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Evaluation of Proposed Railroad Tracks Compared with an Optimized Route Using the Analytic Hierarchy Process and GIS Techniques

Ayman A. Abdulmawjoud * and Aseel Ibrahim Matti

College of Engineering, University of Mosul, Iraq

*Corresponding author: aymanmawjoud@uomosul.edu.iq

Abstract

Selecting a railway route location is a complex task that requires significant time and effort. This study outlines the application of the Analytic Hierarchy Process (AHP) with a Geographic Information System (GIS) to define the best path and compare it with the proposed tracks. The route starts from Mosul in northern Iraq and ends in Fishkhabour near the Iraqi-Syrian-Turkish border. The preferred path was identified based on a set of spatial criteria. With the aid of a group of decision-makers and experts in railway design and transportation planning, a questionnaire was created to highlight the relative relevance of the location criteria. This was carried out using pairwise comparisons after creating a hierarchical framework to assess the criteria of the criteria. The outcomes of the relative importance criterion showed that the highest relative importance was for water sources, which amounted to 29.7%, while the environmental impact criterion had the lowest value of 6.9%. An equivalent cost surface was formulated, and the route path was determined using various maps and a unique framework for data analysis on the adjusted surface. The prepared route path reduces the worthy cost surface by up to 63% compared with the other routes suggested by the General Company for Iraqi Railways. Earthworks, intersections with irrigation canals and valleys, and path length were also considered to determine the best route. The study showed that the path prepared using the analytical hierarchy process and GIS techniques was the preferred path.

Article Info

Keywords:
AHP, GIS, optimum path, railroad, route location.

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1. INTRODUCTION

Railroads contribute significantly to human life by offering reliable, safe, and economical services, while also being environmentally friendly and stimulating the economy. Early in rail projects, important decisions are made to determine the final route to reduce time and expense and improve productivity. This industry must constantly upgrade to keep up with technological advancements, environmental changes, and rising client expectations [1]. However, it is difficult to plan the location of routes for new railways in a country without considering numerous factors and performing data analysis [2].

To reduce the environmental impacts of various alternatives and facilitate the development of substitute solutions, the evaluation of socioeconomic and technological criteria is also included. The crucial information for location planning comprises the transportation network, zonal boundaries of nations, geology, hydrology, socioeconomic statistics, and elevation [3].

Typically, when planning a railroad, it is necessary to consider the "rules and norms" that apply to railroad design and construction in each country. The old method relies on manual processing of the necessary data and maps to find the most economically advantageous route and choose the most alluring railroad route; however, this method requires a lot of time. It is well known that the use of Geographic Information Systems (GIS) is effective for gathering fundamental data for project decision-making in the railroad industry. The idea of using GIS for rail planning was extracted from conventional map processing methods. It is based on the creation of several base maps, which are accomplished by digitization, dereferencing, and entering data that specify their properties [3].

Dev et al. [4] proposed a study to choose the best railway route between China and India via Nepal. The deficiency of modern geospatial data led the concerned authorities in Nepal to rely on analyses and suggestions from grantor countries, considering the criteria of slope, ground cover, distance to ridges, and distance to rivers.

The selection of a railway route was also studied in the hilly region of India, where geographic information systems (GIS) and the multi-criteria decision-making (MCDM) approach were used. The alignment and viability of a rail path in this study depended on several variables, including slope, stream distance, power line distance, and land use/land cover. A hierarchical approach was applied to compare the criteria [5].

Mukund et al. [6] evaluated the optimal route between two sites in an area outside Allahabad, India. They considered the optimal route to be the one with the lowest cost in route selection that satisfies all relevant technical, environmental, economic, and social criteria. This resulted in four alternative routes being identified. Based on a multi-criteria evaluation, the four routes were compared, and one optimal route was selected. A multi-criteria evaluation was conducted to compare the four route paths using the Analytic Hierarchy Process (AHP) and Surface Cost Analysis (SCA). Ultimately, the technical route with the highest priority index (0.297956) and lowest cost (4619 units) was deemed optimal.

Zeng et al. [7] conducted a systematic review of the factors relevant to alignment selection for highway expansion and reconstruction of the G30 Lianhuo Expressway Jingqing section in China, applying the Analytic Hierarchy Process (AHP) combined with expert judgment to derive weights for each factor. The results indicate that environmental factors carry significant weight, reflecting the growing awareness of environmental protection in contemporary projects.

2. PURPOSE OF THE STUDY

The main objectives of this study are:

1. Finding and designing railway routes utilizing AHP and GIS technology while taking into account the impact of various technical, economic, and ecological issues.
2. Comparing the prepared route with the routes suggested by the General Company for Iraqi Railways.
3. Determining the least-cost path for the railway route by changing the cost surface to form several alternatives of different lengths.
4. Calculate the amounts of excavation and filling for each path to find the best and most economical path.

3. MATERIALS AND METHODS

3.1. Study Area

The proposed railway route starts in Mosul, located in the north of Iraq, and ends in Fishkhabour, near the Iraqi-Syrian-Turkish border. The topography of the area is flat to rolling. The study area was selected to collect data, determine the main and secondary criteria, and conduct the analysis. It is possible to define the boundaries of the study area with the borders of Nineveh Governorate from the western side and from the rest of the regions at a distance of no less than 30 km from the expected and proposed paths. It can be determined geographically at the intersection of the two longitudes (41°18' 0"E and 43° 40' 0"E) at the two latitudes (35° 42' 0"N and 36° 57' 0"N), and its area is approximately 18129 km^2, as the Tigris River bisects the studied area into two unequal parts in area and population. The larger half (the western bank of the river) is known as the right side, whereas the smaller half (the eastern bank of the river) is known as the left side. Figure 1 shows the location of the study area.

The General Company for Iraqi Railways proposed three routes for establishing this track, as shown in Figure 2.

3.2. Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP), which was created by Saaty, is a mathematical method for analyzing complex decisions with multiple criteria to establish pairwise comparison-based weights for criteria and alternatives in an organized manner [8]. The decision uses hierarchical structures to illustrate the decision problem and develop preferences for alternatives based on the judgment of the decision-maker [9]. AHP has become the most popular method used in the decision-making process because of its accuracy, robustness, simplicity, and ability to deal with both tangible and intangible criteria [10].

The methodology of applying the Analytic Hierarchy Process (AHP) includes three steps that begin with resolving the general goal into a number of basic criteria and then into a number of subcriteria. The goal represents the highest level of the hierarchy, the second level represents the main criteria of the hierarchy, and the subcriteria form the third level. The second step is to evaluate the criteria of the hierarchy using paired comparisons. The AHP performs comparisons between the criteria included in the decision appropriately to derive priority tables. Generally, values from 1 to 9 are used to evaluate the criteria of the scale. The numbers used correspond to the strength of preference for one criterion over the other; that is, the data are evaluated according to their importance. The third and final step is to create a pairwise comparison matrix using the measurement theory [8].

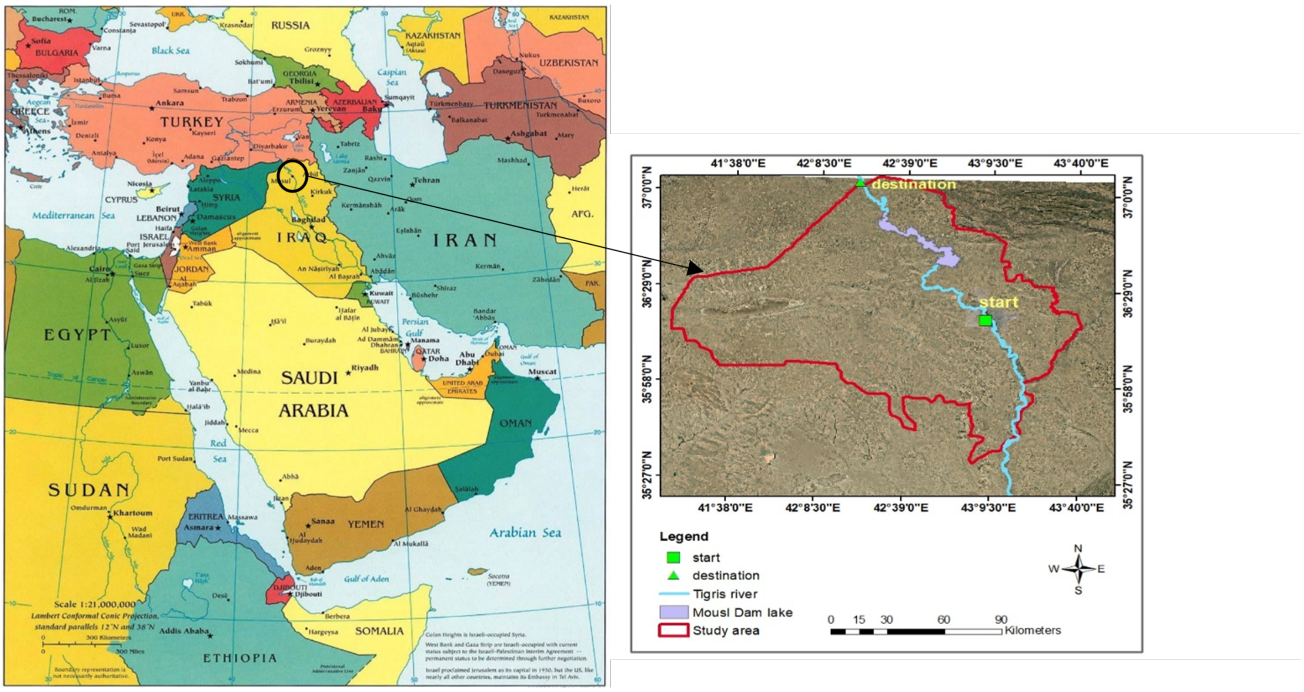


Figure 1. Location of the study area

The consistency ratio is a measurement used to verify pairwise comparisons. The consistency ratio, which quantifies the level of permitted variance, must be lower than 10% [11].

3.2.1. Evaluate the weights of the criteria

A pairwise comparison matrix was created. The criteria are arranged, and values are given for the comparison between the criteria, illustrated by the numbers (1, 2, 3, 4, 5, 6, 7, 8, and 9 or 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, and 1/9), according to the importance of each criterion, as shown in Table 1. This is Saaty's measurement of the relative importance of the two criteria. A group of 47 experts specializing in railway and transportation engineering will evaluate the criteria based on their perspectives and expertise. Each criterion's relative value in relation to another criterion is determined by Saaty's scale for comparison with values from 1 to 9, where a value of 1 indicates equal importance and a value of 9 indicates factors that are given an excessive amount of priority relative to other factors [12]. Table 1 displays Saaty's scale.

3.2.2. Calculate the relative importance of the criteria

In the field of variation in evaluation criteria, the importance of the criteria varies. The weights are typically standardized for the (n) criteria so that they add up to one. The weights are defined as follows:

$$w = (w_1, w_2, \ldots\ldots, w_n)$$
$$\sum_j w_j = 1 \tag{1}$$

An individual or group compares every conceivable pairing and enters the ratings into a pairwise comparison matrix to create a ratio matrix. Because the matrix is symmetrical, only the upper or lower triangle needs to be filled. The remaining cells are the reciprocals of the opposite triangle. The operations listed below can be used to locate the respective weights of the criteria [14, 15].

The first step in calculating the weights is to form a pairwise comparison matrix to facilitate the judgment of the criteria by experts and specialists, as follows:

criteria	A	B	C
A	a_{11}	a_{12}	a_{13}
B	a_{21}	a_{22}	a_{23}
C	a_{31}	a_{32}	a_{33}

Where: A, B, and C represent the criteria adopted in this study. a_{ij}: represents the comparison scales between criteria.

The second step after forming the matrix is to collect the weight of each column of the matrix as follows:

$$\begin{aligned} &\sum \text{column } 1 = a_{11} + a_{21} + a_{31}, \\ &\sum \text{column } 2 = a_{12} + a_{22} + a_{32}, \\ &\sum \text{column } n = a_{1j} + a_{2j} + \cdots + a_{ij} \end{aligned} \tag{2}$$

Where, n is the number of the criteria. The third step involves dividing the value of each number in the column by the sum of the column.

$$b_{ij} = \frac{a_{ij}}{\Sigma_{column}} \tag{3}$$

criteria	A	B	C
A	b_{11}	b_{12}	b_{13}
B	b_{21}	b_{22}	b_{23}
C	b_{31}	b_{32}	b_{33}

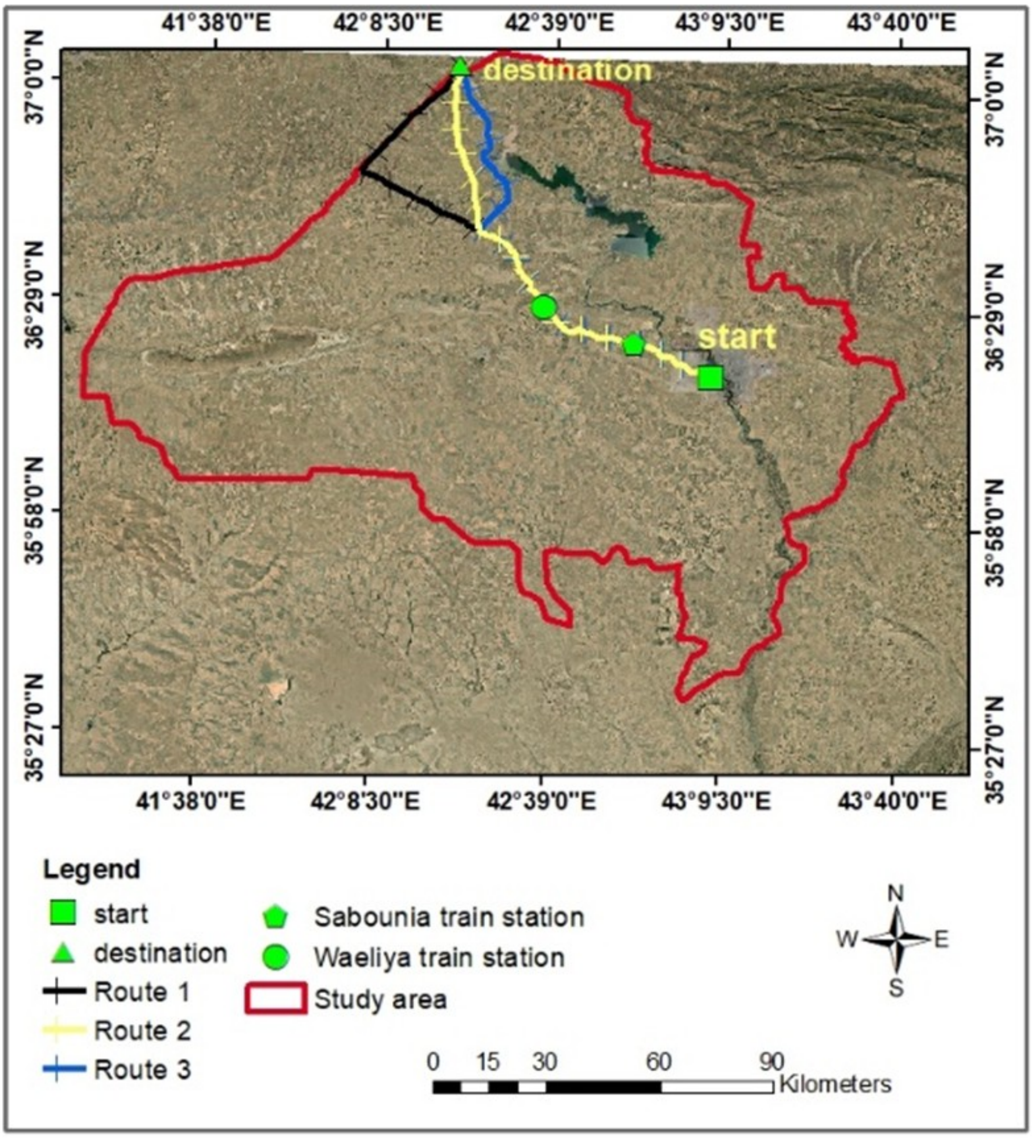


Figure 2. Routes proposed by the General Company for Iraqi Railways

Table 1. Saaty's scales of pairwise comparisons [9, 13]

Intensity of Importance	Definition	Explanation
1	Equal importance	Two criteria contribute equally to the objective
3	Moderate importance of one over another	One criterion slightly outweighs another based on experience and judgment
5	Essential or strong importance	One criterion is substantially preferred over another by experience and judgment
7	Demonstrated Importance	A criterion is very strongly favored, and its dominance is shown in practice
9	Absolute importance	The strongest possible order of affirmation can be found in the evidence supporting one criterion over another
2, 4, 6	Intermediate values between the two adjacent judgments	When compromise is required
Reciprocals	When comparing criteria i and j, if criteria i has one of the aforementioned values assigned to it, then j has the reciprocal value of i.	

The fourth step is adding each row of the matrix.

$$\begin{aligned} \sum \text{row } 1 &= b_{11} + b_{12} + b_{13}, \\ \sum \text{row } 2 &= b_{21} + b_{22} + b_{23}, \\ \sum \text{row } n &= b_{n1} + b_{n2} + \cdots + b_{ni} \end{aligned} \tag{4}$$

The fifth step involved dividing the class total by the number of criteria (n).

$$W_{ij} = \frac{Row_{ij}}{n} \tag{5}$$

The sixth step is to calculate the consistency ratio (stability) of the criteria, which means that the criteria are free of contradictions. Checking the quality of the assessments produced by decision-makers is important. For the decision to be more appropriate, it must be accurate, consistent, and related to the outcomes. Non-contrast is calculated mathematically by finding the value of Lambda (λ), calculating the consistency index, and calculating the consistency ratio based on the value of the random index, as shown in Table 2. The value of the random index was chosen according to the number of approved criteria. The consistency ratio must be less than 10% for the decision to be consistent and the criteria to be related to each other.

Table 2. Random Index values with the number of criteria n [12]

Number of Criteria	1	2	3	4	5	6	7	8	9
Random Index	0.00	0.00	0.58	0.9	1.12	1.24	1.32	1.41	1.45

$$\begin{bmatrix} a_{11} & a_{12} & a_{13} \\ a_{21} & a_{22} & a_{23} \\ a_{31} & a_{32} & a_{33} \end{bmatrix} \times \begin{bmatrix} w_{11} \\ w_{21} \\ w_{31} \end{bmatrix} = \begin{bmatrix} aw_{11} \\ aw_{21} \\ aw_{31} \end{bmatrix}$$

$$\begin{aligned} av_{11} &= \frac{1}{w_{11}} [aw_{11} + aw_{21} + aw_{31}] \\ av_{21} &= \frac{1}{w_{21}} [aw_{21} + aw_{22} + aw_{23}] \\ av_{31} &= \frac{1}{w_{31}} [aw_{31} + aw_{32} + aw_{33}] \end{aligned} \tag{6}$$

To calculate the values of (λ), consistency coefficient (CI), and consistency ratio (CR), the following equations were used:

$$\lambda = \frac{\sum_{i=1}^{n} av}{n} \tag{7}$$

$$CI = \frac{\lambda - n}{eq : 8(8)}$$

$$CR = \frac{CI}{RI} \tag{9}$$

3.3. Methodology

The methodology of the study is represented by the first stage, which represents the physical model and includes preparing the necessary information for the study by defining the starting and ending points of the study. Then, detailed specifications are provided; information on the criteria necessary to choose the best path is identified and collected; the data are analyzed through the process of hierarchical analysis of decisions using the pairwise comparison matrix; and priorities for the criteria are determined based on the judgment of experts and specialists.

The second stage was achieved by entering the information and weights of the criteria that had been examined, ensuring their stability in the GIS program, analyzing the information, and producing the results. In the third stage, the results and paths resulting from the analysis process are verified to select the preferred path. Figure 3 shows the structure of the proposed methodology.

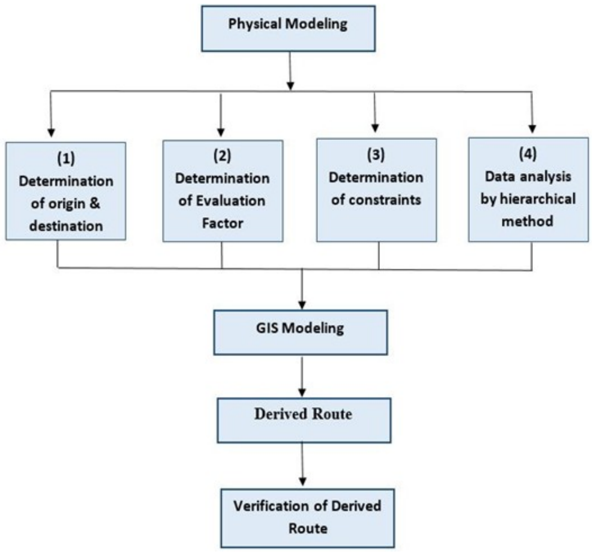


Figure 3. Structure of the work methodology

3.4. GIS-Based Spatial Analysis

This process is based on the concept of weighted averages, where the criteria are unified into a common numerical set and integrated using weighted averages. When decision-makers assign relative importance weights to each criterion derived from the analytic hierarchy approach, a score for each alternative is calculated by multiplying the relative importance of each criterion by its corresponding value of the sub-criteria (attributes) for the criterion itself, and then calculating the sum, thus forming an overall score. This method can be implemented using Geographic Information Systems (GIS) using the overlay abilities of this software, which permits the evaluation of criteria layers and their combination to calculate a composite map layer.

4. APPLICATION

4.1. Data Initialization

To achieve the research objective, useful parameters for selecting railroad routes must be selected. The following parameters were used in the current study:

1– Digital Elevation Model (DEM): It can be used in topographical and hydrological analyses and to determine the magnitudes of elevations and depressions. It was obtained from the United States Geological Survey website via the SRTM radar shuttle with an accuracy of 30 m. Figure 4a shows a map of the digital elevation model used in the study.

2– Land cover: Maps of land cover might be used to select a rail route. A high-resolution land cover map for 2020 was obtained from Sentinel-2 satellite imagery. The map was divided into several categories, including agricultural, built-up, and barren areas. Figure 4b demonstrates the land cover map.

3- Water sources: These include rivers, streams and valleys. As it requires, the construction of railways should be far away from water sources to avoid the construction of bridges and the possibility of floods, which may cause damage to the railway infrastructure. Figure 4c displays a map of water sources, indicating rivers, streams, tributaries, valleys, and their branches.

4– Ground slope: It is essential to choose the most appropriate slope because this parameter has always been an economic, financially costly, and energy-wasting impediment. Areas with lower slopes are more convenient for the construction of railway lines, as they allow locomotives to reach higher speeds while reducing the destruction factor owing to the low engine effort. However, high-slope areas increase costs, engine effort, and fuel expenses while decreasing the speed rate. The topography of Iraq, except for the mountainous region, is a helpful factor in building railway lines and ensuring smooth operation and ease of maintenance. The slopes for the modes of transport and types of trains are shown in Table 3. Figure 4d shows a map of the ground slope of the study area.

Table 3. Longitudinal slope values for different modes of transport [16]

Means of transportation	**Longitudinal slope**
Roadway	8% (roadway with a speed of 60 km/h) not more than 15%-20%
Cog rail	5%-48%
Cable-drive systems (funicular)	9%-120%
Tram	not more than 7%-8%
Metro	not more than 5%
Monorail	not more than 10%, 20% inclination is used in these two cases
Fast-moving network	not more than 3.5%-4%
Suburban train/conventional interurban	not more than 3%-4%

5- Soil bearing strength: The study of soil bearing strength is of great significance in the process of choosing the path of railway lines, as it determines the degree of validity of the fixation, the amount of weight of the rail, and its ability to bear the axial pressure imposed on it. Soil strength information was obtained from relevant departments. Figure 4e. shows the resulting surface of the soil bearing strength using the interpolation approximation in units of KN/m^2 from the GIS program.

6- Irrigation canals: The canals used to transport water for agricultural purposes were divided into five projects within the study area. These canals are the Northern Al-Jazeera Irrigation Project and the Southern Al-Jazeera Irrigation Project, which take water from the Mosul Dam Lake; the Salamiya Irrigation Project and the Eastern Al-Jazeera Irrigation Project, which take water from the Tigris River; and the Zab Irrigation Project, which takes water from the Zab River. These canals will be studied, and attempts will be made to bypass them as much as possible to reduce the cost of railway construction. The irrigation canal tracks were obtained from the Directorate of Water Resources. Figure 4f shows the irrigation canals in the study area.

7- Linear engineering infrastructure: This involves existing roads, railways, pipelines (such as those carrying water and oil), and electric power transmission lines. The intersection of railroads with linear tracks should be minimized to reduce construction costs and increase the safety of transportation. Linear engineering infrastructure data were obtained from the relevant state departments. Figure 4g shows a map of the linear engineering infrastructure.

8- Environmental impact: This includes the environmental impacts that arise from the movement of the train, such as noise and vibration near residential centers and human gatherings, such as districts, sub-districts, and residential complexes. Appropriate buffers will be provided to protect residential centers from the negative environmental impact of train traffic. Figure 4h presents a map of the centers of the districts and sub-districts fixed on the satellite image.

9- Cultural Heritage: Cultural heritage constitutes the identity of every society and nation. Therefore, appropriate prohibitions against trespassing on archaeological sites must be implemented. The information was obtained from relevant government departments.

10- Prohibitions: These involve oil wells, treatment plants, refinery plants, landfill sites, the Badoush cement factory, and water tanks; therefore, the routes must have an appropriate distance so as not to exceed the buffers. Information was obtained from the relevant government departments. Figure 4i shows the prohibited and archaeological sites identified in the satellite imagery.

However, there are areas where it is not desirable for the railway line to pass through because it leads to high construction and operating costs and poses a threat to safety. These undesirable areas include [17].

1- Areas with a ground slope greater than 4.5%,
2- Areas within 100 meters of river banks, and

3- Areas within 50 meters of existing road centers.

4.2. Weighted linear overlay within a GIS environment

GIS plays a significant role in the comprehensive decision-making process because it can perform many spatial tasks. The Weighted Linear Combination (WLC) is one of the most widely applied decision models in GIS. It is a decision base for deriving complex maps, where the decision-maker allocates weights of relative importance to each criterion and then obtains the composite map layer by multiplying the assigned importance weight by the criterion [18].

$$L = \sum w \times x \tag{10}$$

Where L: superposition of layers, w: weight of the criteria, and x: criteria

5. RESULTS AND DISCUSSION

5.1. AHP Results using the EXPERT CHOICE program

The results of the forms were analyzed, and the weights and consistency ratios were determined using the Expert Choice program. Figures (5) and (6) show the weights of the standards derived from the program. The highest relative importance was for water sources (29.7%), followed by ground slope (21.3%). The criterion with the lowest relative importance value was the environmental impact criterion, with a value of 6.9%, which indicates the lack of influence of this factor according to the opinions of experts in choosing the path. However, this is contrary to the views of experts in the study by Zhigang et al. [7].

5.2. Developing a model for choosing a path using GIS programs

The model builder stage, which uses GIS programs to determine and choose the appropriate railway path, is an important stage involving input and output processes and spatial data processing. The data will be used in multiple forms, whether vector or raster, and dealt with to reach the final results that show the best path with the model worked on and configured using the Geographic Information Systems program Arc Map 10.5. The spatial analysis was conducted in two stages, the first of which included the formation of an appropriate model that is represented by identifying the natural and man-made obstacles depending on the Iraqi laws and the General Company for Iraqi Railways using a buffer tool. The second stage includes extracting the cost layer after addressing the different criteria and deducting it according to the suitability model obtained from the first stage. The results of the last layer are used in the process of choosing the best route through the two operations of cost distance and cost path. Figure 7 illustrates the steps for entering, dealing with, and analyzing criteria information in the GIS environment to select the preferred path. Figure 8 shows the results obtained to locate the output path and the proposed paths.

5.3. Evaluation of the output route path

To compare the output path with the other paths proposed by the General Company for Iraqi Railways and to indicate the optimum of these paths, we calculated the cost surface and considered economic considerations in terms of earthworks and intersection with canals and valleys.

5.3.1. Cost surface method

A cost layer is created by overlaying the layers and multiplying each layer by its weight because each cell has a value. The cost layer is classified into 10 cost categories, the number of cells that the path passes through is calculated, and the cells are multiplied by their cost value to obtain the cost of each path.

Table 4 shows the number of cells and cost surface of each path with the percentage increase over the cost surface of the prepared path. The table reveals that the prepared path has the lowest valuable cost surface over the proposed paths by up to 63%.

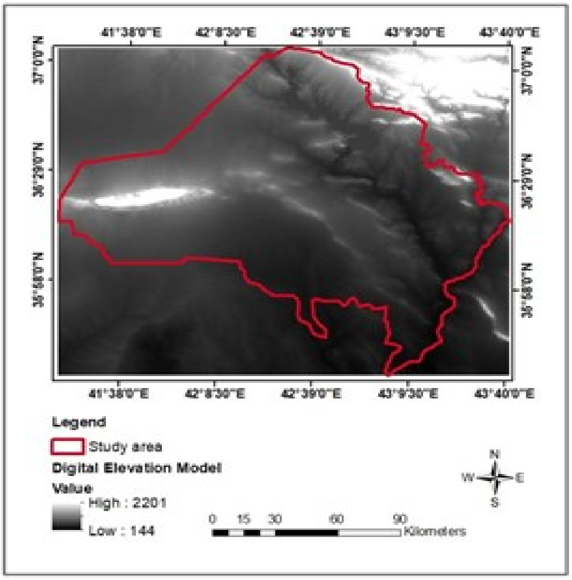
5.3.2. Earthwork quantities

The amounts of excavation and filling for the prepared and proposed paths were calculated using the Civil-3D program, and the length of the paths and the number of intersections with valleys, rivers, and irrigation canals were determined. Table 5 shows the comparison between the paths.

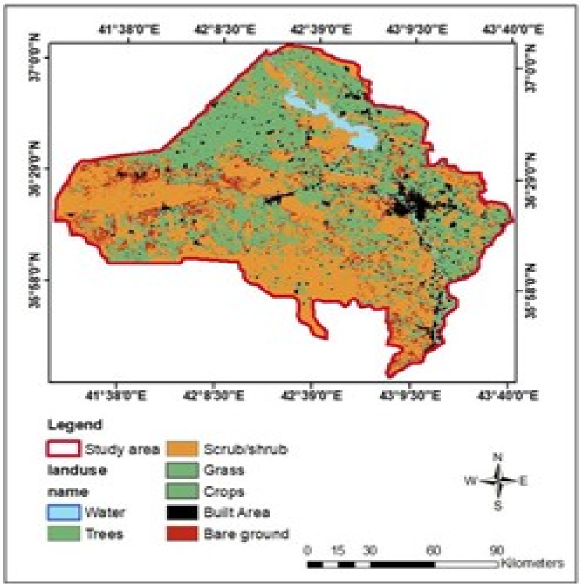
Table 5 shows that the amount of excavation for the prepared path resulting from the analysis process is approximately 598,434 m^3, where the rates of increase in the excavation amounts are 400.5%, 88.8%, and 307.3% for the first, second, and third paths, respectively. The fill quantity for the prepared path was approximately 541,687 m^3, and the rates of increase in the fill quantities were 62.6%, 92.7%, and 91.3% for the first, second, and third proposed paths, respectively. Therefore, it is clear that the earthwork for the prepared path is less than that for the other paths in both excavation and backfilling.

The length of the prepared path resulting from the analysis process was 118.755 km, which was shorter than the proposed paths by 22.9%, 1.5%, and 4.8% for the first, second, and third paths, respectively. Thus, the prepared path was shorter in length than the proposed paths, especially the first proposed path.

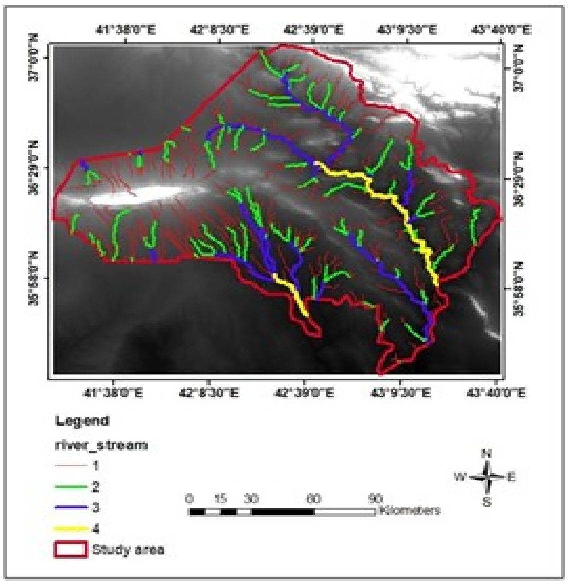
It is evident from the table that the number of intersections with the canals and valleys in the prepared path is



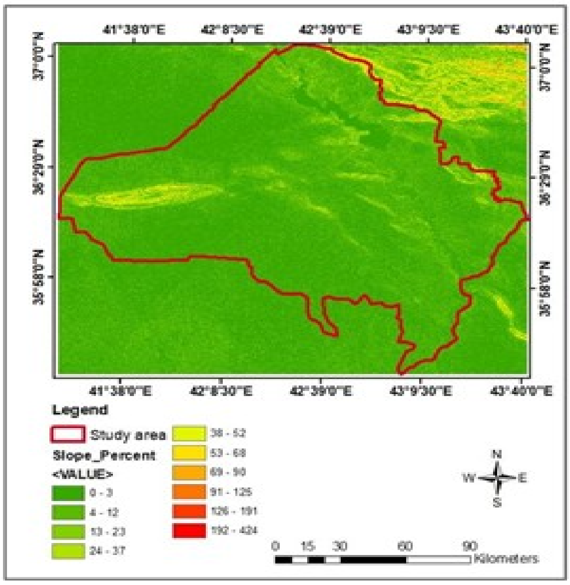
(a) Digital elevation model



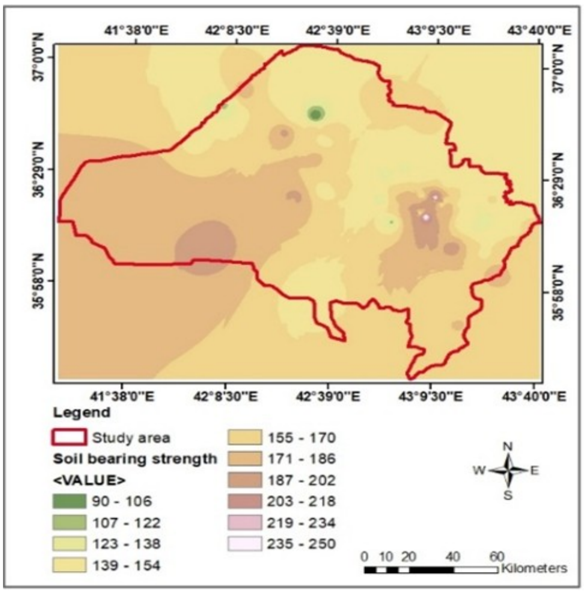
(b) Land cover map



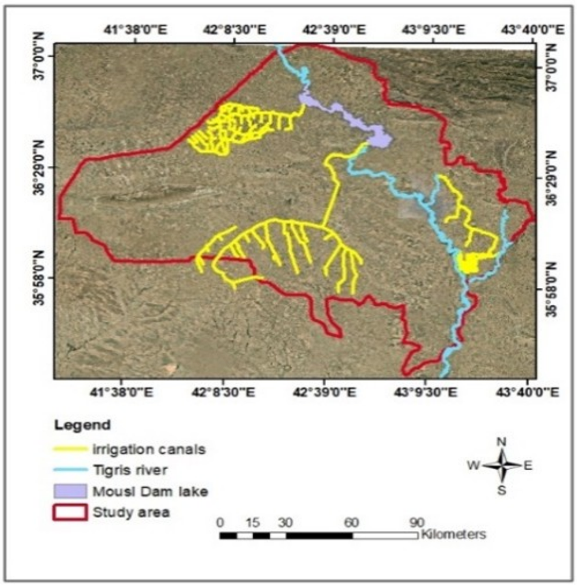
(c) Water sources map



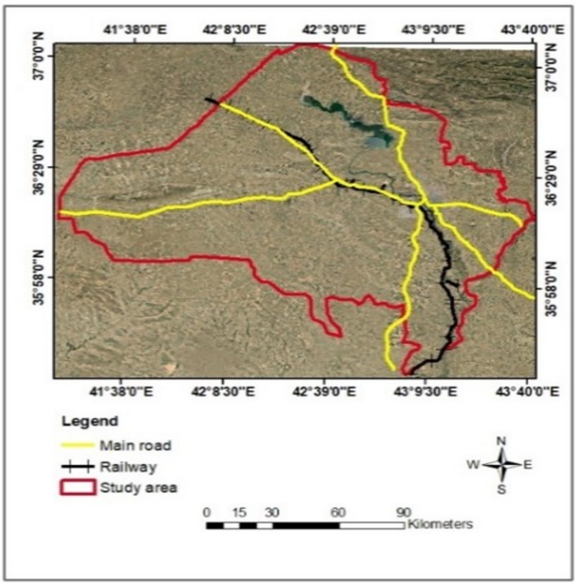
(d) Ground slope of the study area



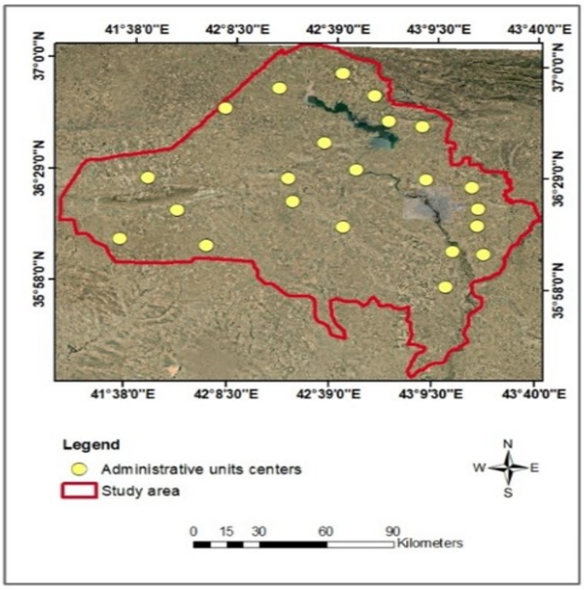
(e) Soil bearing strength map



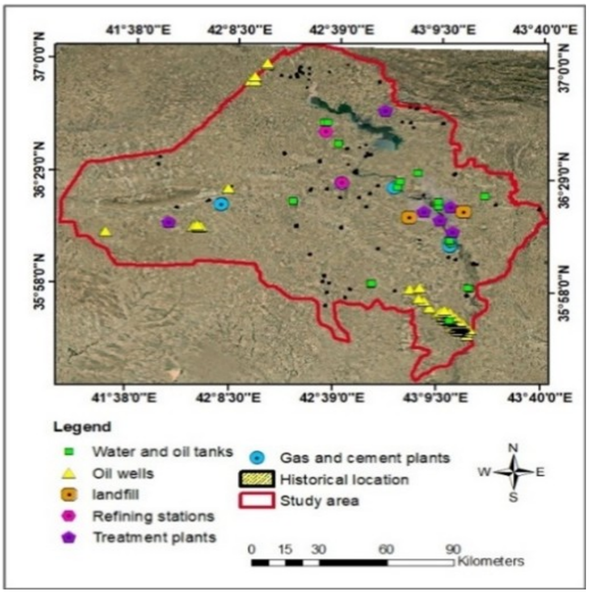
(f) Irrigation canals map



(g) Linear engineering infrastructure



(h) Centers of the districts and sub-districts



(i) Prohibited and archaeological sites installed on satellite visual

Figure 4. Maps prepared for the study area

Table 4. Cost surface of prepared and proposed paths

Cell weight	Value	No. of cell				Cost surface of route			
		Prepared path	First proposal	Second proposal	Third proposal	Prepared path	First proposal	Second proposal	Third proposal
0.79 – 1.64	1	778	778	727	380	945	945	883	462
1.64 – 2.04	2	757	376	194	537	1393	692	357	988
2.04 – 2.44	3	529	143	161	428	1186	321	361	960
2.44 – 2.84	4	489	1281	1050	1084	1291	3381	2771	2861
2.84 – 3.24	5	274	656	560	596	832	1992	1700	1809
3.24 – 3.63	6	216	490	431	457	741	1682	1479	1568
3.63 – 3.99	7	236	203	192	188	899	773	731	716
3.99 – 4.38	8	379	312	335	268	1587	1306	1403	1122
4.38 – 4.92	9	138	441	285	291	642	2052	1326	1354
4.92 – 6.79	10	22	439	307	322	129	2570	1798	1885
SUM		3818	5119	4242	4551	9644	15714	12809	13726
% Increase over the prepared path		——	34	11	19	——	63	33	42

less than that in the other proposed paths. Therefore, the path prepared using the Analytical Hierarchy Process with the GIS technique was the preferred path.

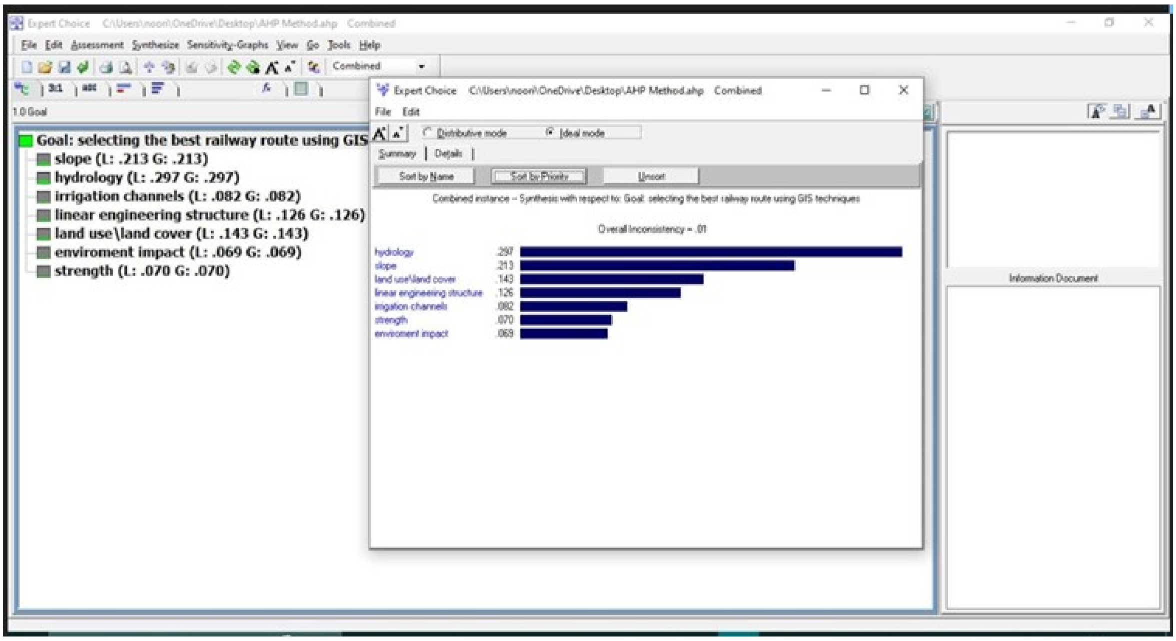


Figure 5. Outputs of the EXPERT CHOICE program

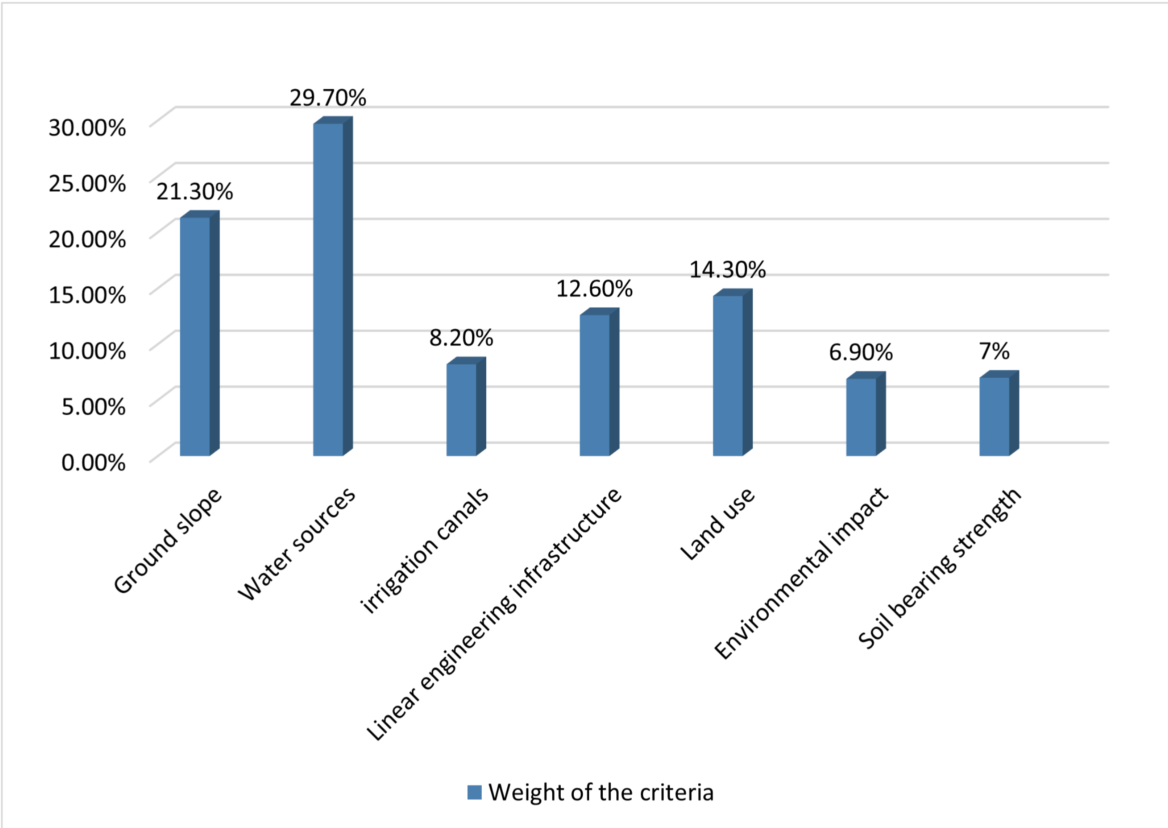


Figure 6. The relative weight of the criteria

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions and recommendations can be drawn from the outcomes of the study:

1- The relative importance of the following criteria was adopted in locating the route path of the railway: ground slope, water sources, irrigation canals, linear engineering infrastructure, land use, environmental impact, and soil bearing strength. The highest relative importance was for water sources (29.7%), followed by ground slope (21.3%). The criterion with the lowest relative importance value was the environmental impact criterion, with a value of 6.9%, which indicates

Table 5. Comparative quantities between the paths

Factor	**Route performance**			
	Prepared path	**First proposed path**	**Second proposed path**	**Third proposed path**
Cut volume (m^3)	598,434.27	2,994,893.51	1,129,773.02	2,437,149.73
Fill volume (m^3)	541,687.00	880,965.49	1,044,084.41	1,036,077.57
Net volume (m^3)	56,747.27	2,113,928.02	85,688.61	1,401,072.16
Length (km)	118.755	145.950	120.572	124.490
No. of intersections with irrigation canals	2	4	2	2
No. of intersections with valleys	6	9	8	10
Percentage increase in the factors for the proposed paths over the prepared path				
Cut volume (m^3) %	....	400.455	88.788	307.254
Fill volume (m^3) %	....	62.634	92.747	91.269
Length (km) %	....	22.900	1.530	4.829

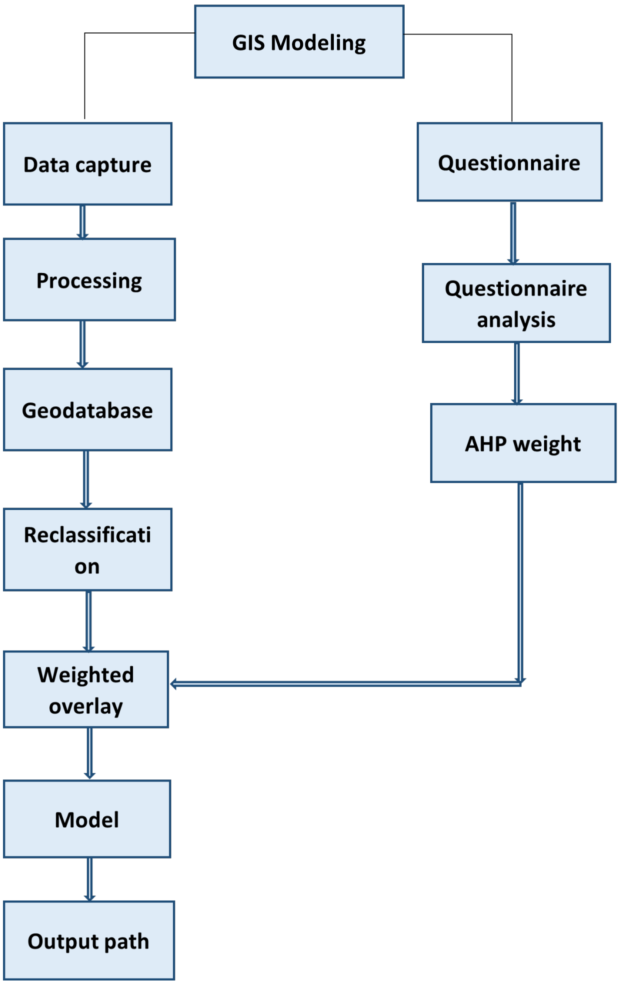


Figure 7. Steps for entering information for the GIS program to choose the output path

the lack of influence of this factor according to the opinions of experts in choosing the path.

2- The relative importance values for the other criteria, which are irrigation canals, linear engineering infrastructure, land use, and soil bearing strength, are 8.2%, 12.6%, 14.3%, and 7%, respectively.

3- The prepared path has the lowest surface valuable cost over proposed paths obtained from the General Company for Iraqi Railways between 33% to 63%.

4- The results of the analysis of the route paths in the study area showed that the earthwork quantities for the prepared path were significantly less than those for the other proposed paths. Moreover, the prepared path shows the shortest of the three proposed paths, as the ideal path length reached 118.755 km, which is shorter than the proposed paths by 22.9%, 1.5%, and 4.8% for the first, second, and third paths, respectively.

5- It is recommended to use GIS programs for defining the least expensive path by spatial criteria.

6- For further studies, it is recommended to conduct a sensitivity analysis to establish the stability of the optimal path when adjusting the weights of the parameters.

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Conflict of Interest

The authors have declared that no conflict of interest exists.

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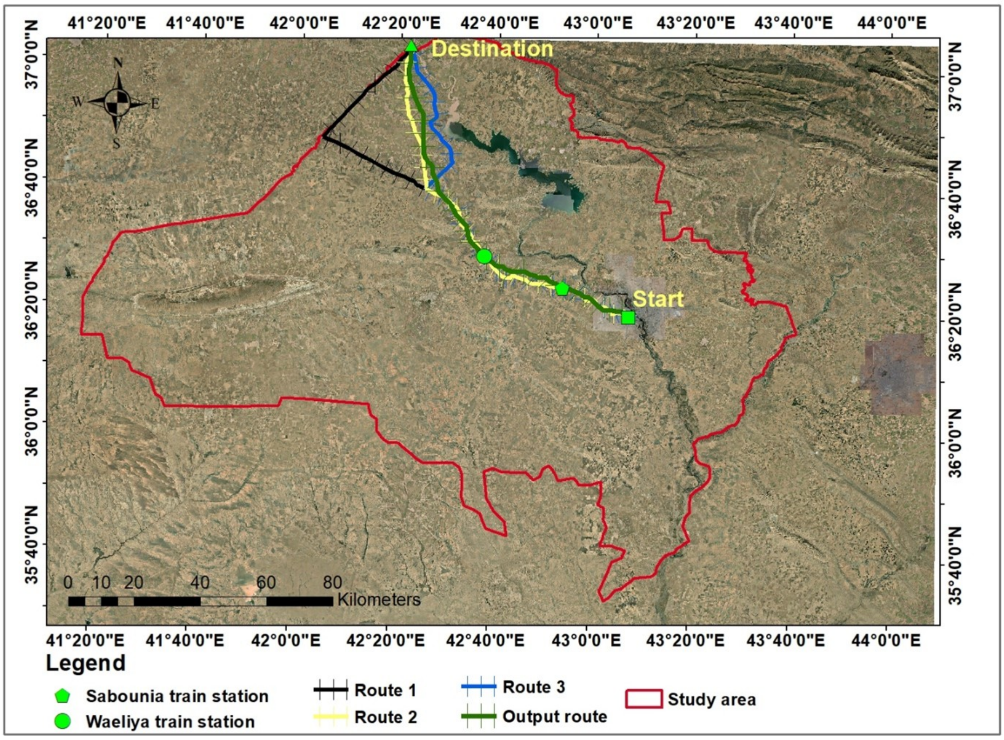

Figure 8. Output path location with the proposed paths

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