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Multicriteria Evaluation and Analytical Hierarchy Process for the Selection of Sustainable Motorway Corridor Using Landsat Images

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Abstract

Roads are the mainstay of any new development and it was requirement to be located occur seamless and optimal connection. Determining the route location is one of the biggest planning problems facing us at present while constructing new one. It was involved to evaluate of different agents in order to obtain optimal and least cost place. The goal of this investigation was carried out to perform a spatial sample that uses multiple standards with different weights for obtaining the least cost path between any two points using modern technologies such as GIS and remote sensing. Different data sources were collected to achieve optimal route location such as satellite images, soil map and minerals map. Other datasets were created as land use from classification of Landsat images and slope map from a Digital Elevation Model. All datasets are combined together in one geodatabase to allow integration with GIS analysis. In this paper, The Analytic Hierarchy Process (AHP) was used to derive the weights for five criteria, Slope, Minerals, Land use, Streams and Soil, in the development of pattern to obtain an optimal road. AHP is a resolution to making proceeding for establish advantage in many standards to decisions making to assess the relative weight of multiple criteria in an intuitive manner. Three paths from the estimates were appreciated which optimal and differed from the original way suggest for the project. It is concluded that GIS with integration of different sources of data and remote sensing and analysis using AHP technique should be adopted as a tool for future projects.

Key words: Optimal Route determination, GIS, Remote Sensing, AHP, Spatial Model, Landsat images

INTRODUCTION

Transportation infrastructures in Egypt are receiving more and more environmental and social concern because of its significant impact on development. Involving of the transport network with the national development plan is encouraging the strong interaction between transport and social and economic development in Egypt while enhancing Egypt's important role in the international society. This requires the use of modern scientific and technological basics in the road construction process. Roads could have contributor in the national wealth and it was necessary elements in many countries because they have been represented a significant component of national infrastructure underling (Dixon *et al*., 2010). Hence the importance of the use of modern techniques in choosing the least cost path between two points began to take the attention of many people especially in developing countries. Therefore, there is a significant importance for these roads to be optimal and low costing during building as well as could be using modern techniques to complete transfer like Geographic Information System (GIS) and remote sensing methods. Additionally, there is a requirement to avert reverse effect and it was occurred long time for benefits leading to the meaning of sustainable development.

The problem of choosing and designing new roads between cities is considered a common problem in transportation engineering and many papers tried to solve the problem depending on many techniques such as mathematics and optimization (Bashar S. Al-Joboory *et al*., 2006). Modern technologies like GIS and remote sensing have had a very large influence in reaching an optimal solution to this problem.GIS employments are benefit in combine different datasets and performing design analysis for optimum way location (Isaac K. Gitau *et al*., 2017). These functionalities address different difficulties to get an optimized way depended on the different criteria. Remotely sensed data became widely available, allowing it to be used in many applications as in planning of roads and land use detection. So, integration between GIS and remotely sensed data caused a significant change in implementation of many applications.

Allocation problems involve judgment of multiple criteria according to one or more desired objectives. During the least cost path analysis, different criteria (slope, geology, soil and land use) were used and affected greatly the final route. Each criterion should be given a suitable weight depending on the desired goal. Analytical Hierarchical Process (AHP) was used to derive weights of each criterion after pair wise comparisons between multiple criteria. AHP, developed by Thomas Saaty (1980), is an influence tool to dealing with complex resolutions making, and help the resolve maker to set priorities and make the best decision. It decomposes the problem using more easily and it could be understanding and also subjectively evaluated. In this paper, combination between GIS and remotely sensed data was used to establish a model that uses multiple criteria in order to obtain a least cost path for Qena – Safaga road located in the eastern desert region of Egypt in an area known as the Golden Triangle. This study will help the decision makers to use the least cost path analysis for similar applications instead of traditional planning procedures.

Methodology:

The Least Cost Path methodology for determining the optimal route of a linear feature between source and destination points is a grid based GIS technique. It consists of sequential basic steps as shown in Figure 1. At first, the overall objective and related components of the overlay model must be clearly identified and all phases of the modeling process must contribute to this overall objective. Secondly, the sources of data that affect the overlay model such as satellite images, Digital Elevation Model (DEM) and soil map should be collected from available data sources. All factors that contribute to defining the problem should be included in the overlay model. After data collection process, some preprocessing operations may be done on specific layers such as vector to raster conversion,

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Digitization and getting all layers in one coordinate system. Certain layers may need to be created as is the case to derive slope map from the DEM and land use map from supervise classification of satellite images. In order to combine all layers in the overlay mode for analysis each layer must be reclassified to a common scale (for example, 1 to 10), with the lower value being more favorable. Particular factors may be more important to the overall goal than others and so each factor should be weighted based on its importance. AHP is an effective tool for deriving weights and make the best decision. Finally, all the input factors with their weights are combined together in the overlay model to form a suitability map from which the least cost path is originated.

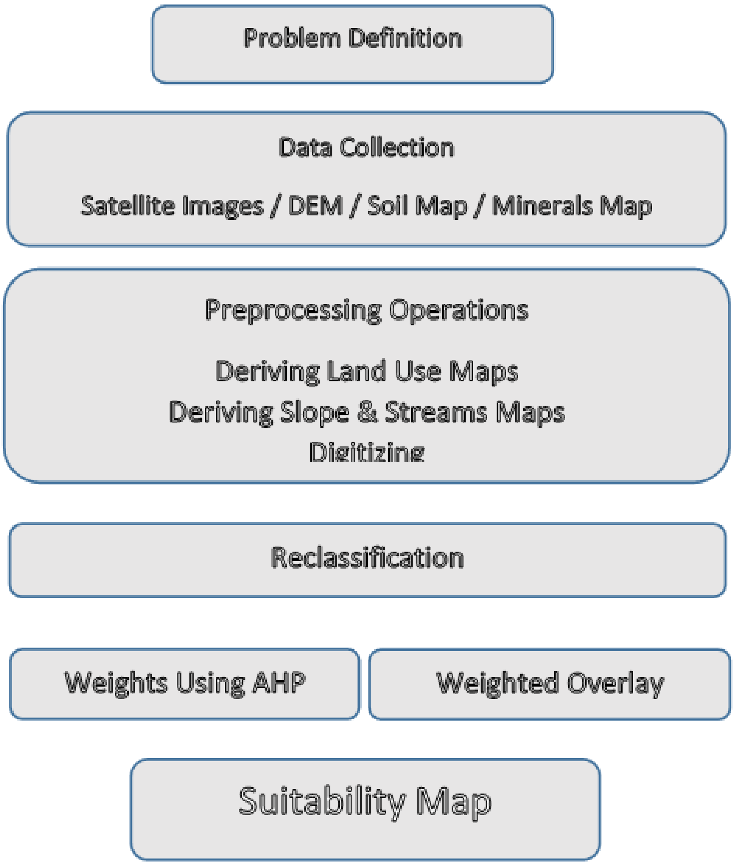

Fig. 1: Least cost path methodology.

Study Area:

The road considered in this paper is Qena – Safaga road. It is located in the eastern desert region of Egypt in an area known as the Golden Triangle. Figure 2shows the location of the study area. It extends between latitudes 24˚58'19" N and 26˚55'17" N and longitudes 31˚47'53" E and 34˚54'40" E. The total study area is 38600 km^2. The Qena – Safaga road with a length of about 160 kilometers is considered to be the most important crossroads located in this area. It has valuable importance and plays a pivotal role in the overall development process taking place in this region. It connects provinces of Qena, Assiut, Sohag and Luxor located at the Nile River with the Red Sea province overlooking the Red Sea. Also, it is an essential mean for tourist traffic which departs daily from the cities of Hurghada, Safaga and Quesir to visit the archaeological sites in Qena and Luxor.

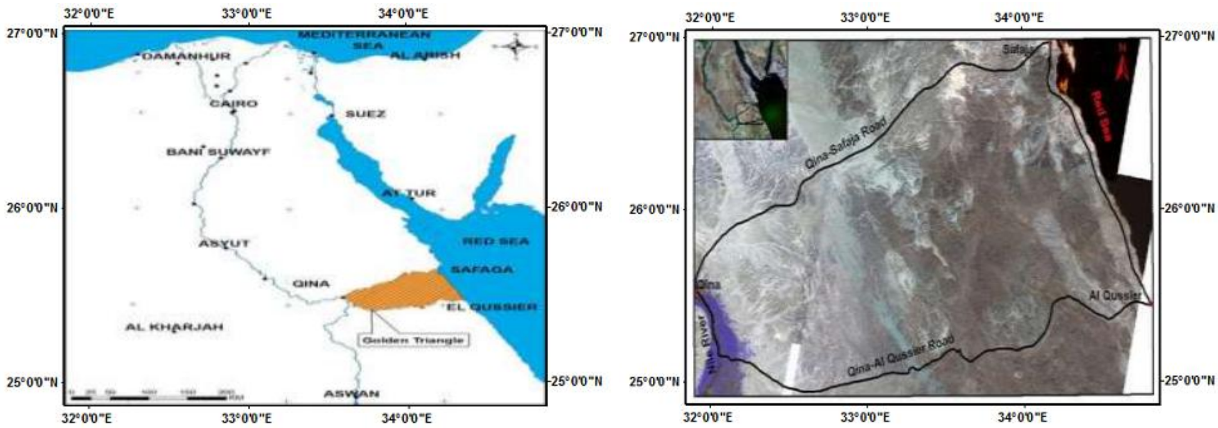

Fig. 2: Study area (left) and its corresponding Google Earth image (right).

Data Collection and Preprocessing:

Different sources of data were used to perform the routing of the road. It includes free images from Landsat 8 satellite. Landsat 8 (OLI/TIRS) images used in the analysis were seven spectral bands with a spatial resolution of 30 meters for Bands 1 to 7. Also, Band 8 (panchromatic) with 15 meters of spatial resolution was used. The study area was covered by 9 scenes. Land use map is one the most important factors affecting path analysis. It is obtained from the classification process done using Landsat images covering the study area. Bands for each scene were staked together to create a single raster dataset from these multiple bands. After staking bands, the panchromatic band (Band 8) of resolution 15 meters was used to create pan-sharpened dataset for each scene. Afterwards, a mosaic was created from combination of pan-sharpened images by mosaicking them together using overlapped areas between each successive images as shown in Figure (3). Then, from the mosaic dataset the study area image was extracted by clipping the mosaic using a polygon shape for the area of interest. With the ArcGIS Spatial Analyst extension, supervised classification was done to assign each cell in the study area to a known class.

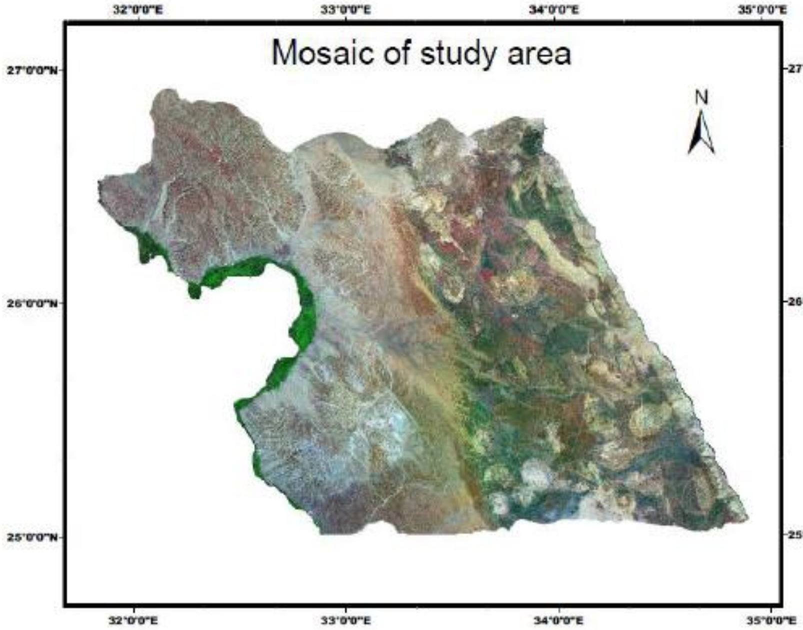

Fig. 3: Mosaic the study area.

More training areas were selected to represent each particular class. In this study area, there were five classes: Agriculture lands, Built-up areas, Mountainous areas, Sandy lands and Wet lands. The final result of supervised classification was as shown in Figure (4).

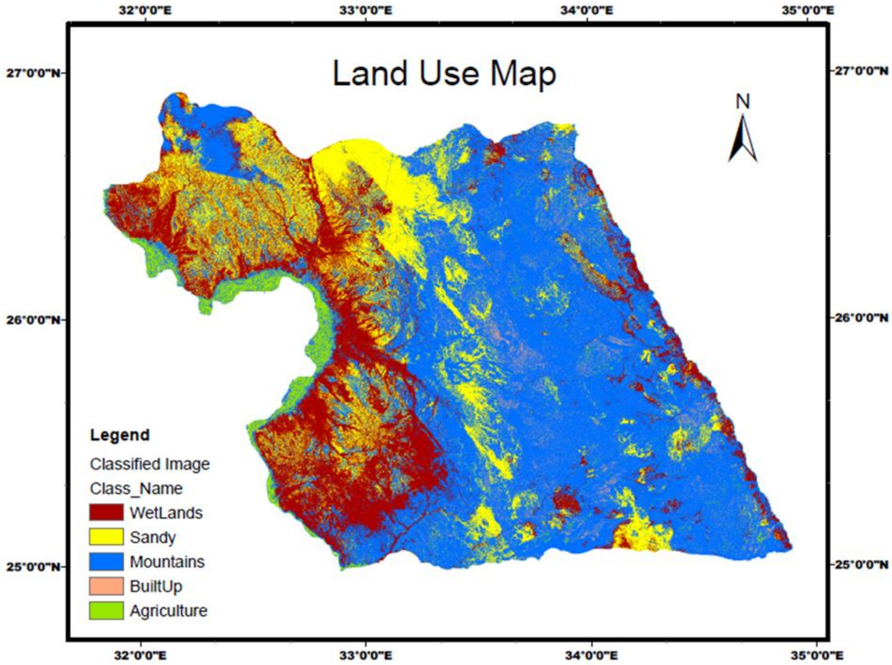

Fig. 4: Land use map of the study area.

The classified image (Land Use map) resulted from supervised classification should be assessed in order to ensure the accuracy of results. The evaluation of the accuracy of the land use map has been carried out using random points distributed on each class of the classified image and compared with their ground truth from Google Earth. A total of 500 points were created in the classified image of the study area. For instance, Figure (5) shows the classified Agriculture layer (left) with distributed random points on it and its corresponding ground truth (right) of random points through Google Earth. A comparison process between each random point established on the classified image and its corresponding ground truth from Google Earth was done producing an error matrix. Table 1 shows the error matrix of the accuracy assessment which demonstrates the relationship between the ground truth data and their corresponding classified data. The overall classification accuracy can be obtained by dividing the number of corrected classified random points by the total number of points used in the accuracy assessment. Therefore, the overall accuracy of the image classification was 86 % and the Kappa coefficient was 0.82 which indicates that there was 82 % agreement for the classified image.

Figure (6) displays the soil map of the study area. Also, the distribution of economically important minerals in the study are shown in Figure (7). Slope map and streams are derived from the DEM using Arc GIS Spatial Analyst extension as shown in Figures (8) and (9) respectively.

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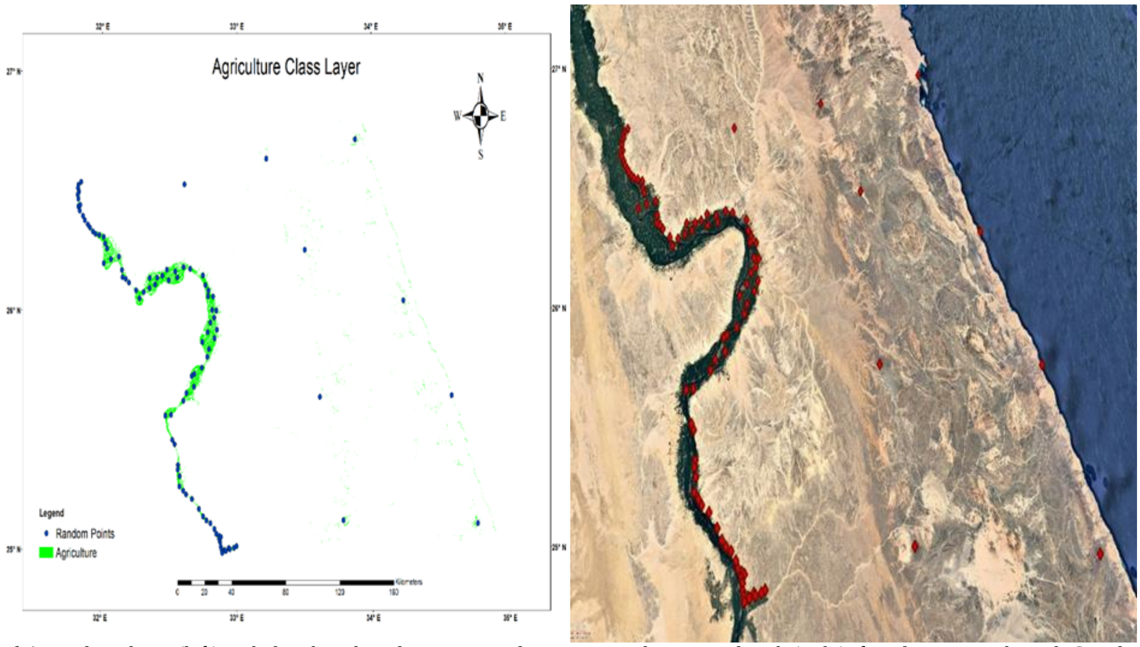

Fig. 5: Classified Agriculture layer (left) with distributed random points and its corresponding ground truth (right)of random points through Google Earth.

Table 1: Error matrix of the assessment of the classified image.

		Reference Data						User Accuracy
	Classes	Agriculture	Built Up	Wetland	Mountains	Sandy	Total	
Classified Data	Agriculture	91	1	1	5	2	100	**91**
	Built Up	5	79	2	11	3	100	**79**
	wetland	1	3	86	6	4	100	**86**
	Mountains	0	4	5	89	2	100	**89**
	Sandy	1	6	4	5	84	100	**84**
	Total	98	93	98	116	95	500	
	Producer Accuracy	**92**	**84**	**87**	**76**	**88**		**Overall accuracy=86%**

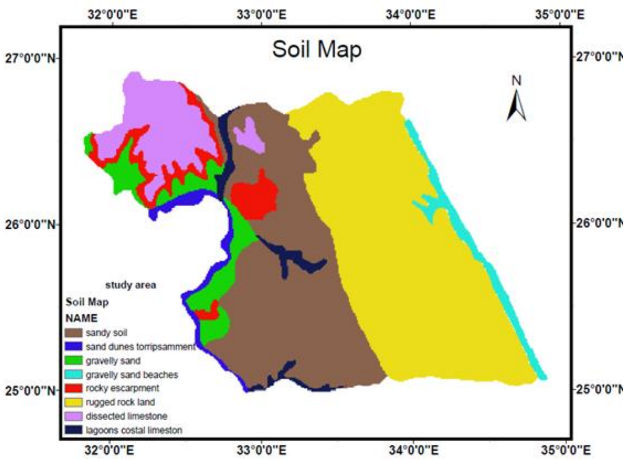

Fig. 6: Soil map for the study area.

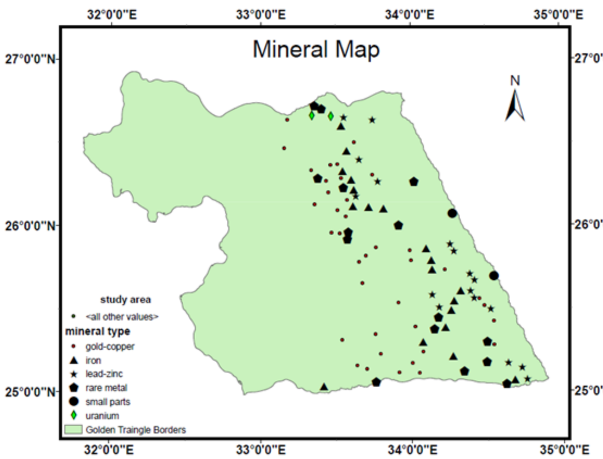

Fig. 7: Distributions of minerals.

Weighting And Results:

Deriving weights in multi criteria decision making process is one of the most essential parts which face us in choosing the best route. Generally, best site location decisions include evaluation of multiple criteria according to several objectives. The Analytic Hierarchy Process (AHP) (Saaty 1977, 1980) is a decision making method to establish preference in many criteria resolution making to assess the relative weight of multiple criteria in an intuitive manner. It is a method to derive weights from paired comparisons between different factors affecting the desired objective. Saaty (1980) is the inventor of the AHP methodology and he established a consistent way of converting such pairwise comparisons into a set of numbers representing the relative priority of each of the criteria (Malczewski, 1999). AHP decomposes the problem into more easily to be understood and subjectively evaluated. The individual evaluations are turn into numerical values and processed to rank each substitute on a numerical scale (Saaty, 2008).

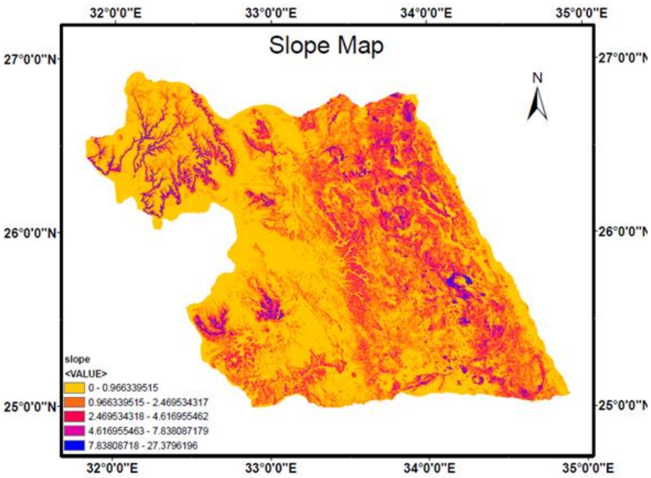

Fig. 8: Slope map of the study area.

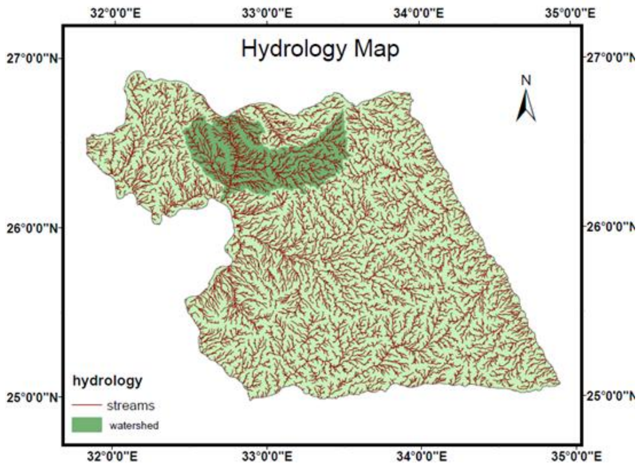

Fig. 9: The most important watershed.

In this paper, AHP was used to derive the weights for five criteria, Slope, Minerals, Land use, Streams and Soil. Also, expert questionnaire was an important step to support this method. Table (2) showed that the first step in the AHP procedure is to comparative pair wise between each criterion. Results in the same table reported that the comparison matrix for each factors pair were described in terms the integer amount from 1 (equal value) to 9 (extreme different). Whereas the highest number means the chosen factor is considered more significant degree than other factor being compared with according to (Saaty & Vargas, 1991). If the criteria in the column was preferred to the criteria in the row, it can be given the opposite of evaluate. The second step is to normalize the matrix in Table (1) using totaling the numbers in each column. Each entry in the column it can be divided by the column sum to yield its normalized score. After normalization the numbers of each row are summed and divided by the number of criteria used to give the priority vector which represent the weights of each criterion as in Table 2.

At this stage, we attain the desired goal but AHP requires calculating a consistency ratio. This ratio is useful to make confirm that the original advantage estimate was consistent. For this example, the consistency ratio was 0.08 which is considered acceptable if it is 0.1 or below. While the value of the consistency ratio is above 0.1, pair wise comparisons must be revised. As the same the weights of the alternative routes are produced, for the first alternative as shown in the figure (12) the weights was (slope 26%, minerals 27%, land use 15%, streams26%, soil 6%), the second alternative as shown in the figure (13) the weights was (slope 23%, minerals 4%, land use 20%, streams 32%, soil 21%)

Table 2: Pair-wise comparisons between each criterion.

Factor	Slope	Minerals	Land Use	Streams	Soil
Slope	1.00	9.00	2.00	1.00	1.00
Minerals	0.11	1.00	0.20	0.20	0.20
Land Use	0.50	5.00	1.00	2.00	0.50
Streams	1.00	5.00	0.50	1.00	2.00
Soil	1.00	5.00	2.00	0.50	1.00
Total	3.61	25.00	5.70	4.70	4.70

Table 3: Normalized matrix to derive priority vector (weights).

Factor	Slope	Minerals	Land Use	Streams	Soil	Total	Average		Weights	
Slope	0.28	0.36	0.35	0.21	0.21	1.41	0.283	Priority Vector	28	Slope
Minerals	0.03	0.04	0.04	0.04	0.04	0.19	0.038		4	Minerals
Land Use	0.14	0.20	0.18	0.43	0.11	1.05	0.209		21	Land Use
Streams	0.28	0.20	0.09	0.21	0.43	1.20	0.241		24	Streams
Soil	0.28	0.20	0.35	0.11	0.21	1.15	0.229		23	Soil

Model Builder:

Results:

Based on AHP method used in weighting of different factors in the proposed criteria and GIS application in transportation design the locative analysis module is applied in the optimum way selection. The present study is investigating how non-locative and locative information can be integrated within a multi criteria resolution frame work to formulate and select the best suitable way accordingly and regarding the study methods was suggested to be selected as the best route to connect Qena and Safaga city is route (2) with a length 151.86it is shorter than the original road by 8.14Km and with path cost 259285. 906.

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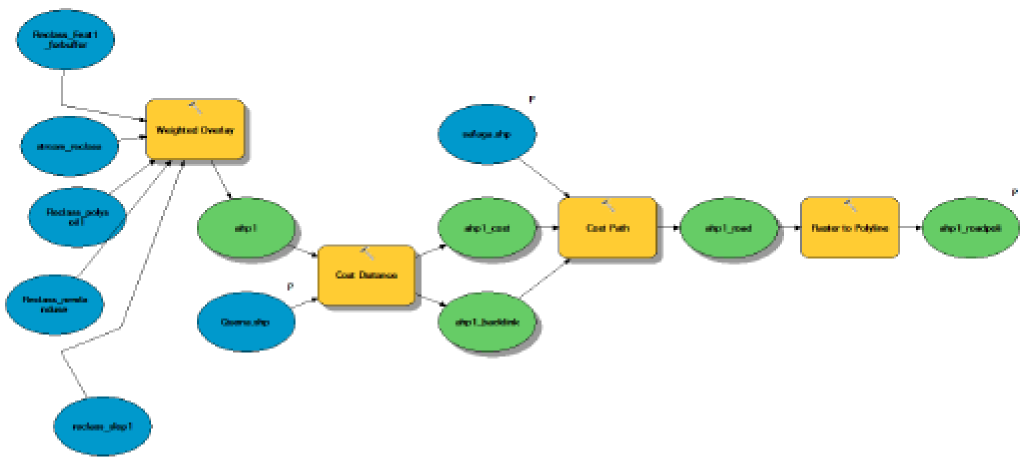

Fig. 10: Part of the model builder.

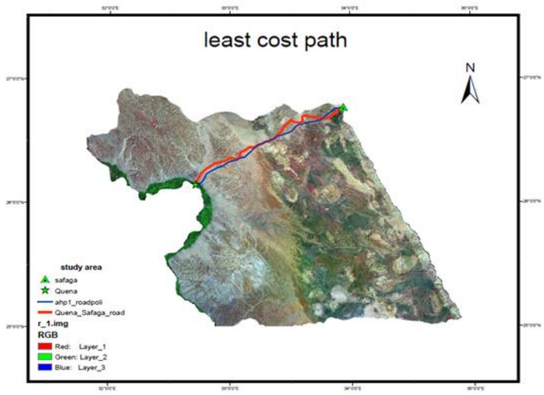

Fig. 11: Least cost path (1).

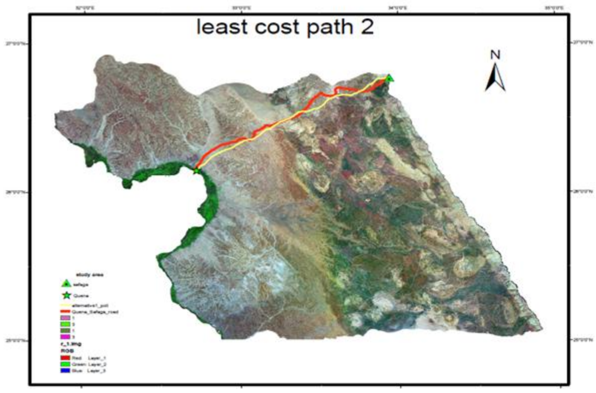

Fig. 12: Least cost path (2).

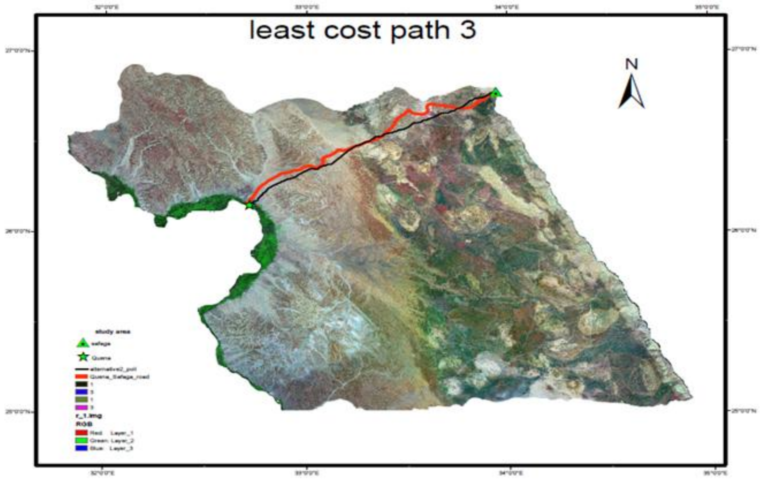

Fig. 13: **L**east cost path(3).

path	Length (Km)	Cost(unite)
Route (1)	152.51	332653.47
Route (2)	151.86	259585.906
Route (3)	150.66	333429.719

Conclusions and Recommendations:

From the presented study, it was easy to conclude how a vital role the GIS analysis could play in selecting road paths, because of its effectiveness and its logical visual (geographic) solutions for such problems. The weighted analysis offered by the model builder technique is easy, logical, and flexible since it offers the facility to add new factors, change weights, scale values, and run the constructed model every time you need to get new solutions in a very short time. However, the research should not be treated as a single event, but rather serve as a good introduction to more in-depth studies. The achievements of the research are recognition of previous corridor location research and planning practice, background in multicriteria techniques, as well as geographic information system practice and theory.

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