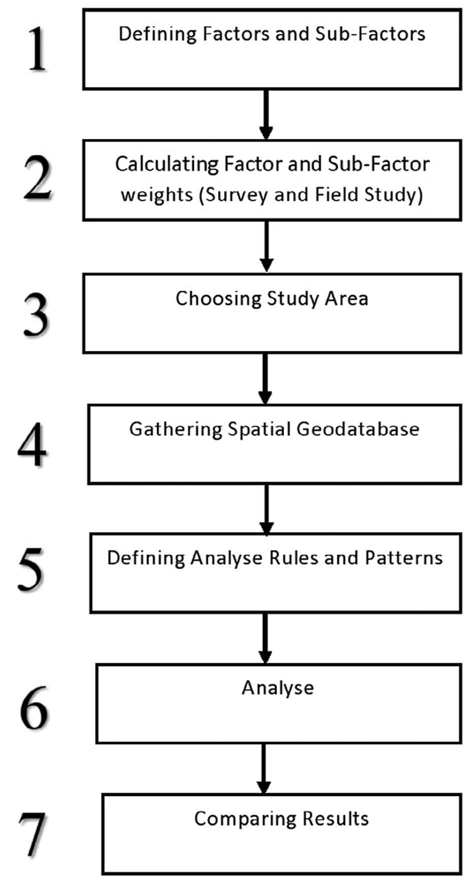


Figure 1. Workflow schema of the study.

2. Methods and materials

Solving spatial-based decision problems usually requires an intelligent and integrative use of information, domain-specific knowledge and an effective means of communication. Although GIS and MCDM play important roles in solving spatial decision-making problems, each of these tools has its own limitations in dealing with such problems. For instance, GIS is a great tool for handling physical suitability analysis. However, it has limited capabilities for incorporating the decision-makers' preferences and heuristics into the problem-solving process. There is a wide range of related methodologies, including S-MCDM, which endeavour to solve 'real-world' GIS-based planning and management problems. They offer a variety of techniques and practices which incorporate knowledge from various disciplines in addition to integrating the decision-makers' preferences. The workflow process is shown in Figure 1.

2.1. *Spatial analytic hierarchy process (S-AHP)*

The AHP is one of the most popular methods used to obtain criteria weights in MCDM (El-Abbasy, Senouci, Zayed, & Mosleh, 2015; Nyström & Söderholm, 2010) and has been employed in GIS-based MCDM. It calculates the needed weights associated with criterion map layers via the help of a preference matrix where all identified relevant criteria are compared against each other with preference factors. The weights can then be aggregated with the criterion maps in a way similar to weighted combination methods. The GIS-based AHP is popular because of its capacity to integrate a large amount of heterogeneous data and the ease in obtaining the weights of a large number of criteria; therefore, it has been applied in tackling a wide variety of decision-making problems (Chen et al., 2010).

The principle of comparative judgement deals with the development of a solid base for establishing priorities among the decision parameters. Local priorities are obtained by comparing each node qualitatively with each of its peers with respect to its parent node using the nine levels of the fundamental scale of preferences. Technically, this is achieved by forming pairwise comparison matrices (PCM) $A = [a_{ij}]_{n \times n}$, in which the ratio a_{ij} assigned by the decision-makers expresses the dominance relation of the factor in row i when it is compared with the factor in column j. The measure of the dominance relation is determined using the strict preference (A_iPA_j) and indifference (A_iIA_j) preference structures (Equations (1) and (2)). Consequently, the PCM are positive and reciprocal (Equation (3)), and the elements in the diagonal are equal to 1 (Equation (4)). Local or relative priorities or weights are then established as the principal Eigenvalue λ_{max} of the PCM solving the system of Equation (5). When the transitive property holds (Equation (6)), the matrix is consistent, and $\lambda_{max} = n$. In real-life situations, it is very rare to obtain consistent judgements by decision-makers; thus, AHP provides measures of inconsistency as a function of the deviation between λ_{max} and n. Finally, global priorities at each node of the hierarchy are calculated by weighting the local priorities with the weights of the corresponding parent nodes. When $\boldsymbol{w}_{k-1}$ is the vector of global priorities (weights) of the elements in the level (k–1), $\boldsymbol{W}_k$ is the matrix of local priorities of the level k with respect to elements of level (k–1). The global priorities at the level k are given by $\boldsymbol{w}_k = \boldsymbol{W}_{k\times}\boldsymbol{w}_{k-1}$. Since local and global priorities are the same at the second level ($\boldsymbol{w}_1 = [1]$), the global priorities at the level p can be computed by Equation (7).

$$A_iPA_j \rightarrow a_{ij} > 1 \tag{1}$$

$$A_iIA_j \rightarrow a_{ij} = 1 \tag{2}$$

$$a_{ij} = 1/a_{ij} \tag{3}$$

$$a_{ij} = 1 \tag{4}$$

$$(A - \lambda_{\max} I) \times w = 0 \tag{5}$$

$$a_{ij} = a_{ik} \times a_{kj} \tag{6}$$

$$w_p = W_p \times W_{p-1} \times \dots W_3 \times w_2 \tag{7}$$

2.2. Spatial technique for order preference by similarity to ideal solution (S-TOPSIS)

Another method commonly used is the TOPSIS. This method is currently used to identify solutions that are as close as possible to an ideal solution, while applying some measure of distance; consequently, indicated solutions are called compromises. The main idea of TOPSIS is that the solution should be as far as possible from the worst possible solution and as close as possible to the best possible solution. This method is quite simple and intuitive, presenting a satisfactory performance in many applications. The TOPSIS method has four advantages: (1) a sound logic that represents the rationale of human choice; (2) a scalar value that accounts for both the best and the worst alternatives simultaneously; (3) a simple computation process that can be easily programmed; and (4) performance measures for all alternatives that can be visualised on a polyhedron for any two dimensions (Wang & Wang, 2014).

The procedure of TOPSIS can be expressed in a series of steps (Billah & Alam, 2014; Yadollahi, Abd Majid, & Mohamad Zin, 2015):

Step 1: Establish a decision matrix for the ranking. The structure of the matrix can be expressed as follows:

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ \cdot\cdot \\ \cdot\cdot \\ A_3 \\ . \\ . \\ A_J \end{array} \begin{array}{c} \begin{array}{ccccccc} F_1 & F_2 & \cdot\cdot & F_j & \cdot\cdot & F_n \end{array} \\ \left| \begin{array}{ccccccc} f_{11} & f_{12} & \cdot\cdot & f_{1j} & \cdot\cdot & f_{1n} \\ f_{21} & f_{22} & \cdot\cdot & f_{2j} & \cdot\cdot & f_{2n} \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ f_{i1} & f_{i2} & \cdot\cdot & f_{ij} & \cdot\cdot & f_{in} \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot & \cdot\cdot \\ f_{J1} & f_{J2} & \cdot\cdot & f_{Jj} & \cdot\cdot & F_{Jn} \end{array} \right| \end{array} \tag{8}$$

where A_j denotes the alternatives j, $j = 1, 2,\dots, J$; F_i represents the ith attribute or criterion, $i = 1, 2,\dots, n$, related to the ith alternative; and f_{ij} is a crisp value indicating the performance rating of each alternative A_i with respect to each criterion F_j.

Step 2: Calculate the normalised decision matrix R (=$[r_{ij}]$). The normalised value r_{ij} is calculated as:

$$r_{ij} = \frac{f_{ij}}{\sqrt{\sum_{j=1}^{n} f_{ij}^2}}, \quad j = 1, 2, \dots, J; i = 1, 2, \dots, n \tag{9}$$

Step 3: Calculate the weighted normalised decision matrix by multiplying the normalised decision matrix by its associated weights. The weighted normalised value v_{ij} is calculated as:

$$V_{ij} = w_i \times r_{ij}, \quad j = 1, 2, \dots, J; I = 1, 2, \dots, n \tag{10}$$

where w_i represents the weight of the ith attribute or criterion.

Step 4: Determine the positive-ideal and negative-ideal solutions.

$$A^+ = \{ v_1^+, v_2^+, \dots, v_i^+ = \{(\max v_{ij} |\ i \in I'), (\min v_{ij} | i \in I'') \tag{11}$$

$$A^- = \{ v_1^-, v_2^-, \dots, v_i^- = \{(\min v_{ij} |\ i \in I'), (\max v_{ij} | i \in I'') \tag{12}$$

where I' is associated with the positive criteria, and I'' is associated with the negative criteria.

Step 5: Calculate the separation measures, using the n-dimensional Euclidean distance. The separation of each alternative from the positive-ideal solution (D_j^+) is given as:

$$D_j^+ = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^+)^2}, \quad j = 1, 2, \dots, J \tag{13}$$

Similarly, the separation of each alternative from the negative-ideal solution (D_j^-) is as follows:

$$D_j^- = \sqrt{\sum\nolimits_{i=1}^{n}(v_{ij} - v_i^-)^2}, \quad j = 1, 2, \ldots, J \tag{14}$$

Step 6: Calculate the relative closeness to the ideal solution and rank the performance order. The relative closeness of the alternative A_j can be expressed as:

$$CC_j^+ = \frac{D_j^-}{D_j^+ + D_j^-}, \quad j = 1, 2, \ldots, J \tag{15}$$

Since $D_j^- \geq 0$ and $D_j^+ \geq 0$, then clearly $CC_j^+ \in [0, 1]$. The larger the index value, the better the performance of the alternatives.

2.3. Spatial simple additive weighting (S-SAW)

The SAW method, also known as the weighted linear combination (WLC) or scoring method, is another common method which was used to design the model. This method is based on the weighted average, where an evaluation score is calculated for each alternative by multiplying the importance of the weight assigned for each attribute by the scaled value given to that alternative on that attribute, followed by a summing of the products for all criteria. This technique was chosen for its easy implementation within a GIS using map algebra operations and for its transparency in aiding decision-making. The standardised rasters were then weighted and combined using the raster calculator. The simple additive function multiplies each distance raster by a weight and then adds together the resulting layers. Weights represent the per cent of influence in the evaluation model and can range from 0 (no influence) to 1 (total influence) with the total of all weights as 1 (Kropp & Lein, 2012).

The mathematic formulation of the method is described by:

$$V_{ij} = \sum_{j=1}^{n} w_j v_{ij}, \tag{16}$$

where V_i is the suitability index for area i, w_j is the relative importance weight of criterion j, v_{ij} is the grading value of area i under criterion j, and n is the total number of criteria. Based on the total cost surface from the study area, S-MCDM examples (out of a 3 × 3 grid) are shown in Figure 2. According to the linear transformation method, sample normalised values are shown in Table 1. The total cost surface according to S-AHP is given in Table 2, for S-TOPSIS in Table 3, and for S-SAW in Table 4.

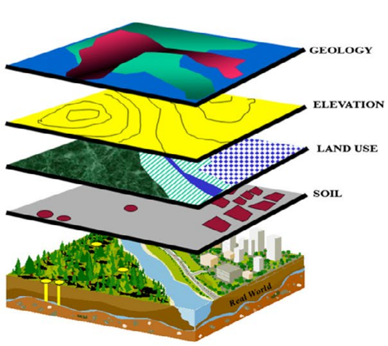
2.4. Factors and factor weights

Important points of NGTP routing include identifying the factors that affect the route, calculating the degree to which the factors affect the route and obtaining spatial data related to these factors. Input data for NGTP route determination such as cost, operation, maintenance and management are also used at different stages of the pipeline project. Proximity to settlements, slopes, roads, infrastructures, protected areas, industrial areas, recreation areas, land cover, geology, soil, power lines, streams, landslides and mines are all factors that were determined according to the questionnaire points, and according to these points, factor scores were calculated using the pairwise comparison method (Table 5). The soil factor included the land use capability class (LUCC). These eight classes provide information about the agricultural value of the soil. Class 1 has excellent potential for agriculture, while Class 8 has no potential for agriculture. Therefore, Classes 1, 2 and 3 were not selected for the pipeline routing.

A survey was conducted for the purpose of identifying the factors and subfactors that affect natural gas pipeline routes. Institutions and organisations in charge of the preliminary project preparation were represented by professionals working and specialising in the field. This survey included 65 contacts, 25 being from the private sector, 23 from government personnel and the remaining from amongst academicians in related areas of study. In order to develop the final stage of the project, the aim was to minimise mistakes during factor and subfactor selection by choosing experienced professionals such as field experts, project planners and technical study experts. The survey was also supported by interviews, and a positive coherency between the survey and the interview results was detected.

In addition, the survey results were analysed statistically via SPSS. Two different indicators were used. The first consisted of central and distributional indicators. In this case, the coherence between the central value (75) and the median value (68.14) was determined. The second evaluation showed that the skewness value (.777) and the kurtosis value (−.601) were in a normal distribution.

A mean test was applied in order to determine the concurrence of the survey. For this, one way ANOVA was utilised as a parametric test, and the confidence level was shown to be 95% ($p = .000 < .05$), thus indicating that the results were significant.



Geology			Elevation			Soil			Land use			
13	8	5	330	364	387	6	6	4	10	6	2	
12	7	2	335	363	384	6	3	3	10	10	6	
11	6	1	341	364	381	4	3	3	6	6	2	
0.3			0.2			0.1			0.4			Ordering
0.314			0.121			0.068			0.497			Pairwise

Figure 2. Calculated weights according to sorting and PCM, with sample raster layers.

Table 1. According to the linear transformation method with sample normalised layers.

Pixel value	9	8	5	220	230	235	5	8	4	3	4	5
	1	7	2	185	230	290	6	3	1	1	2	5
	5	6	1	160	200	245	2	3	3	5	8	9
Maximum value	9	9	9	290	290	290	8	8	8	8	9	9
Normalised value	1.00	.89	.56	.76	.79	.81	.63	1.00	.50	.38	.44	.56
	.11	.78	.22	.64	.79	1.00	.75	.38	.13	.13	.22	.56
	.56	.67	.11	.55	.69	.84	.25	.38	.38	.63	.89	1.00

Table 2. The total cost surface according to S-AHP.

Geology W:0.314			Elevation W:0.121			Soil W:0.068			Land use W:0.497			AHP cost surface		
1.00	.89	.56	.76	.79	.81	.63	1.00	.50	.38	.44	.56	.635	.664	.583
.11	.78	.22	.64	.79	1.00	.75	.38	.13	.13	.22	.56	.225	.476	.475
.56	.67	.11	.55	.69	.84	.25	.38	.38	.63	.89	1.00	.569	.760	.660

Table 3. The total cost surface according to S-TOPSIS.

Geology W:0.314			Elevation W:0.121			Soil W:0.068			Land use W:0.497			TOPSIS cost surface		
1.00	.89	.56	.76	.79	.81	.63	1.00	.50	.38	.44	.56	.496	.517	.494
.11	.78	.22	.64	.79	1.00	.75	.38	.13	.13	.22	.56	.078	.355	.400
.56	.67	.11	.55	.69	.84	.25	.38	.38	.63	.89	1.00	.538	.761	.607

Table 4. The total cost surface according to S-SAW.

Geology W:0.3			Elevation W:0.2			Soil W:0.1			Land use W:0.4			SAW cost surface		
1.00	.89	.56	.76	.79	.81	.63	1.00	.50	.38	.44	.56	.664	.666	.601
.11	.78	.22	.64	.79	1.00	.75	.38	.13	.13	.22	.56	.286	.518	.501
.56	.67	.11	.55	.69	.84	.25	.38	.38	.63	.89	1.00	.552	.731	.640

Table 5. Factors and factor weights.

	A	B	C	D	E	F	G	H	I	K	L	M	N	O	Scores
A	1	4	7	5	2	1	8	6	3	7	8	5	1	3	17
B	1/4	1	3	1	1/2	1/3	4	2	1	3	5	1	1/3	1	6
C	1/3	1/3	1	1/2	1/5	1/6	1	1	1/4	1	1	1/3	1/7	1/5	2
D	2	1	2	1	1/3	1/4	3	1	1/2	1	3	1	1/5	1/3	4
E	3	2	5	3	1	1	1/6	4	1	5	7	3	1	1	10
F	1	3	6	4	1	1	7	5	2	5	7	3	1	1	12
G	1/7	1/4	1	1/3	6	1/7	1	1/2	1/5	1	1	1/3	1/7	1/5	4
H	2	1/2	1	1	1/4	1/6	2	1	1/3	1	3	1	1/5	1/3	3
I	3	1	4	2	1	1/2	5	3	1	3	5	1	1/3	1	8
K	1/3	1/3	1	1	1/5	1/5	1	1	1/3	1	1/2	1/2	1/6	1/4	2
L	2	1/5	1	1/3	1/7	1/7	1	1/3	1/5	2	1	1/4	1/8	1/6	2
M	4	1	3	1	1/3	1/3	3	1	1	2	4	1	1/4	1/2	6
N	4	3	7	5	1	1	7	5	3	6	8	4	1	2	15
O	1/2	1	5	3	1	1	5	3	1	4	6	2	1/2	1	9

Notes: A: proximity to settlement, B: slope, C: road, D: infrastructure, E: protected areas, F: industrial areas, G: recreation areas, H: land cover, I: geology, K: soil, L: power line, M: stream, N: landslide, O: mine.

Another mean test was applied to determine whether the results were altered due to the career area. Because the career areas were independent from each other, the independent sample t-test was employed, which indicated that the confidence level was 95% ($p = .702 > .05$). This showed the results to be significant in terms of the career and job distribution of those surveyed.

2.5. Least cost path analysis

Route problems including route selection, route planning and optimal route determination can be solved using network analysis based on GIS technologies. Network analysis can be carried out on both vector-based and raster-based data from a non-defined space (Church & Murray, 2009). Most of the time, this can be linked, respectively, to the vector and raster modelling alternatives, where vector data of an existing network are used to build a network topology manageable by algorithms operating on graphs; however, the last option appears to be more adequate when the objective is to explore a free terrain to locate a usable path (Gonçalves, 2010). Nevertheless, applications of network analysis for the route determination of linear engineering structures must be carried out with raster-based data because there is no defined space. Routing with raster-based data is advantageous in that it is simple to perform cost calculation, designing and modelling and to obtain remote sensing data directly in raster format. Among the network analysis techniques, least cost path

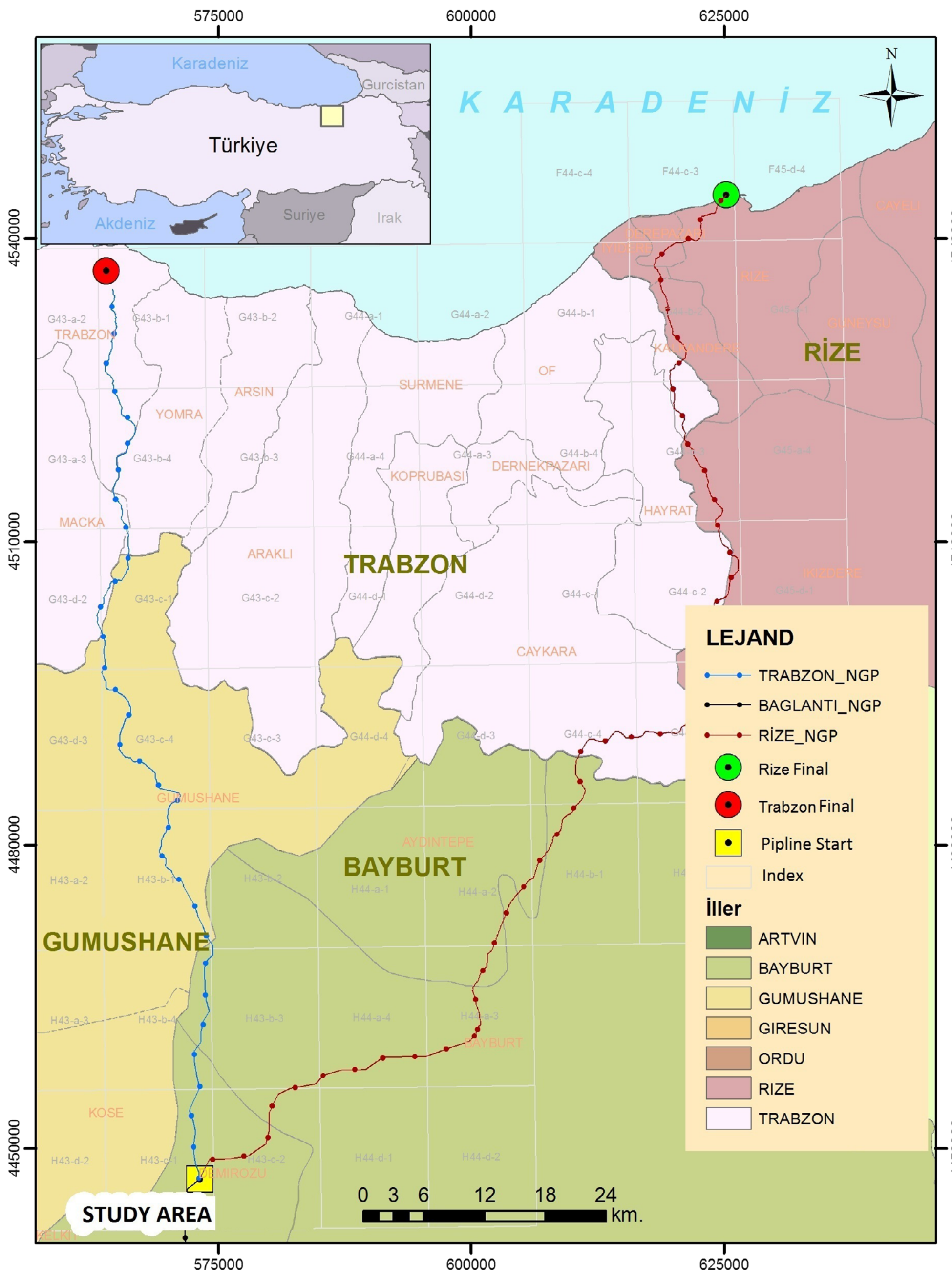


Figure 3. Study area.

analysis (LCPA) is particularly useful for this purpose. The LCPA method allows the user to find the cheapest path from one point to another over a cost or friction surface (Mahini & Abedian, 2014).

3. Study area

The study area is located in the Eastern Black Sea Region of Turkey, covering Trabzon, Gumushane, Bayburt and Rize (Figure 3). On the whole, the land consists of mountains, hills and plateaux. The mountains rise from the coast and there are a number of rivers flowing into the Black Sea, so the region is dominated by rugged terrain. In general, pipelines pass through farmland and forest areas. The agricultural areas consist of tea and hazelnut plantations. Study area data were compiled and a database was prepared with ArcGIS 10.0 software, which included a geodatabase with vector and raster data-set features. The geodatabase consisted of the received data. A single database was created for both raster and vector data. A symbolic structure of the generated database is shown in Figure 4.

4. Results

The Trabzon NGTP is 103.6 km in length and the analyses within the optimisation process and queries, in accordance with the statistical evaluation of the results obtained, are shown in Table 6. The Rize NGTP is 60.89-km long and the analyses within the optimisation process and queries in accordance with the statistical evaluation of the results obtained are shown in Table 7. The S-AHP routes are shown in Figure 5(a) and (b), the S-TOPSIS

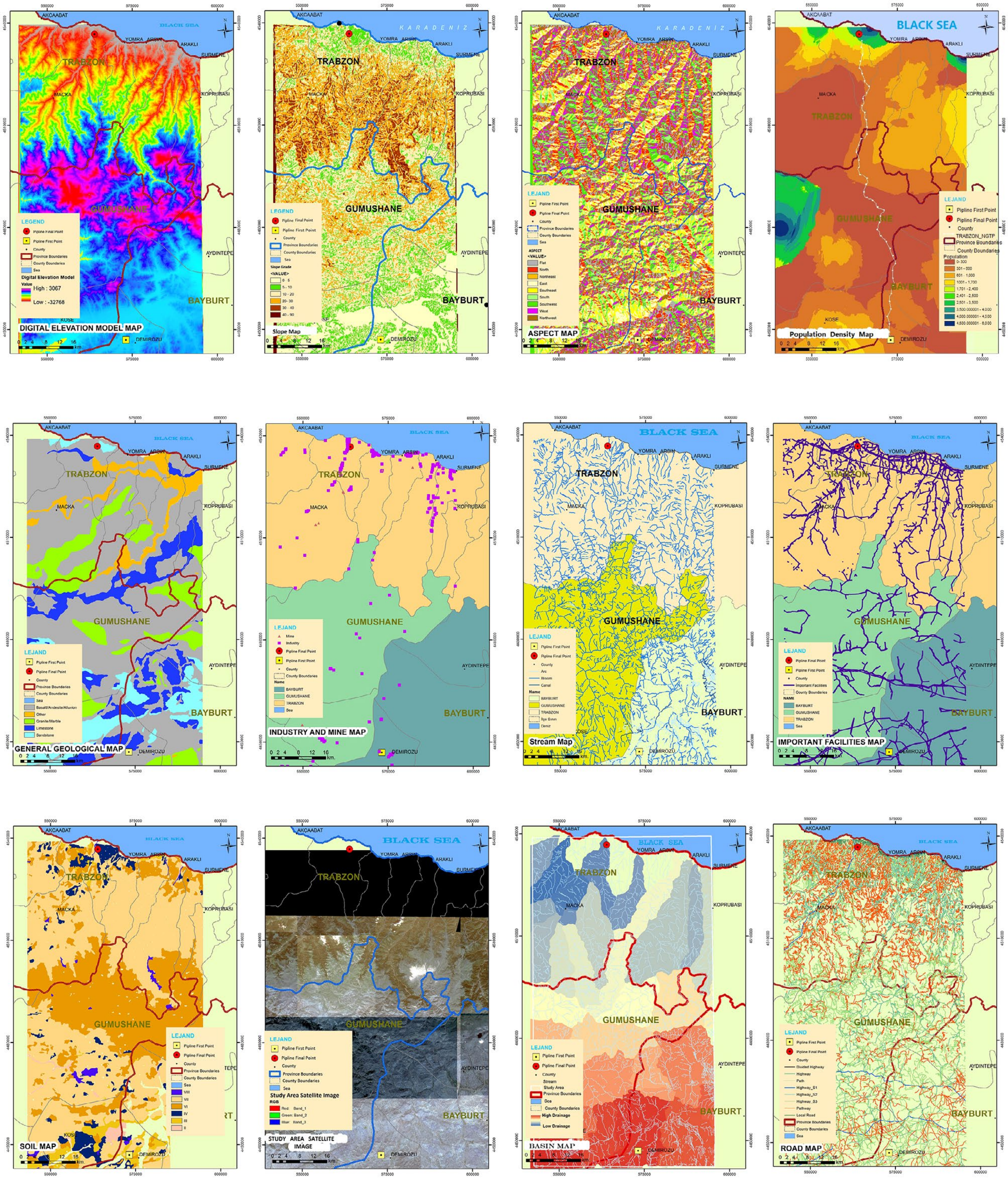


Figure 4. Spatial data layers.

routes in Figure 6(a) and (b) and the S-SAW routes in Figure 7(a) and (b).

4.1. Determination of the most appropriate spatial MCDM methods

In order to decide on the best pipeline route, as a priority, it was necessary to determine the main factor. Although in some studies determination of the factors is based on a questionnaire, in the majority, factors are determined by experts using brainstorming. In this context, in order to decide which alternative routes were more effective, for this study, expert engineers working in BOTAŞ General Directorate, BTC, in coordination with the Şah Deniz project, were consulted in the evaluation of the criteria. In addition, experienced individuals who had worked on the Trabzon and Rize NGTPs (n = 65) were interviewed. Subsequently, a

Table 6. Trabzon TP factors and subfactors related to spatial data.

Factors	Subfactors	AHP (Figure 4(a))	TOPSIS (Figure 5(a))	SAW (Figure 6(a))	CR
Economic	Stream transition	47	46	48	69
	Road transition	158	173	165	177
	Transition of slopes	6.45 km	5.41 km	6.91 km	7.51 km
	Geologic area transition	64.82 km	55.78 km	60.05 km	73.98 km
	Infrastructure transition	23	18	21	37
	Length	94.7 km	104.5 km	97.7 km	103.6 km
Environmental	Forest area transition	9.33 km	9.06 km	7.62 km	8.56 km
	Proximity to protected areas	2.26 km	1.34 km	1.47 km	2.56 km
Sociological	Proximity to settlement	.47 km	.62 km	.64 km	.64 km
	Transition of fertile agricultural areas	4.40 km	1.59 km	1.69 km	1.45 km
	Proximity to recreation areas	1.30 km	1.44 km	.88 km	1.10 km
Sustainability	Proximity to roads	299 m	435 m	422 m	360 m
	Transition of landslide areas	2	1	1	4
	Transition of wetlands	20	24	27	28

Note: AHP: analytic hierarchy process, SAW: simple additive weighting, TOPSIS: ideal point method, CR: current route.

Table 7. Rize TP factors and subfactors related to spatial data.

Factors	Subfactors	AHP (Figure 4(b))	TOPSIS (Figure 5(b))	SAW (Figure 6(b))	CR
Economic	Stream transition	6	2	6	11
	Road transition	13	10	14	17
	Transition of slopes	8.30 km	2.98 km	8.91 km	11.88 km
	Geologic area transition	6.12 km	13.36 km	8.07 km	14.00 km
	Length	44.84 km	70.99 km	4.90 km	60.89 km
Environmental	Forest area transition				
	Proximity to protected areas	1.23 km	1.70 km	1.47 km	.73 km
Sociological	Proximity to settlement	1.47 km	1.62 km	1.64 km	2.64 km
	Transition of fertile agricultural areas	3.28 km	2.01 km	1.64 km	5.59 km
	Proximity to recreation areas	2.30 km	2.44 km	2.58 km	1.10 km
Sustainability	Proximity to roads	576 m	656 m	539 m	420 m
	Transition of landslide areas	3.07 km	.76 km	2.85 km	.10 m

Note: AHP: analytic hierarchy process, SAW: simple additive weighting, TOPSIS: ideal point method, CR: current route.

detailed list of factors was prepared and the selection was made (Table 8). In addition, the process of determining pipeline routes, related factors, subcriteria and weight values identified in other studies were taken into consideration. The information required for the determination of subfactor weights is shown in Tables 6 and 7, and the weights determined in the light of this information in Table 9.

4.2. Evaluation methods with AHP

In the evaluations of the NGTP routes determined by TOPSIS, Trabzon (33%) and Rize (32%) had the highest values (Table 10). The SAW method gave the second highest values for NGTPs, with Trabzon having 30% and Rize 26%. The AHP took third place, with a 24% value for the Trabzon NGTP and 23% for the Rize NGTP. Finally, the current route (CR) NGTPs for Trabzon and Rize at 13 and 19%, respectively, showed the lowest ranking values.

The GIS-based TOPSIS method generally consists of several steps. The process includes the determination of possible options, normalisation of the criterion layers, determination of the weight to be assigned to each criterion, normalisation of layer criteria values via multiplication by the concerned weights, obtaining the normalised weighted layers, determination of the maximum value (which determines the ideal point) for each of the normalised weighted layers, determination of the minimum value (which determines the negative ideal point) for each of the normalised weighted layers using the separation (distance) measurement, determination of the positive ideal point between the distance options using the same separation measurements, determination of the negative ideal point between the distance options and calculation of the relative proximity to the ideal point. According to the ideal point, the options are arranged in descending order. The TOPSIS method uses paired comparison weighting matrices similar to the ranking methods used by AHP and SAW. The routes obtained by the three methods exhibited similar ranking patterns for both Trabzon and Rize; however, the CR in both applications had a very low value.

5. Discussion of the results

The sustainability of NGTP projects depends on the compatibility of the route. This study has shown that determining the route using conventional methods can create many problems. These problems affect the whole project negatively in terms of economic, environmental and sociological factors and impact the cost of the project in terms of sustainability. This recommended model employed raster-based network analyses using GIS and S-MCDM integration. In addition to NGTP, this model can be used for many linear engineering projects (Dedemen, 2013; Hayati, Majnounian, Abdi, Sessions, & Makhdoum, 2013; Kosijer, Ivic, Markovic, & Belosevic, 2012; Yakar & Celik, 2014) since factors and subfactors affecting any linear project route can be determined.

The main purpose of this study was to establish which of the three GIS-based raster network analyses using S-MCDM was

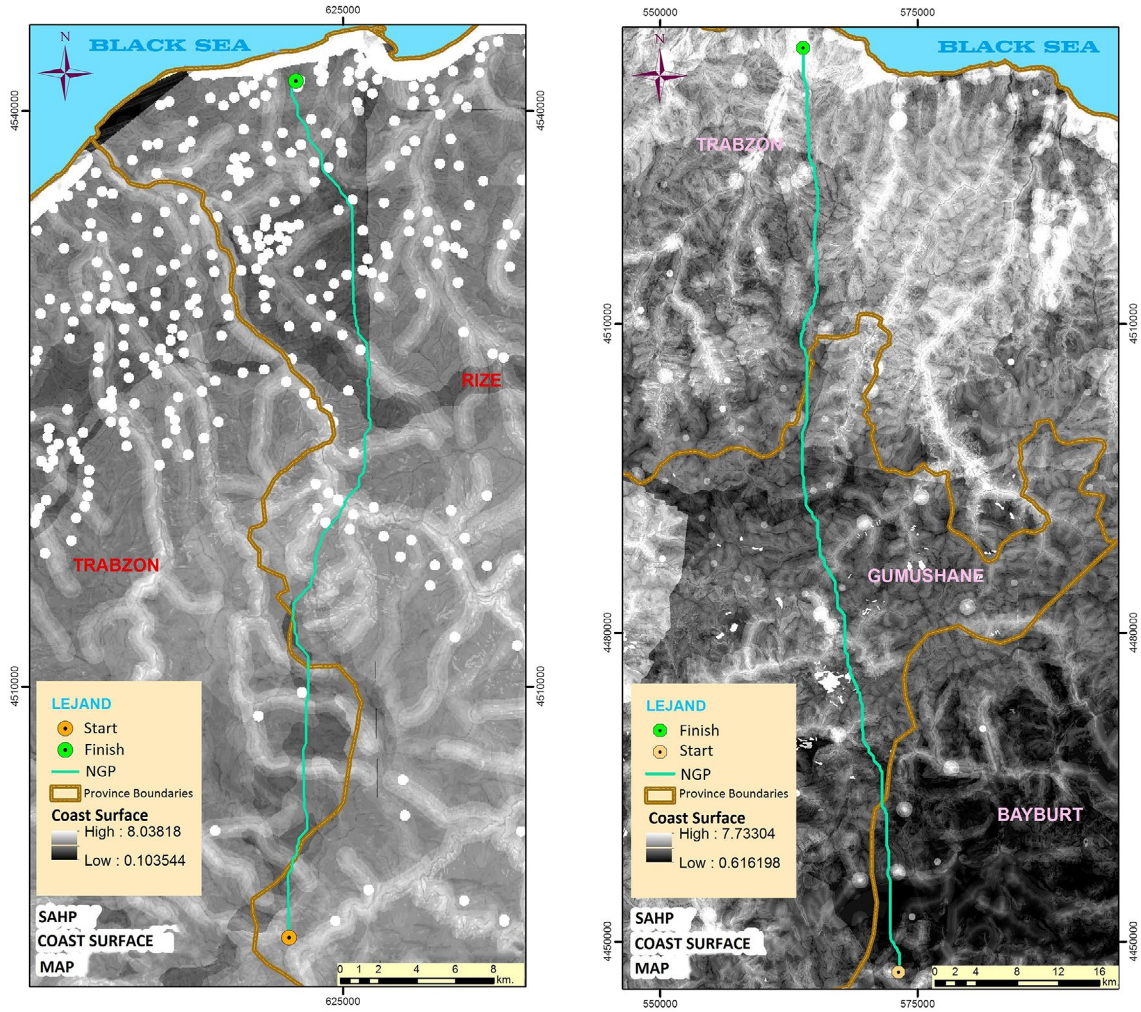


Figure 5. Generated cost surface map via S-AHP: (a) Trabzon; (b) Rize.

the best for NGTP route determination. Results indicated that TOPSIS was the best for these projects and this was confirmed through field studies. The second important point made by the study was that TOPSIS and GIS-based methods lower construction costs by approximately 21%.

When evaluating unit cost value, many factors were considered, including route length, stream transitions, road transitions, transitions of landslide areas, transitions of forest areas, transitions of dangerous geological areas, proximity to settlements, corridor width, average slope and so on. The route located on the model was proven to be 21% less costly when compared with the CR.

There are many different studies affirming GIS and S-MCDM as cost efficient tools for NGTP routes. Some of the current studies are discussed in this section. White et al. (2014) demonstrated that AHP provided effective solutions for offshore pipeline route determinations. Balogun, Matori, and Hamid-Mosaku (2015) reported that the AHP-fuzzy method had many advantages and showed that proper pipeline route selection using GIS had numerous benefits including minimising pipe failures and negative environmental and economic impacts. Dedemen (2013) declared that GIS and S-MCDM were efficient in determining energy transmission lines. In another study, Yakar and Celik (2014) worked on determining highway routes and declared GIS and S-MCDM to be efficient tools for this purpose.

Depending on the length of the project, the use of MCDM to determine the route is a complex process requiring analysis of a combination of several parameters and a plurality of data. The most significant point of this recommended model stresses the use of high-quality data, which is especially a big problem in Turkey. Another significant point is the identification of well-defined factors and subfactors in a sensitive context. Under these circumstances, surveys, interviews and field studies help in arriving at an accurate decision. Applying AHP, TOPSIS and SAW separately under similar conditions allows the route alternatives to be assessed using different mathematical models and the best fitting method and compartments to be chosen.

The GIS has many effective tools which enable the use of analytic functions. The GIS has the capability to combine thematic data layers to create a cost surface from which the optimal route is calculated. Losses of time and labour can be eliminated, thus leading to a considerable reduction in costs. The MCDM method integrates GIS technologies with complex decision-making in a way that provides a successful outcome. This study demonstrated the increased effectiveness of integrating GIS technologies with AHP, SAW and TOPSIS, especially in linear engineering

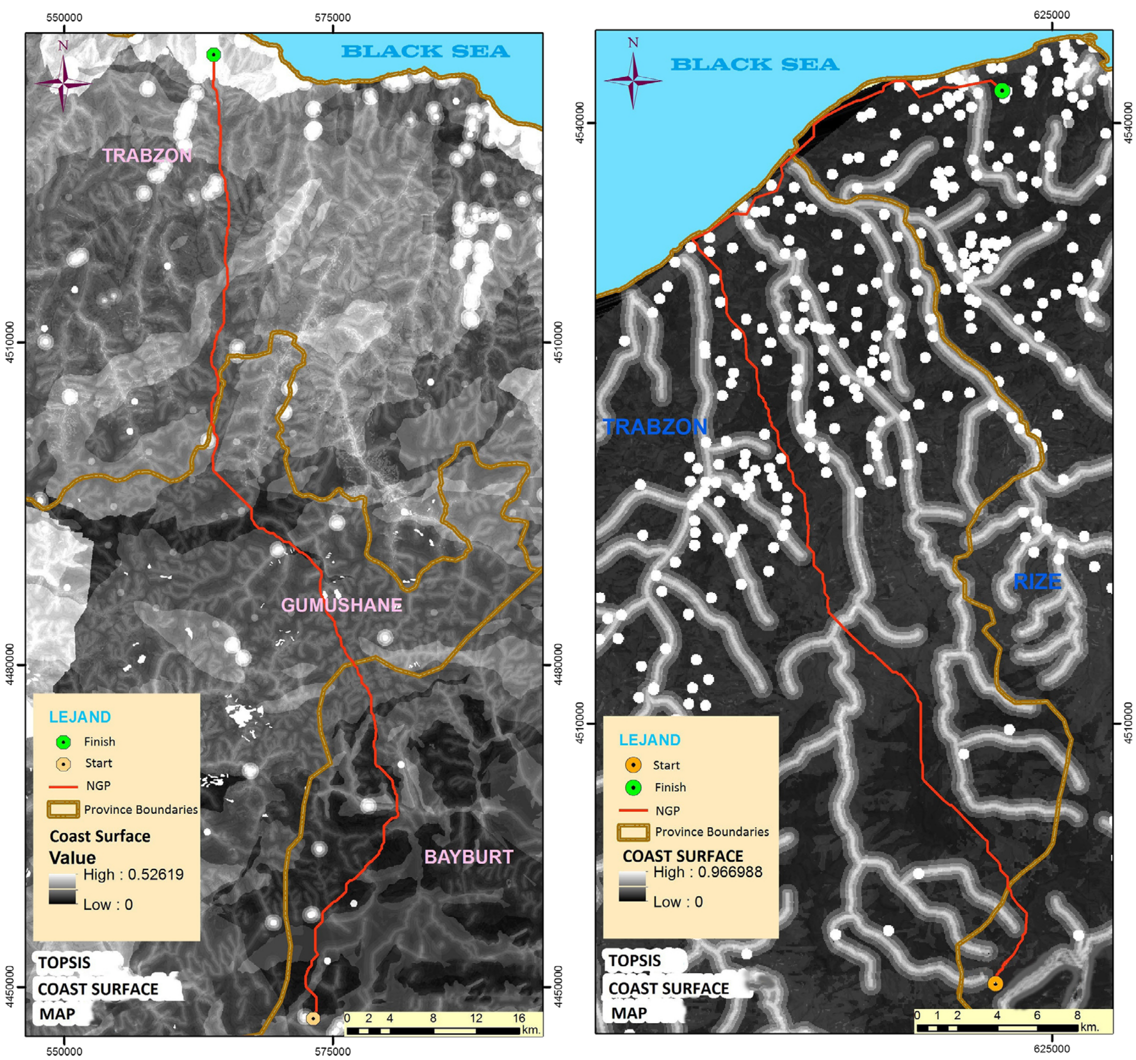


Figure 6. Generated cost surface map via S-TOPSIS: (a) Trabzon; (b) Rize.

structures. The three MCDMs were investigated to find the one offering the most effective solution in integration with GIS. In addition to these three MCDM methods, other spatial-based methods including WLC, elimination and choice expressing reality (ELECTRE) and ordered weighted average (OWA) can also be used in such applications.

There are many different sensitivity analysis techniques for the purpose of testing the sensitivity of an S-MCDM model to any change on any parameter of the model, and these are discussed in this section. According to Chen et al. (2010), three of the most commonly used ways to analyse criteria sensitivity are by changing criteria values, changing the relative importance of criteria and changing criteria weights. This study was interested in varying criteria weights only, with four specific features of interest: (1) investing the stability of an evaluation by introducing a known amount of change to criteria weights; (2) identifying criteria that were especially sensitive to weight changes; (3) quantifying changes in the rankings of criteria and evaluation; and (4) visualising the spatial change of evaluation results. Attention was particularly focused on the stability of evaluation rankings relative to changes in criteria weights in the spatial domain.

According to the workflow schema (Figure 1), the implementation of sensitivity testing should take place during Stages 2, 3 or 6 of the study. The final NGTP route was calculated with cost distance-cost path algorithms running on a raster-based accumulated cost surface. Any changes on the accumulated cost surface would directly affect the final route; therefore, implementing sensitivity tests at the cost surface calculation stage was the correct approach. Thus, a sensitivity analysis was conducted for Steps 2 and 6. Factor and subfactor weights were changed, and the accumulated cost surface was then recalculated with the changing input parameters. The factor weights were calculated at three decimals. The first change was that of decimal accuracy, by calculating at two decimals versus three. The factor weights were then switched crosswise and the accumulated cost surface recalculated. Statistical tests were applied to factor weight tests and the results were positive. At this stage, pure parameter changing tests were applied. The results showed that the developed model was sensitive to changes, as seen in Figures 8 and 9. The histogram at Figure 9 belongs to difference layer between two situations. First is normal raster (accumulated cost surface), the second is different weighted raster. Minus function of Map Algebra analysis in

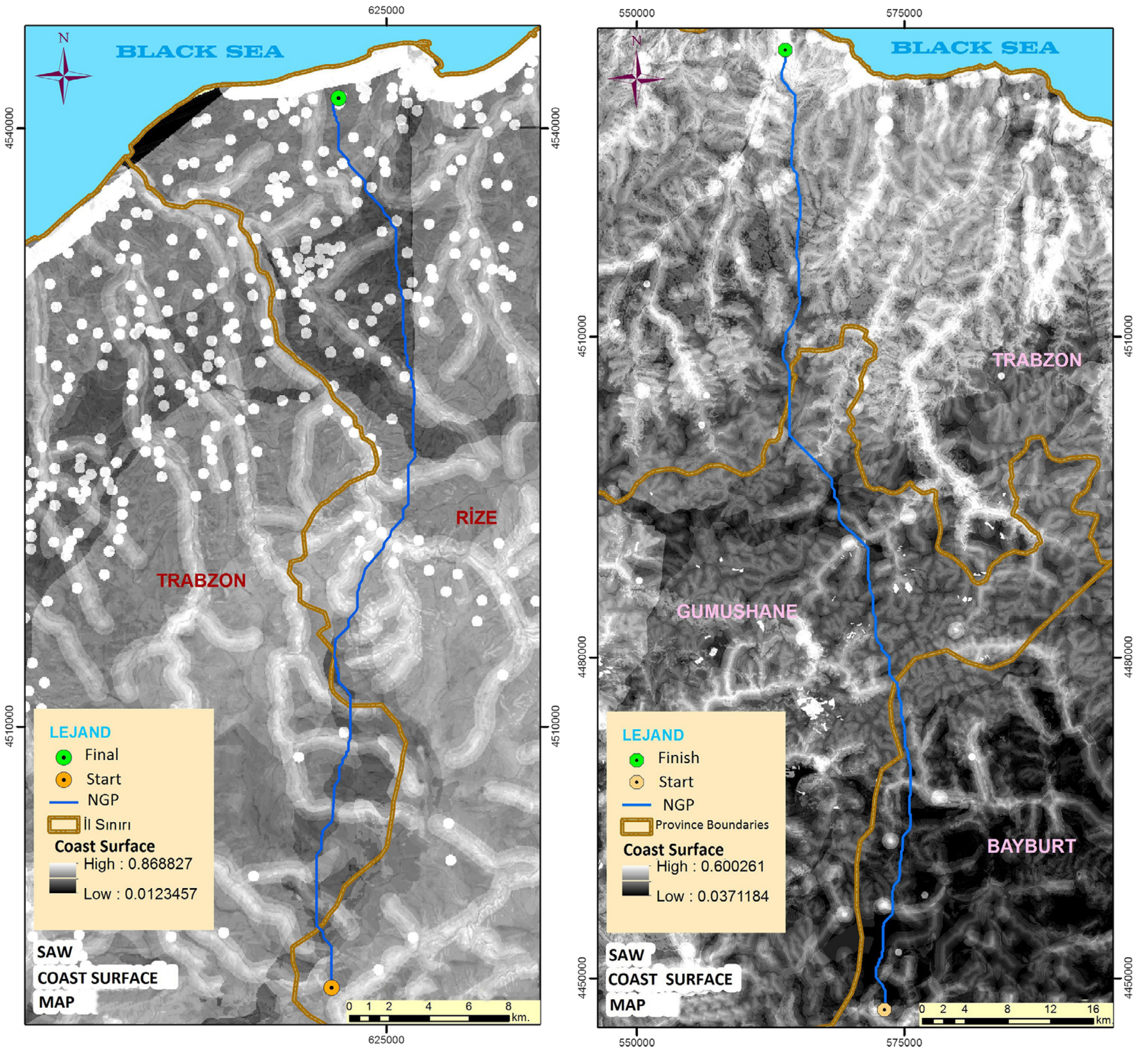


Figure 7. Generated cost surface map via S-SAW: (a) Trabzon; (b) Rize.

Table 8. Factors and weights to determine the optimum route.

	EC	ES	SS	S	Weights
EC	1	1	7	5	.4487
ES	1	1	5	3	.3639
SS	1/7	1/5	1	1/3	.0595
S	1/5	1/3	3	1	.1279
TO: 0.0376 < .10					

Note: EC: economic correspondence, ES: environmental sensitivity, SS: sociological sensitivity, S: sustainability.

Table 9. Subcriteria weights of Trabzon and Rize provinces.

Main factors	Subfactors	For trabzon TP weights	For Rize TP weights
Economic .4487	Stream transition	.181	.211
	Road transition	.103	.133
	Transition of slopes	.136	.166
	Infrastructure	.150	–
	Length	.214	.244
	Geologic area transition	.216	.246
Environmental .3639	Forest area transition	.450	.450
	Proximity to protected areas	.550	.550
Sociological .0595	Proximity to settlement	.582	.582
	Transition of fertile agricultural areas	.309	.309
	Proximity to recreation areas	.109	.109
Sustainability .1279	Proximity to roads	.200	.426
	Transition of landslide areas	.349	.574
	Transition of wetlands	.451	–

Table 10. The evaluation of the optimisation methodology used in TP.

Routes	Trabzon TP route values	Rize TP route values
AHP route	.24	.23
SAW route	.30	.26
TOPSIS route	.33	.32
Current route	.13	.19

Table 11. Statistics of individual layers.

Layer	Min	Max	Mean	STD
1	2,2200	80,6020	31,8865	7,9419
2	2,2200	73,4740	20,4863	11,9881

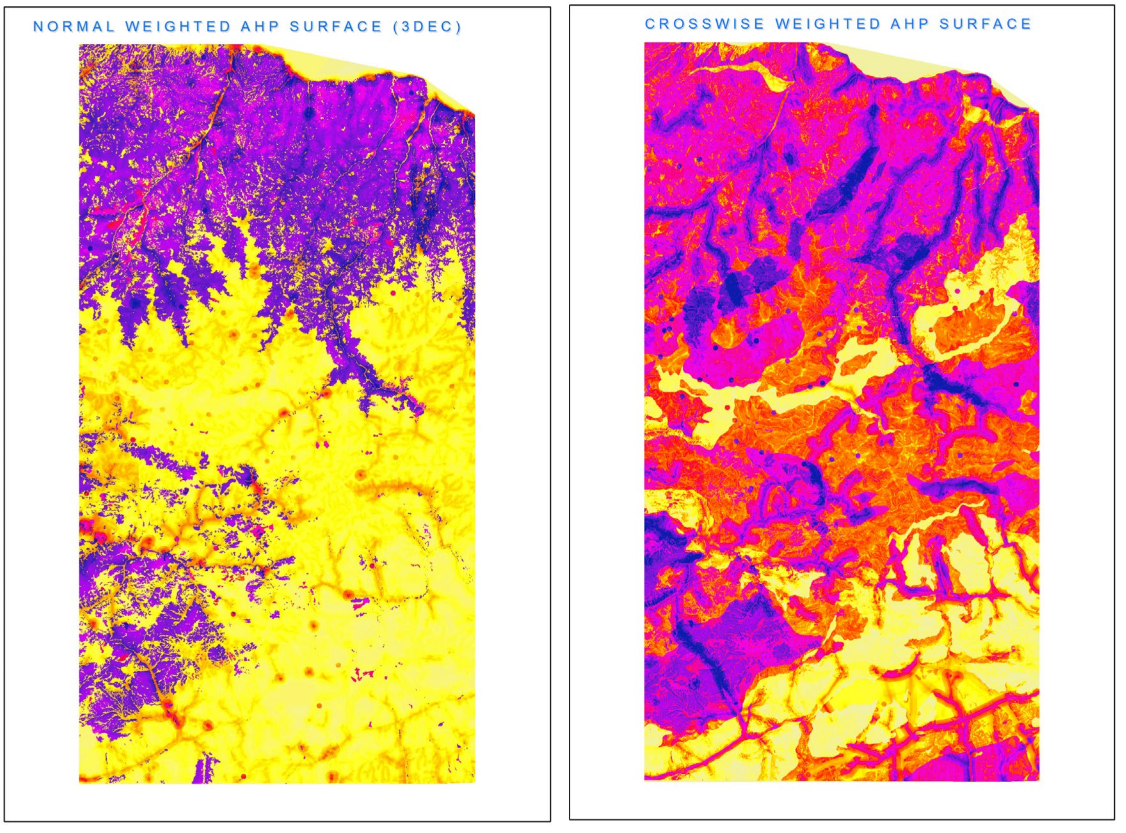


Figure 8. Sensitivity analysis visual results.

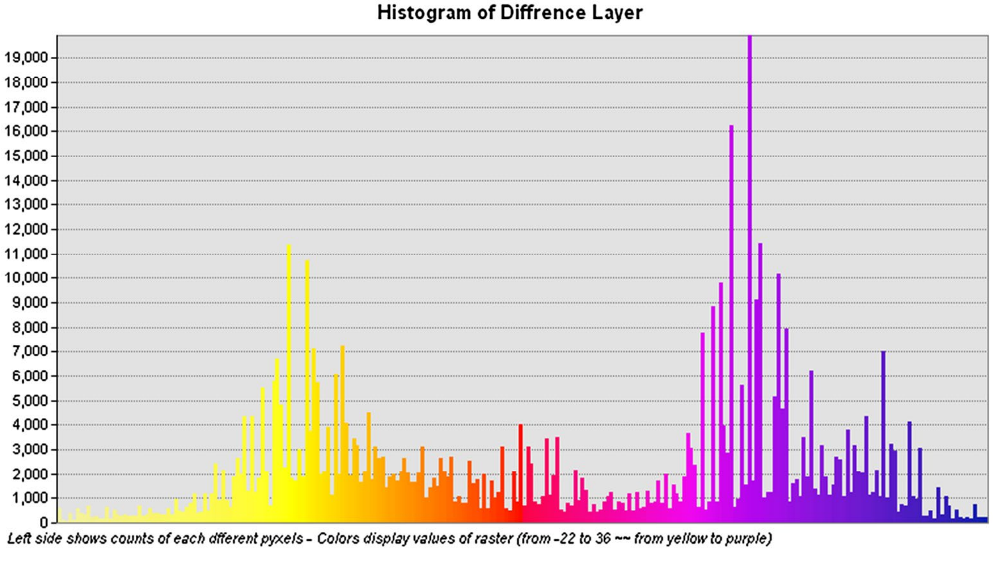


Figure 9. Histogram of compared raster data-sets.

ArcGIS was applied for creating this difference layer. Histogram displays how the pixel values of accumulated cost surface are sensitive to changes. After all differences were compared, the analysis was applied to the different raster data-sets. A histogram of this difference layer is shown in Figure 9, and a statistical summary table is given in Table 11.

6. Conclusions

According to the literature, SAW, TOPSIS and AHP are the most commonly used MCDM methods for route determination projects. In this study, applications were performed and field studies were made. From the obtained results, along with geostatistical considerations, TOPSIS was found to be the most suitable among the three methods. The TOPSIS method can be applied in both raster and vector GIS, although it is much more convenient for raster GIS. With TOPSIS, additional advantages were provided by the use of PCM in the process of determining weights. With the benefit of the algorithm used in the calculation of the cost surface, this method proved quite successful in giving satisfactory results in the determination of NGTP routes.

Ranking, scoring and pairwise comparison methods were used in the determination of the weight factors. The AHP and TOPSIS were used with PCM in the process of determining the route. The SAW was used with the ranking method in determining the route. Determination of weights involves subjective evaluations; therefore, weights may change according to the opinions of the decision-makers and the characteristics of the study area. Furthermore, results are affected by the different ways in which the weights are being determined, thus causing significant changes. Despite the difficulty in implementation, the PCM method was used effectively in the process of determining the NGTP routes; by controlling the weights to be consistent, more accurate results were produced.

As a result of the applications in this study, four routes in specially selected land areas were chosen, overlay work was done with GIS and a number of tests were carried out in order to verify the accuracy of the positional data. According to the positional deviation values in the test results, the project proved to be within the overall limits of accuracy. The current NGTP route to Trabzon made by BOTAŞ has 177 road transitions, 69 stream transitions, 7.51 km of extreme slope area transitions, 74 km of transitions of hard rock structures and 8.6 km of forest area transitions. The employment of classical methods for the determination of routes increases economic, environmental, social and temporal costs. The findings of this study proved the CR to be 21% more costly than the route located on the model. According to the positional data, 70% of the study area was found to be in locales with slopes of 30%. Particularly in works carried out in the Eastern Black Sea Region, the slope factor will affect the cost much more. It was concluded that the scale of the effects of these factors may increase when creating models.

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