



Geospatial modeling for planning an optimum and least-cost route to link three historical sites in El-Fayoum desert, Egypt

Hala A. Effat¹ · Ahmed El-Zeiny¹ · M. Sowilem¹ · K. Mansour¹ · Khaled Elwan¹

Received: 19 July 2022 / Accepted: 9 August 2023
© The Author(s) 2023

Abstract

Improving the accessibility to archaeological sites in a desert is a crucial issue; it enhances the landscape value and helps in achieving sustainable tourism development. El-Fayoum Oasis and Governorate in Egypt, has a unique heterogenic environment that encompasses desert, lakes, agriculture lands, and urban areas. It is quite rich in historical heritage reflected by abundant archaeological and cultural sites, many of which fall in desert zones. A main constraint is the poor or lack of accessibility to such sites. In this study, we designed a geospatial model for planning a sustainable least cost tourist route (path) to link and develop three archaeological sites namely; Madinet Madi, Watfa city and Ummal-Barijat ruins. Spatial multicriteria decision analysis was integrated with the analytical hierarchy process (AHP) and the least cost path modules. Three cost criteria themes were created associated with economic, social and environmental costs. A cost surface and a least-cost path were created for each criterion and for each theme. The themes were combined using weighted linear combination to create four least cost scenarios for the path. Five preference criteria were used to compare the four route scenarios. Results show that the environmental scenario scored first scoring 0.69 while the economy path scores second 0.42, the equal weights path scores third 0.40 and finally the social path comes to be the last having a preference score 0.36. The method is flexible because priority can be changed and adapted according to specifications and site variances. It can be helpful for decision makers and planners in planning routes based on visual maps and priority visions.

Keywords Least cost path · Analytic hierarchy process · Multicriteria · El-Fayoum · Egypt

1 Introduction

The development of a new tourist road in a desert may greatly influence its economic, environmental and social developments. Landscape value (especially in desert areas) can be significantly raised by a tourist corridor located in proximity to cultural and recreational sites. In traditional design, perception of a desert road may falsely appear to be a simple

✉ Hala A. Effat
haeffat@yahoo.com

¹ Division of Environment and Land-Use, National Authority for Remote Sensing and Space Sciences, NARSS, Cairo, Egypt

issue. This perception generally focuses on the abundant vacant lands, lack of land obstacles, mild slopes, clear information about geology. Yet, taking the environmental, social and economic considerations more depth could be added to the route selection issue. This need can be efficiently satisfied by spatial analysis and least-cost path models LCP. Spatial LCP models are based on cost surfaces. The challenge is to model a path from such surface to link an origin point to a destination point creating a least cost path. GIS-based least cost path models can produce a number of options and alternative solutions (paths) based on decision makers' preferences (Song et al., 2021). Whereas such cost maps and alternatives are usually lacking during the traditional road design that does not utilize GIS techniques.

1.1 Review of previous studies

A review of the previous studies showed that modeling past routes or networks (of any time period) between sites is perhaps the most common archaeological LCA utilization (Herzog, 2013a), there are many potential and often creative applications. Most LCP studies cover the prediction of old routes in historical eras. Some authors (Abou Diwan and Doumit, 2017) conclude that the results of validated modeled path remains hypothetical as long as the archaeological evidence of such road remains lacking. A least cost path (LCP) is the theoretical, most efficient route between two locations across a landscape, with respect to a specified expense. As early as the 1970s, GIS has played a role in archaeological research. (Schild, 2016). While LCP has been prevalent in social sciences for some time, the application to archaeology is relatively new (and has considerably increased within the past two decades (Herzog, 2013a, 2013b). Most previous studies emphasized on modeling movement across historical landscapes.

Lewis (2017) used LCPs technique, to examine the suitability of using LCP analysis to predict the location of Roman roads in two distinct zones of Roman Britain. The researcher concluded that the social features of the study area should be well known and able to be incorporated within an LCP calculation. Also higher resolution DEMs, generates more accurate LCPs, and that the paleoenvironmental data has to be available to conduct a LCP analysis for prediction of ancient historical roads. Abou Diwan and Doumit (2017) conducted a case study to find the least cost path for the ancient road joining the colony of Berytus to its territorial possessions in the northern Bekaa which included the town of Heliopolis Baalbak in Lebanon. This case study aims to find the least cost path for the road between both cities based on slope dependent functions using GIS technologies. The authors conclude that the validated modeled path remains hypothetical as long as the archaeological evidence of such road remains lacking. Schild (2016) conducted a study to utilize a least cost analysis across the Amanus Mountains to map potential routes of these merchants. The study generated individual least-cost paths for seven sets of points. The modeled paths illuminated several passes across the mountains that were possibly utilized in Bronze Age merchant travel.

Bagli et al. (2011) studied the most suitable route for a 132 kV power line as part of an environmental impact assessment process, where possible alternatives routes were to be discussed and compared. An evaluation matrix was built that included the performance scores of each path with respect to each of the comparison criteria. Comparing the four routes, using additional criteria, the study found that small changes in the location of the power line start and end points can result in significantly different paths, and consequently on the levels of impacts. The researchers suggested that planners should always consider alternative potential locations of terminals paths in order to identify the best.

Despite the few applications that utilized LCP in tourism route design, the least-cost path models (LCP) have been extensively employed to promote sustainable planning and suitable design of various types of linear infrastructure. Such studies covered most applications of linear infrastructures. LCP applications have been studied by Seifrieda and Gardnerb (2019), Effat and Hassan (2013), Abdel Aziz (2013), Howey (2011), Atkinson et al. (2005), Berry (2004), van Leusen (2002), Collischonn and Pilar (2000), Douglas (1994), Lee and Stucky (1998) and many others. In general, highway planning has some struggles between environmental and economic perspectives. Singh & Singh (2017) conducted a study that combines GIS with MCDA to design the best path alignment between two sites at Allahabad City in India. Three levels of analyses, as criteria map, surface cost, and least-cost path, were performed. Many alternate paths can be designed using the multicriteria decision analysis (Bagli et al., 2011; Effat and Hassan, 2013, Wahdan et al., 2019).

The analytic hierarchy process (AHP) is a pairwise comparison measurement theory that bases priority scales on the opinions of experts. It is a well-developed method for assigning relative weights for criteria and provides scales that measure intangibles in relative terms. The factor weights are computed using a pairwise comparison matrix. The following steps are included in the method: The first step is to add up the values in each column. The second is to divide each element in the matrix by the sum of its respective columns. The third step is to average the elements in the rows of the normalized matrix and divide the total by the number of components. The consistency ratio should be less than 0.10, and these averages give an indication of the relative weights of the various elements (Jiang 2009; Janda & Tan, 2017). Deriving weights from the pairwise comparison matrix has been studied by numerous researchers (Saaty, 1980, 1990, 2008; Brazili, 1997, Alonso and Lamata 2006, Leung & Cao, 2000, Vaidya & Kumar, 2006).

The least-cost path algorithm (LCPA) enables users to determine the "cheapest" route connecting two points over a cost or friction surface. A raster map is used to illustrate the cost surface, and each cell has a cost assigned to it that indicates how "expensive" it is to pass over that cell. A line that connects a starting point with a destination can be found using LCPA by creating an accumulated cost surface (Douglas, 1994). The cumulative cost of each cell from the beginning point is calculated to create the accumulated cost surface from the cost surface. Taking into account all factors influencing the routing of the linear infrastructure and combining them through a multicriteria evaluation, the cost surface can be determined. (Atkinson et al., 2005; Bagli et al., 2011). Finding a minimum cost path over a surface divided into areas of varying movement resistances involves a number of fundamental processes (Atkinson et al., 2005; Collischonn & Pilar, 2000; Douglas, 1994): (1) Each assessment criterion results in the creation of a friction surface, where each grid cell is given a value based on the relative cost of passing through that cell. (2) To represent the entire cost of visiting each cell, a cost surface is made by weighting and combining several friction surfaces. (3) To calculate an accumulated cost surface, a spreading function joins the cost surface grid with two additional grids that represent source points and destination points. The raster of cost distance defines, at each cell, the least overall cost distance over a cost surface to the defined source site which may be a cell or a set of cells, feature(s) or location(s). A back link raster identifies the direction to the following neighboring cell among least cumulative cost path from a certain cell to reach its least-cost source (Esri ArcGIS 10.5 help). The least-cost path between any destination point and the pre-defined starting point is found by moving backwards from the destination point over the accumulated cost surface, step by step, choosing cells at decreasing value (Singh & Sing, 2017; Yakan & Celik, 2014; Bagli et al., 2011; Lee & Stucky, 1998). (4) The accumulated-cost surface is traced from a departure point to a destination, finding the lowest cost line (path). A cost

surface can be computed through accounting different parameters, such as environmental impacts, and economic investments, social, political impacts, etc. For all factors taken into consideration, the final path is deemed ideal (Atkinson et al., 2005; Lee & Stucky, 1998). This process can be simply employed using the technologies of geographical information system (GIS).

A survey of literature showed a gap in the research applications of LCP route selection for improving accessibility in desert tourism. Reviving, linking isolated archaeology sites and improving accessibility to such sites by designing route networks (especially in desert regions) are quite few. It is a main objective for the current study to contribute in such an issue.

1.2 The Need for LCP in El-Fayoum desert

Egypt contains a number of untapped tourist and archaeological destinations. El Fayoum Governorate, is chosen for the case study, for it is endowed with rich natural and cultural heritage providing high potentials for both eco and cultural tourism. However, most of its unique potentials have not yet contributed in its economy (Ramzy, 2017). One constraint is accessibility to such locations. Accessibility to remote desert heritage and cultural sites is a key factor for achieving sustainable tourism development. It is an aim of the current research to propose a least-cost path to link and provide accessibility between three archaeological sites in El-Fayoum desert zones. The first site is Madinet Madi, one of El Fayoum's most impressive monuments and a temple from the Middle Kingdom with enormous cultural significance. The second site is *Watfa city ruins* which are the remnants of the Romanian-Greek era; the third site is *Ummal-Barijat ruins*, a large temple of the god Sobek from the beginning of the Ptolemaic period. The three sites are located in the desert, in the vicinity of the cultivated lands and in proximity to the lakes thus they provide a great opportunity for developing cultural and eco-tourism zones. Since the study is conducted on a desert zone, the proposed LCP is supposed to provide accessibility and to be a base for eco and cultural tourism development and for supplying the region with the needed infrastructures and services. Another objective of the current study is to use geospatial models in creating a flexible model for planning a LCP route. The model can be helpful for decision makers and planners in planning routes based on visual maps and priority scenarios. It is worth to mention that the whole Governorate would benefit from developing a new tourist corridor, as it can provide jobs and income to the population who work mostly in land cultivation. Yet, such issue was not within our objectives, as it needs extensive data which was not available to the current study.

2 Description of study area

The Western desert's El-Fayoum Governorate is located in a depression. Arable areas, lakes, natural preserves, villages, sand dunes, and desert all make up its distinctive landscape. The study area is located between latitudes of 29°N and 29.5°N; longitudes of 30.15° E and 30.50° E. It covers an area of about 1483 km². The land-cover encompasses sand dunes, nature reserves, such as Lake Wadi Al-Rayan, part of Lake Qaroun and archaeological sites. In 2005, the UNESCO designated Whale Valley, also known as "Wadi El Hitan," as a World Heritage Site (Eraqi, 2007). Three historical sites namely Ummal-Barijat monuments, Madi City Temple monuments, and watfa City monuments

in El-Fayoum Governorate exist in the study area and provide potentials for the planning and development future tourism in the region.

Watfa city ruins are the remnants of the Romanian-Greek era surrounded by a trac dedicated to conducting and performing exercises, as well as a place that was used perhaps as a swimming pool, indicating that there may have been an Olympic village on this site. Located 30 km south-west of Fayoum is *Ummal-Barijat ruins* were found on a large temple of the god Sobek from the beginning of the Ptolemaic period. It was found in a large number of Greek and Demotic papyri, First century AD. The remains of the temple and the city of Umm al-Buraijat, the Roman ruins, have recently been unearthed in the remains of its ancient temple (Ayoub and Tawab 2017). *Madi city or Narmuthis (Latin name)* is an ancient city in the southwest of Fayoum Governorate. It contains the ruins of temples built by the Pharonic kings Amenemhat III and Amenemhat IV from the Twelfth Dynasty dedicated to the goddess Subak (crocodile) and Rennot (snake). Additions in the Roman era were added, where it placed statues of lions with human heads, and is the largest temple of the rest of the central state in Egypt. The idea of linking the three sites through a tourist desert path would revive and accelerate tourism activities in such locations such as local Bedwian oriental handicrafts and tourism services. Such idea is the objective of the current study. The study area location along with its main land-cover features is shown in Fig. 1.

3 Methodology

3.1 Data sets and pre-processing

(1) Acquired in February 2000 by the Shuttle Radar Topography Mission (SRTM). With a sampling of 1 arc-second, or roughly 30 m (98 feet), the latest data, which were published in 2014, show the entire resolution of the initial measurements. The data was freely downloaded USGS EROS data center (<https://www.usgs.gov/centers/eros>). (2) Free downloads of two multispectral Landsat 8 images covering the entire El-Fayoum Government region in August 2021 are available at <http://glovis.usgs.gov>. There are two scenes that make up the study area: 177–39 and 177–40. Each scene was individually subjected to radiometric calibration and atmospheric correction, and a mosaic was produced before being cropped to alter the size of the research region. To create a map of land use and cover, supervised classification was used with the Maximum Likelihood Classifier. Field validation visits were elaborated to confirm the accuracy of classification. Accuracy assessment was carried out using 310 field validation points located within the whole Governorate classified image. The overall accuracy obtained was 85.9%. (3) The paths layers were obtained in a shapefile format from the Governorate of El-Fayoum. (4) Digital faults and classifications of rocks were drawn using the 1987 geological map scale 1:500,000 (CONOCO Coral) (EGPC, 1987). (5) The Egyptian Environmental Affairs Authority (EEAA) provided the map of the natural protectorates as part of a 1998 report. A feature class was created by reproducing, and correcting, and digitizing this analogue map. (6) The General Organization for Physical Planning (GOPP, 2007) provided the archaeological sites layer, which was used to map the archaeological sites. Data layers were imported into the geographic database and projected to the zone 36N of the Universal Transverse Marketer (UTM) projection. 100 m was utilized as the cell size for the raster layers format.

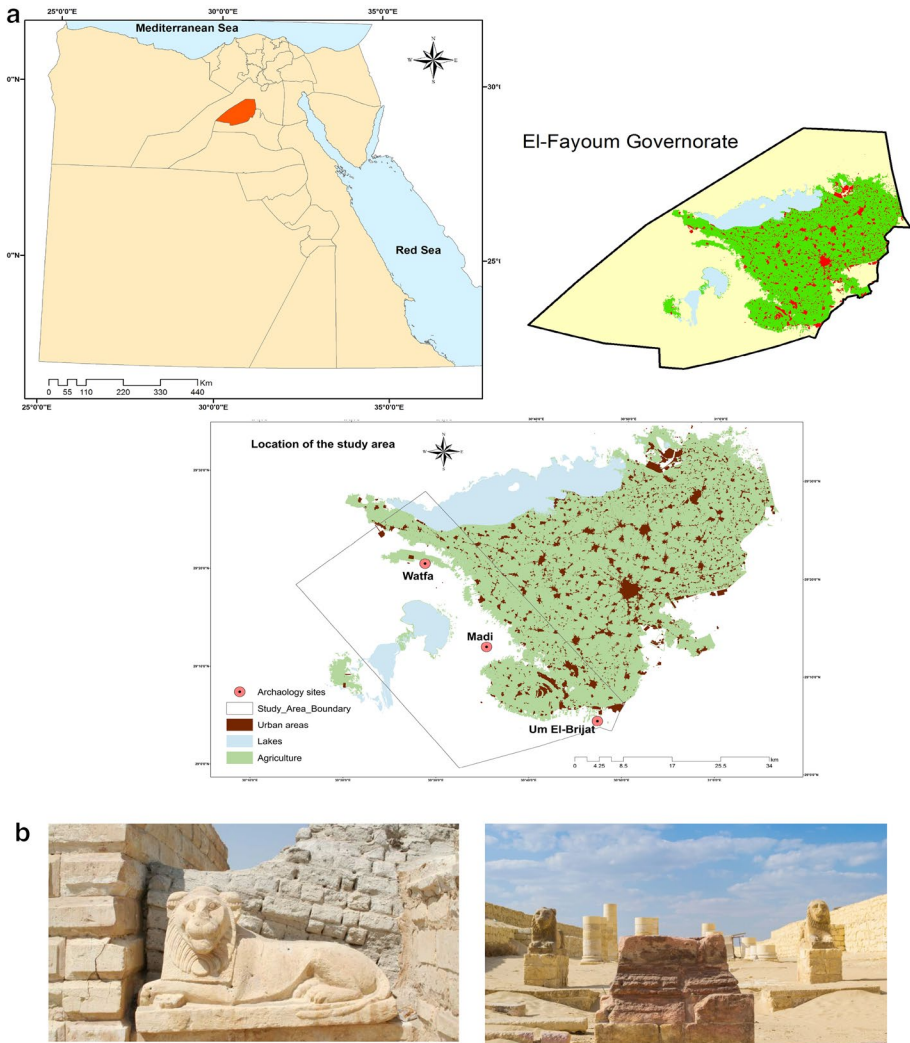


Fig. 1 a Location of El-Fayoum Governorate and the three archeological sites b Madinet Madi archaeological site (Madinet Madi Archaeology Site, 2013) Source: <https://fayoumegypt.com/medinet-madi-narmouthis/>

3.2 Methods

Spatial multicriteria analysis SMCA and least-cost path LCP were combined to generate model a least cost path, to create scenarios for the path based on cost themes, to identify and compare such alternative paths. First, three cost criteria themes were defined. Second, Criteria were standardized and assigned weights using the AHP. Third, Spatial multicriteria analysis was conducted to produce a cost surface reflecting such criteria in a theme. This was done for each criterion in the three themes; the Environmental, the Economic and the Social theme. Aggregation of the standardized weighted criteria in each theme was

done to create a cost surface for such theme. Fourth, an analysis of least-cost path (LCPA) was done to find the “cheapest” paths to link the three archaeological sites (two at a time) within a cost surface. An origin and destination point (archeology sites) was input and the accumulated cost surface for each of the three themes was modeled. Subsequently, a least cost path was modeled linking the archeological sites in each theme. Finally, a MCE was used to compare the alternatives, and rank them according to their overall suitability.

Following is a detailed description of the LCP applied method modified after (Seifried and Gardner 2019): LCP is analyzed using ArcGIS (ESRI, 2004). The comparison of alternative was conducted using definite software.

3.2.1 Modeling the least cost path for linking the three archaeological sites

Step 1: Defining the Themes and the related Cost Criteria sets: Three themes and their related cost criteria were defined to model the least cost paths. Such themes are associated with economic, social and environmental costs, such themes are depicted in Table 1 and Fig. 2.

Step 2: Define and a create cost raster surface for each criterion in each theme: A cost surface (friction) was created for each single evaluation cost criterion, where each cell in the grid is assigned a value based on a relative cost of traversing that cell. Using the origin and destination points, the least cost path was also created for each criterion (Fig. 2).

Step 3: Calculate a least-cost path for each criterion in each theme: The least cost (path) is traced down the accumulated cost-surface from an origin point representing each of the three archaeological sites. This step was done for Um El-Brijat (origin) to Madi for destination and from Madi (origin) to Watfa (destination).

Step 4: Calculate an accumulated cost surface and backlink raster: The accumulated cost surface was calculated by combining all criteria in each of the three themes.

Step 5: Calculate a combined least-cost corridor for each theme: The pairwise comparison matrix (Saaty 2000; Sadasivuni et al., 2009) was used to calculate the weights of the cost surfaces of the standardized criteria within a theme. A weighted linear combination function was used to combine the criteria in such theme. The step was repeated to create the social, economic and environmental themes. As a result, a least-cost path was generated for each theme.

Step 6: Creating the LCP Scenarios.

The three themes were combined to create priority scenarios for the path. Maximizing the weight for the social theme produced LCP for the social vision. This was repeated for the economic and environmental themes, in addition to the equal weight theme resulting in four alternatives (scenarios) for the path. The values were assigned using the direct weights for each scenario.

To create the Environmental scenario, we assigned a weight of 0.70 to the Environmental theme, 0.20 to the Economic theme and 0.1 to the Social theme. For creating the Economy scenario, we assigned 0.70 to the Economy theme, 0.20 to the Environmental theme and 0.10 to the Social theme. For the Social scenario, a value of 0.70 was assigned to the Social theme, 0.20 to the Economic theme and 0.10 to the Environmental theme.

Step 7: Comparing the LCP Scenarios and selection of the most optimum route

The four alternative paths were compared based on the path length, length of path sector passing through protectorate and sand dunes. The comparison and ranking of the paths were conducted by using a set of additional criteria. Criteria included was the length of the paths, the length of the path sector crossing sand dunes and the length of the path sector

Table 1 Criteria and costs rules

Alternative	Criterion	Costs
Economic	Slope	Steep slopes are considered high cost as steep slopes require more pre-construction and ground leveling cost. (Djenaliev, 2007)
	Crossing Roads	Road intersections are high cost as they may need tunnels or bridges (Diefallah et al., 2017)
	Rock Type	Rocky areas are considered high cost due to cut and fill costs. (Abdelaziz, 2013)
	Crossing streams	Crossing a stream is considered a high cost (Wahdan et al., 2019)
	Crossing sand dunes	Crossing sand dunes is considered a high cost as these may need dune stabilization and treatments
	Land use	Passing through cultivated lands is a high cost due loss of arable lands which has high economic values. (Effat and Hassan, 2013)
	Natural Protectorate	Crossing such protectorate is considered a low cost due to the touristic-cultural nature of the road and the protectorate is an attraction to tourists
Environmental	Stream network	Proximity to streams may cause environmental disturbance and is considered a high cost. (Diefallah et al., 2017)
	Cultivated land	Passing through cultivated land is considered a high cost due to the disturbance of the rural environment. (Abdelaziz, 2013)
	Lakes	Proximity to the lake is considered a low cost due to the touristic-nature of the road
	Sand Dunes	Passing through sand dunes is considered high cost because of dune encroachment threat to the road. (Abdelaziz, 2013)
Social	Urban Areas	Proximity to urban areas a considered low cost for providing road utility and service
	Existing Roads	Proximity to existing road network is considered low cost for accessibility and services. (Diefallah et al., 2017)

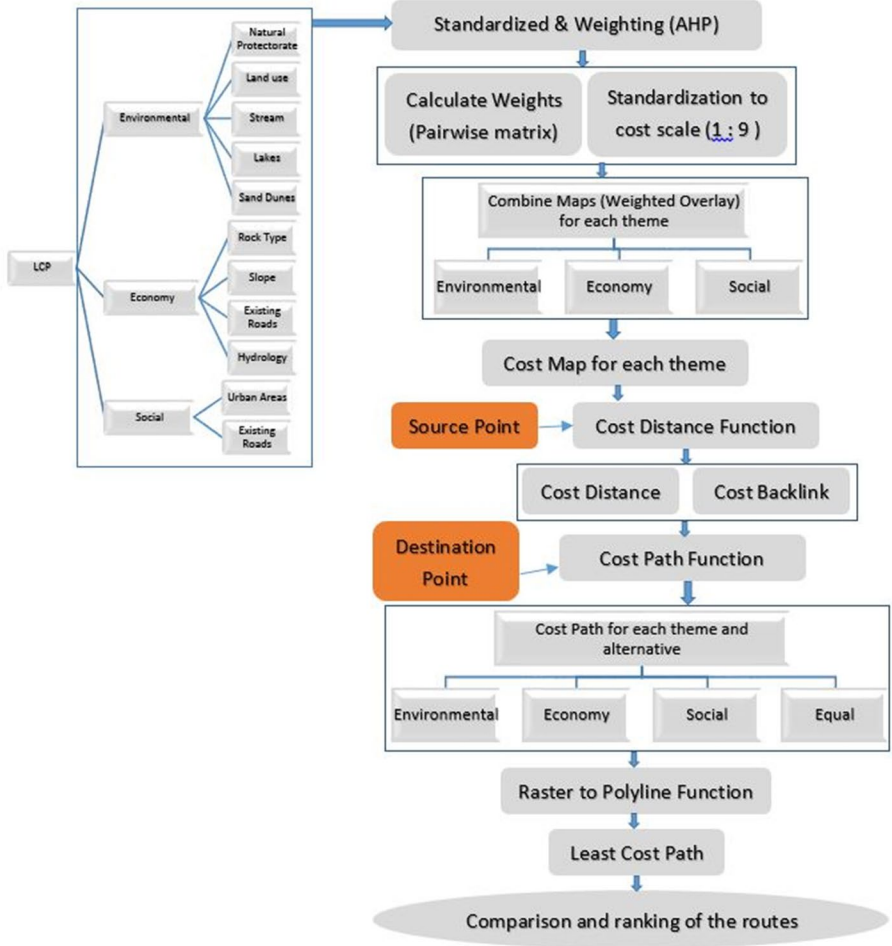


Fig. 2 Flowchart for the applied methodology

crossing the natural protectorate. Proximity to sand dunes, cultivated land and proximity to lakes. The result of ranking the three scenario paths was calculated using DEFINITE software (Janssen et al., 2001). A standardized effects table was created for comparing the four alternative paths. A spatial benefit is defined as a criterion.

4 Results and discussion

Tables 2, 3 and 4 depict the results of the standardization process of the criteria attributes into a cost value scale that range from 1 to 9 the higher the value, the higher the cost. The criteria and cost rating in the Social theme are depicted in (Table 2). The distance to urban areas, a distance less than 0.3 km was considered a high cost due to noise nuisance. Proximity to the road network was another factor, it is considered a favor for the new path to be close to roads, therefore, a distance more than 3 km or more was

Table 2 Standardization of Social theme criteria and attributes to cost values

Alternative	Criteria	Attribute category	Cost value
Social	Urban areas (km)	0–0.1	9
		0.1–0.2	6
		0.2–0.3	3
		> 0.3	1
	Distance to Roads (km) (Diefallah et al., 2017)	0–1	6
		1–3	1
		> 3	9

Table 3 Standardization of Environmental theme criteria and attributes to cost values

Alternative	Criteria	Attribute category	Cost value
Environmental	Distance to Cultivated land (km) (Abdelaziz, 2013)	0–0.1	9
		0.1–0.2	6
		0.2–0.3	3
		> 0.3	1
	Distance to Streams (km) (Diefallah, et al. 2017)	0–1	9
		1–2	6
		2–3	3
		> 3	1
	Distance to lakes (km)	0–1	9
		1–2	1
		2–3	3
		> 3	6
	Distance to sand dunes	0–0.1	9
		0.1–0.2	6
		0.2–0.3	3
		> 0.3	1
	Protected area	Inside core area	1
		Inside protectorate	3
		Inside proposed area	6
		Outside	9

considered a high cost and vice versa. The criteria within the Environmental theme are depicted in (Table 3). The path should not pass by cultivated land, therefore, a distance of 0.3 km from the path or more was considered the least cost value. Same distance was considered for the sand dunes as the road should not pass through sand dunes. A buffer zone was (considered a high cost) after which the proximity to sand dune is considered a least cost. The lakes was considered a high cost within a distance of one kilometer (protective buffer zone favorable for pedestrian and tourism commercial activities). After the buffer, a least cost distance is between 1 and 2 km is considered a least cost (benefit) distance. The distance from stream is considered highest within a buffer of one kilometers and decreases till it reaches the least cost value at distance of 3 km and more.

Table 4 Standardization of Economy theme criteria and attributes to cost values

Alternative theme	Criteria	Attribute category	Cost value
Economy	Slope (Djenaliev, 2007)	0–3	1
		3–5	2
		5–8	3
		8–10	4
		10–15	5
		15–18	6
		18–20	7
		20–24	8
		> 25	9
	Land-use (Effat and Hassan, 2013)	Water	9
		Urban	9
		Agriculture	5
		Desert	1
	Stream network (Adel Karim 2013)	Stream	9
		No streams	1
	Existing roads (Diefallah et al., 2017)	Roads	9
		No roads	1
	Rock Type (Abdelaziz, 2013)	Lake	9
		Agriculture	4
		Shale	2
		Clay	2
		Marl	2
		Gypsum	5
		Lime Stone	4
		Pebbles	3
		Sand Sheets	2
	Natural Protectorates	Sand Stone	1
		Wadi El-Rayan	9
		Protectorate under study	5
Non-protectorate		1	

Passing inside the core of the protectorate is considered a least cost (benefit). The path being a tourist path can promote tourism activities inside the protectorate, such as restaurants and bazaars.

Criteria and cost rating within the Economy theme are depicted in Table 4. Slope angles more than 25 degrees are considered a high cost. For land-use criteria, the cost of passing through water was rated the highest, while desert zones were the lowest. Intersections or passing through streams and paths were considered a high cost and vice versa. The rock type criteria were ranked highest for lakes and cultivated lands, while sand stone and sand sheets were assigned a least cost. Results of the current study revealed several intermediate sub-model results. Creating a cost surface for each individual criterion in the three themes and finding the least cost path for such criterion is depicted in Fig. 3 for Economy theme, Fig. 4 for Environmental theme and Fig. 5 for Social theme. The LCP for passing through or cutting the least possible streams is depicted in Fig. 3a, LCP avoiding the cultivated

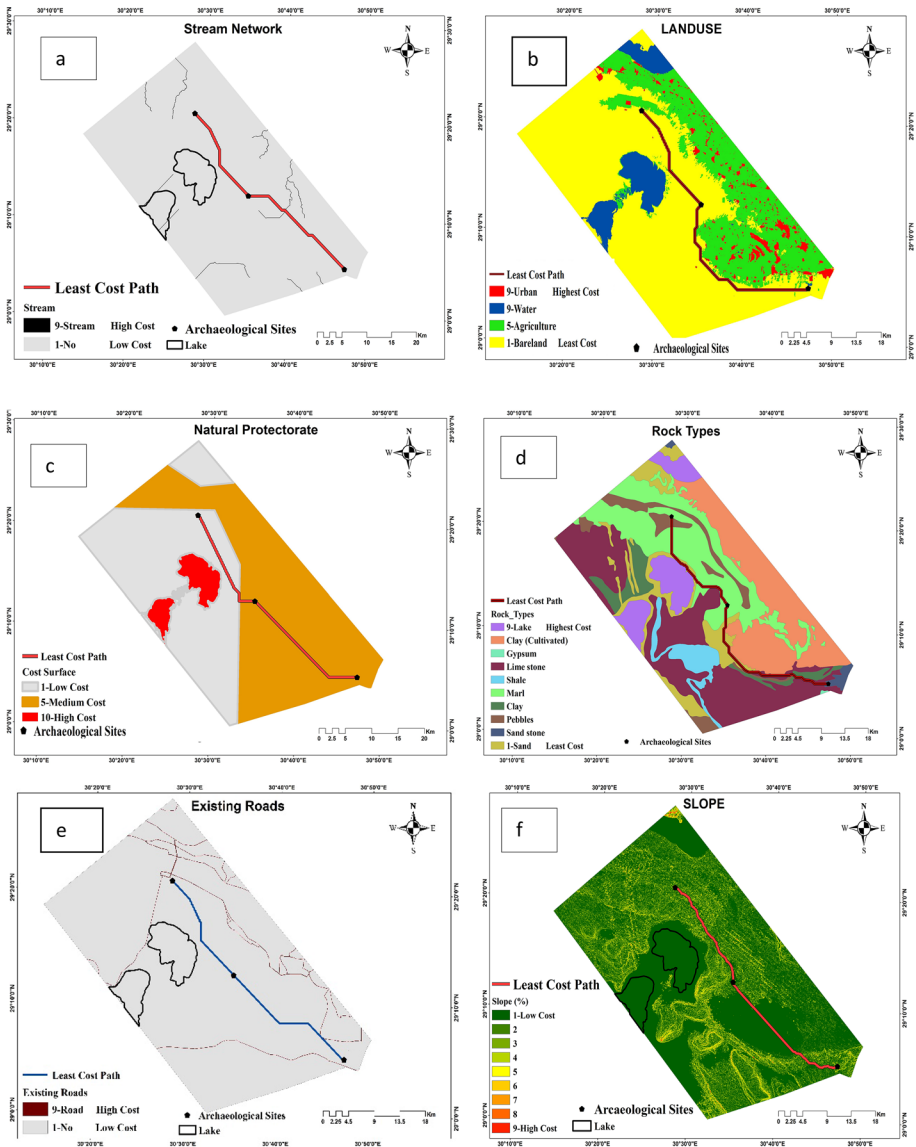


Fig. 3 LCP paths created from cost (friction) surface for each criterion in Economy theme

land (Fig. 3b), LCP passing through Marl and sand (Fig. 3c). Figure 3d depicts the LCP passing through protected zones which is considered a low cost because having a new path develops the tourism activities in the protected zones. The LCP for slope angles and paths are depicted in Figs. 3.e and 3.f consecutively. The result of the weight calculations using pairwise matrix are depicted in Tables 5a, 5b and 5c

Criteria and cost rating within the Economy theme are depicted in Table 4. Slope angles more than 25 degrees are considered a high cost. For land-use criteria, the cost of passing through water was rated the highest, while desert zones were the lowest. Intersections or

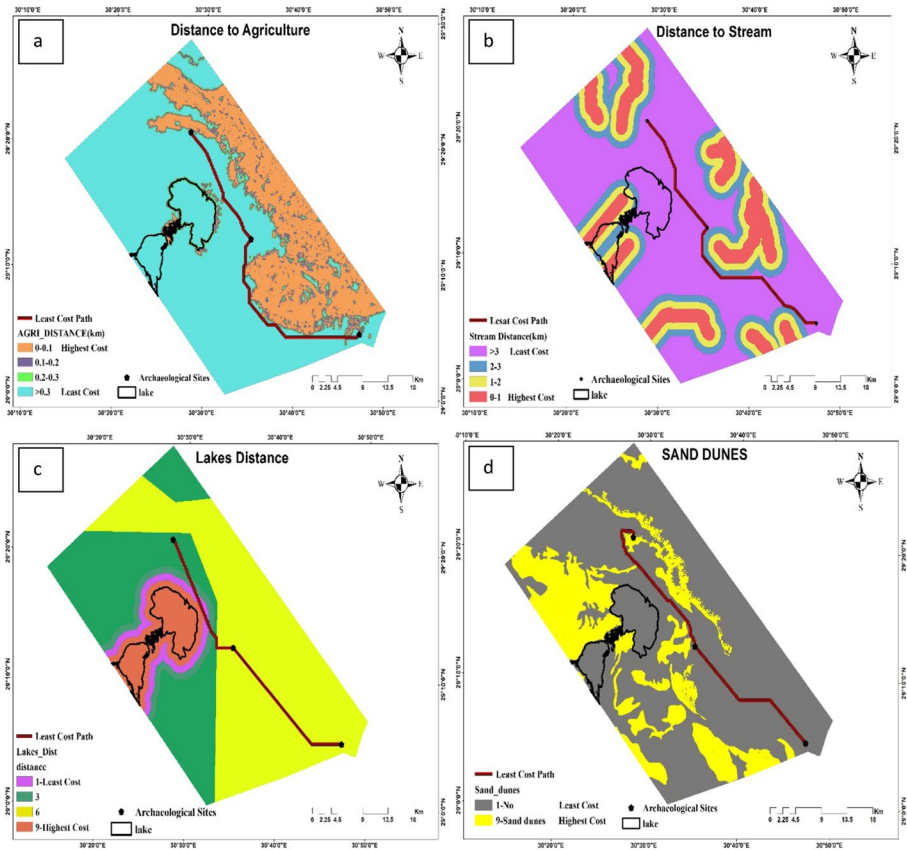


Fig. 4 LCP paths created from cost (friction) surface for each criterion in Environmental theme: **a** distance to agriculture land, **b** distance to streams, **c** distance to lakes and distance to sand dunes

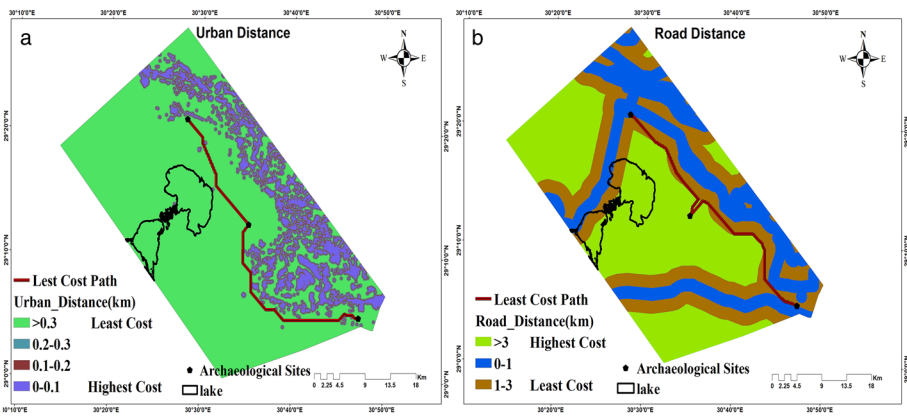


Fig. 5 LCP paths created from cost (friction) surface for each criterion in Social theme **a** distance to urban communities, **b** distance to road network

Table 5a AHP Pairwise comparison matrix: Economy theme

Economy theme							
FACTORS	Slope	Land use	Rock type	Natural Protectorate	Stream	Existing Roads	Weight
Slope	1.00	0.33	1.00	0.33	3.00	3.00	14.4%
Land use	3.00	1.00	3.00	1.00	3.00	3.00	28.7%
Rock type	1.00	0.33	1.00	0.33	3.00	2.00	13.2%
Natural Protectorate	3.00	1.00	3.00	1.00	3.00	3.00	28.7%
Stream	0.33	0.33	0.33	0.33	1.00	2.00	8.2%
Existing Roads	0.33	0.33	0.50	0.33	0.50	1.00	6.7%
							100

Table 5b AHP Pairwise comparison matrix: Environmental theme

Environmental theme						
Factors	Dist. to lakes	Dist. to agriculture	Dist. to Streams	Dist. to Sand dunes	Weight%	
Distance to lakes	1.00	4.00	3.00	2.00	46.6	
Distance to streams	0.25	1.00	0.50	0.33	9.6	
Sand Dunes Dist	0.33	2.00	1.00	0.50	16.1	
Distance to agriculture land	0.50	3.00	2.00	1.00	27.7	
					100	

Table 5c AHP Pairwise comparison matrix: Social theme

Social theme			
Factors	Dist. to Urban	Dist. to Road	Weight%
Distance to urban	1.00	2.00	66.70
Distance to roads	0.50	1.00	33.30
			100.00

passing through streams and paths were considered a high cost and vice versa. The rock type criteria were ranked highest for lakes and cultivated lands, while sand stone and sand sheets were assigned a least cost. Results of the current study revealed several intermediate sub-model results. Creating a cost surface for each individual criterion in the three themes and finding the least cost path for such criterion is depicted in Fig. 3

Figure 4 depicts the LCP paths generated for each criterion in Environmental theme. Figure 4a the LCP for proximity to agriculture land where the optimum path (least cost) should avoid passing agriculture land, yet passes in its proximity (Fig. 4a). Cost distance to streams (Fig. 4b) depicts the least surface and path avoiding streams within a buffer zone of one kilometer. Cost distance to protectorates (Fig. 4c) points out the least cost path to be passing in proximity to the lake and passing through the protected area. A protection lake's buffer of one kilometer is supposed to be preserved for pedestrian activities and amenities.

Proximity to the lake's buffer is considered a least cost due to the nature of the road being a tourist service road. Figure 4d depicts the least cost surface and path for the road to avoid passing through a sand dune body.

Figure 5 depicts the cost surface and LCP paths generated by modeling LCP for each criterion in Social theme. Figure 5a shows the cost of passing in proximity to the urban areas considering a distance of 300 m or more as the least cost to avoid nuisance. Figure 5b depicts the cost surface and least cost path for proximity to the existing paths. A distance of 300 m was considered a least cost while a distance more than 3 km or more was considered a high cost. Result of criteria overlay for creating the three (combined) themes is depicted in Fig. 6. Results of the four visions created by prioritizing the themes are depicted in (Figs. 7–8). Such visions (scenarios) resulted by changing priority weights to the three themes. In the Economy vision (Fig. 7a) the path pursues the least economic costs. In Fig. 7b, the path peruses the least environmental cost and passes in proximity to the lake. In Fig. 7c, the path pursues the least cost for social criteria and approaches the urban areas. In Fig. 7d, the path depicts the least cost for the equal weights scenario. The four paths avoid passing through the cultivated lands.

A simple bar graph (Fig. 9) is used to visually represent the outcome of the multicriteria evaluation utilizing the effect table and derived weights (Fig. 9). All options are listed on the X-axis, while the ranking value is listed on the Y-axis. The length of the bar indicates

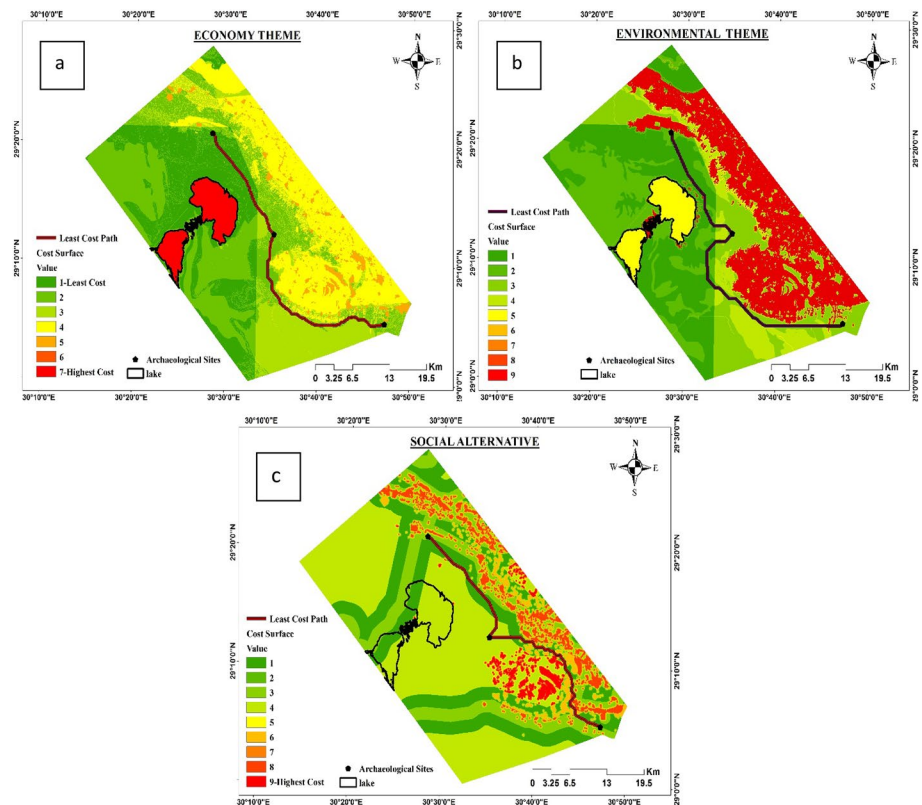


Fig. 6 LCP for the three combined themes a Economy theme b Environmental theme, c Social theme

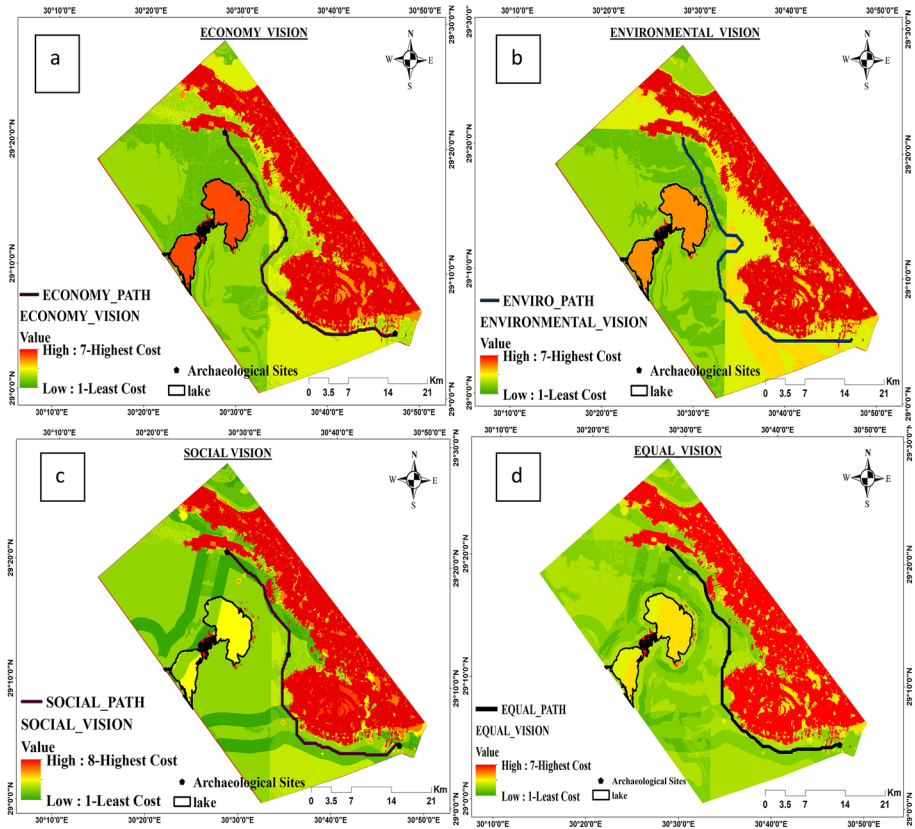


Fig. 7 The four visions **a** Economy theme **b** Environmental theme, **c** Social theme, **d** Equal weight vision

how preferred the choice is. Better options equate to higher bars. Following is an explanation of how the ranking for each cost criterion was analyzed:

In order to create the four scenarios or visions for the modeled routes, we exaggerated the importance of each theme. Weights can be set by direct assessment, we assumed that the direct weight assignment method would provide a set of weights with maximum preference value to a specific theme. A set of weight was proposed by the expert panel. The set of weight we used aimed to assign a high preference to each scenario; for the Environmental scenario: The environment theme was assigned 70%, the economy 20% and the social 10%. For the Economy scenario, the economy theme, was assigned a 70% importance, the environment theme 20% and the social theme 10%. For the social scenario, the social theme was assigned 70%, the economic theme 20% and the social theme 10%. For the equal weight theme all themes were assigned 33%. We realize that the possibilities of changing the weights are endless and the direct weight assignment method may be subjective, yet, our point of view was to try a simple, fast and a most comprehensive method for a decision maker. We tried to get a biased result for each scenario.

To compare the four modeled path scenarios (visions) we used an effect table in DEFINITE software (Singh & Sing, 2017; Yakan & Celik, 2014). The comparison was based on a set of five criteria: "Passing through sand dunes"; "passing through protectorates"; "proximity

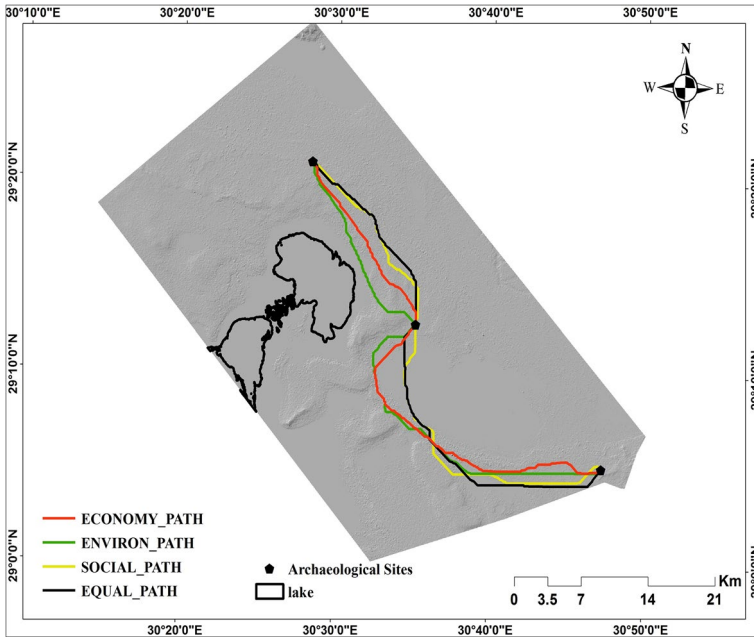


Fig. 8 An overlay of the four least-cost paths results of the four alternative routes (scenarios)

to cultivated land", proximity to lakes and "route length". Table 6 depicts the comparison criteria results and Fig. 9 depicts the result of the comparison graphically. It is observed from Fig. 9 that the graphical presentation of all the criteria was sufficient in this case to rank the alternative four paths vision.

Prioritizing the weight for the cost criteria "Passing through sand dunes", the Environmental scenario path scores 0.71 and ranks first. Prioritizing the weight for the cost criteria "Route Length", the Economy and Social scenario paths score the best. Prioritizing the weight of the criteria "cost of crossing a protected area" the environmental path scores best (1.0). The Equal-weights path ranks second with score (0.75), both the Social and Economy paths score (0.72) meaning an equal preference. Prioritizing the criteria "Proximity to cultivated land", the Social path scores first with a score of (1.0), followed by the equal path option scoring (0.97), the Economy path comes third (0.56) while the Environmental path comes last (0.21). A multicriteria evaluation resulted in ranking the Environmental path as first (0.69). "Proximity to lakes", the Environmental path ranks first (1.0) while the Economic path comes in the second position (0.43). For the overall cumulative effect, the Environmental path ranks first choice while the Economy path ranks second (0.42), the Equal path ranks third (0.40) and finally, the Social path ranks last scoring (0.36). The shortest path is the Equal weights scenario path 53,324 m followed by the Environmental path 53,654 m.

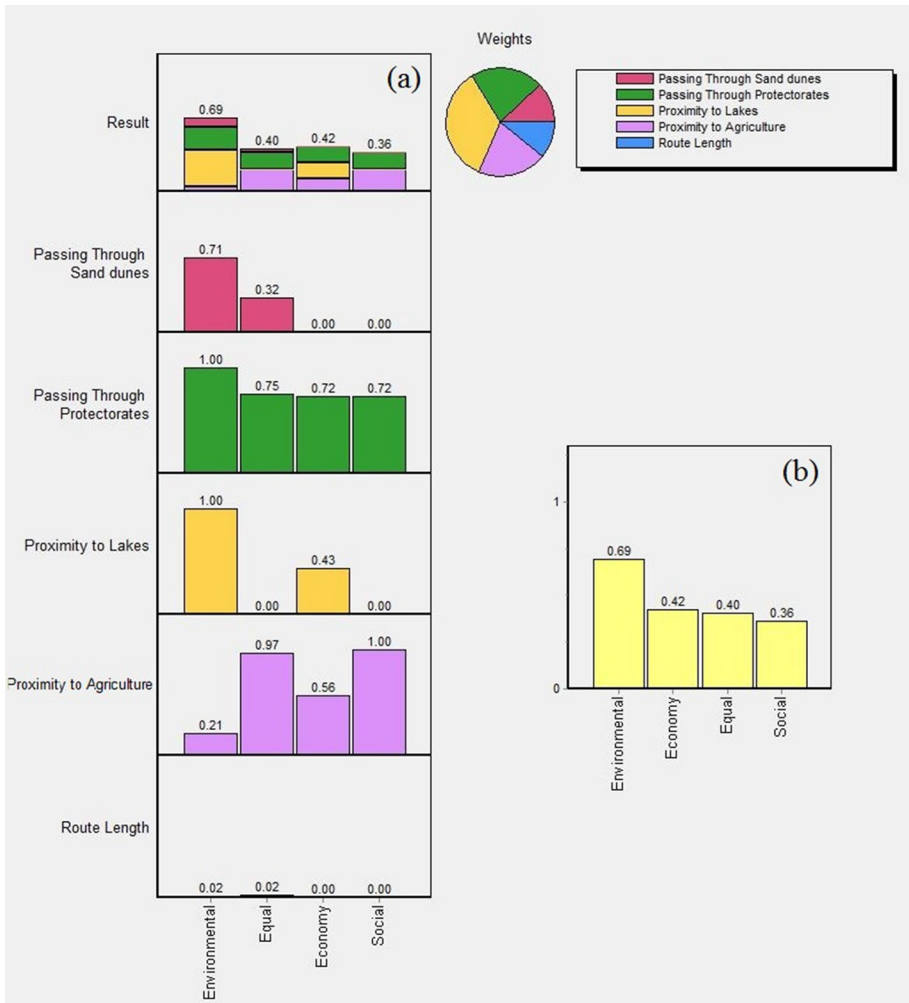


Fig. 9 comparison results of MCE **a** Testing the weights of the evaluation criteria on ranking of the three route alternatives. **b** Result of ranking of the three alternative routes using DEFINITE software

Table 6 Criteria for comparison and ranking of the four scenarios for the three LCP routes

Attribute	MCDA			
	Economy	Environmental	Social	Equal
Passing Through Sand dunes (m)	23,407	6,847	23,407	15,884
Passing Through Protectorates (m)	11,005	15,192	11,005	11,333
Proximity to cultivated lands (m)	4,156	1,516	7,393	7,168
Proximity to lakes (m)	3,866	9,015	0	0
Route Length	54,475	53,654	54,475	53,324

5 Conclusion

A study conducted by De Lima et al. (2016) to choose transmission line routing indicated that the classical approaches based on paper maps, aerial photographs and field visits can generate inconsistent results. They explained that it is a costly process being a time consuming and requires intensive labor. A study by Bagli et al., (2011) indicates that different route alternatives have to be compared in order to arrive to avoid negative impacts, and to choose the most appropriate path. The authors agree that the evaluation of different visions is useful to adapt the decision and solve any problem in different contexts. Both studies also agree that the use of geospatial models is crucial to route planning, comparison of alternatives and in environmental impact assessment. Although the current research proposes a tourism route to improve access ability to heritage sites in a desert. It experimented a combined method using geographic information systems (GIS), multi-criteria assessment (MCA) and analytical hierarchy process (AHP) to generate time and cost savings solution of four alternatives. Such alternatives can be a shedding light for the planning and environmental impact assessment decisions.

We therefore conclude:

- (1) The aim of the current study is to apply geospatial methods to provide accessibility and to link three archaeological sites in El-Fayoum a desert zone. The first site is Madinet Madi, a temple from Middle Kingdom. The second site is Watfa city ruins of the Romanian-Greek era and the third site is Ummal-Barijat ruins temple of the god Sobek from the beginning of the Ptolemaic period. The proposed route is assumed to revitalize the region by providing a base for cultural tourism and researches. It would trigger tourism development and supplying the region with the needed infrastructures and services.
- (2) This research methodology examined the generation of various accumulated cost surfaces and least-cost models outputs. Multi-criteria evaluation and analytic hierarchy process (AHP) were used to create and compare the four route scenarios (alternatives); the social, environmental, economic and equal weights. Results of comparison revealed that the environmental scenario route being the least cost and the most optimum path.
- (3) It can be concluded that GIS, AHP and LCP models are time and cost saving decision support tools. Such tools, if embedded in the early stages of physical planning can provide alternative solutions that reflect the decision makers' objectives, facilitates clear comparison, reduce arguments and foster public participation in the decision making process.

Acknowledgements The authors acknowledge the National Authority for Remote Sensing and Space Sciences for facilitating and providing tools for conducting the current research.

Author contributions HAE: conceptualization, methodology, model review and corresponding author. KE: modeling and data processing, KM: image processing. MS: review of model and draft writing, AEZ: reviewing of model, editing text and revision of manuscript as a whole.

Funding Open access funding provided by The Science, Technology & Innovation Funding Authority (STDF) in cooperation with The Egyptian Knowledge Bank (EKB). None.

Data and materials availability All data generated or analyzed during this study are included and available in this article.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Ayoub, Y., & Abdel Tawab, A. (2017). Um El- Braijat, the Archaeological city that provided one hundred papyrus. *Journal of Sout El-Omma* 5 September 2017. Cited on 24 January 2022 at <http://www.soutalomma.com>
- Abdelaziz, U.H. (2013). Rural highway alignment selection by implementation of a gis methodology and multi-criteria decision making. <http://www.erepository.cu.edu.eg/index.php/cutheses/thesis/view/11843>.
- Abou, D. G., & Doumit, J. (2017). The Berytus-Heliopolis Baalbak road in the roman period: a least cost path analysis. *Mediterranean Archaeology and Archaeometry*, 17(3), 225–241.
- Alonso, J.A. & Lamata, M.T. (2006). *International Journal of Uncertainty, Fuzziness and Knowledge-Based Systems*, World Scientific Publishing Company 14(4), 445–459.
- Atkinson, D., Deadman, P., & DDudycha S Traynor. (2005). Multi-criteria evaluation and least cost path analysis for an arctic all weather path. *Applied Geography*, 5, 287–307.
- Bagli, S., Genelettib, D., & Orsi, F. (2011). Pathing of power lines through least-cost path analysis and multicriteria evaluation to minimise environmental impacts. *Environmental Impact Assessment Review*, 31, 234–239.
- Berry, J., (2004). Optimal path analysis and corridor routing: infusing stakeholder perspective in calibration and weighting of model criteria. http://www.innovativegis.com/basis/present/GeoTec04/GIS04_Routing.htm.
- Brazili, J. (1997). Deriving weights from pairwise comparison matrices. *Journal of the Operational Research Society*, 48, 1226–1232.
- Collischonn, W., & Pilar, J. V. (2000). A direction dependent least-cost path algorithm for paths and canals. *International Journal of Geographical Information Science*, 14, 397–406.
- CONOCO Coral Company (1987). The Egyptian general petroleum corporation; geological map of Egypt, Scale 1: 500,000 Cairo, Egypt.
- De Lima, R. M., Osis, R., de Queiroz, A. R., & Santos, A. H. M. (2016). Least-cost path analysis and multi-criteria assessment for routing electricity transmission lines. *IET Generation, Transmission & Distribution*, 10(16), 4222–4230.
- Diefallah, M., Ragab, A., Ragheb, A., & Abdelkarim, A. (2017). A case study for best path selection using integrated GIS-multicriteria decision approach. *Surveying and Land Information Science*, 76(2), 83–96.
- Djenaliev, A. (2007). Multicriteria decision making and GIS for railroad planning in Kyrgyzstan (MSc dissertation), Royal Institute of Technology, Sweden.
- Douglas, D. H. (1994). Least cost path in GIS using an accumulated cost surface and slope lines. *Cartographica*, 31(3), 37–51.
- Effat, H. A., & Ossman, A. H. (2013). Designing and evaluation of three alternatives highway paths using the analytical hierarchy process and the least-cost path analysis, application in Sinai Peninsula Egypt. *Egyptian Journal of Remote Sensing and Space Science*, 16(2), 141–151. <https://doi.org/10.1016/j.ejrs.2013.08.001>
- Eraqi, M. (2007). Ecotourism resources management as a way for sustainable tourism development in Egypt. *Tourism Analysis*, 12, 39–49.
- Herzog, I. (2013a). The Potential and limits of optimal path analysis. In A. Bevan & M. Lake (Eds.), *Computational approaches to archaeological spaces* (pp. 179–212). Walnut Creek: Left Coast Press.
- Herzog, Irmela. (2013b) Review of least cost analysis of social landscapes. Archaeological case studies. *Internet Archaeology* <https://doi.org/10.11141/ia.34.7>
- Howey, M. C. L. (2011). Multiple pathways across past landscapes: Circuit theory as a complementary geo-spatial method to least cost path for modeling past movement. *Journal of Archaeological Science*, 38, 2523–2535.

- Janda, K. and Tan, T. (2017). Integrated multi-attribute value and analytic hierarchy process model of sustainable energy development in Central Europe and East Asia. Munich Personal RePEc Archive. Paper No. 76716, posted 11 February 2017 08:24 UTC. cited on 23/3/2019 at https://mpra.ub.uni-muenchen.de/76716/1/MPRA_paper_76716.pdf
- Ron Janssen and Marjanvan Herwijnen, Decision Support for Discrete Choice Problems : The Definite Program. Institute of Environmental Studies. Vrije Universiteit Amsterdam, The Netherlands. Definite @i vm.vu.nl
- Janssen, R., van Herwijnen M. & Beinat E. DEFINITE (2001). Case studies and user manual. Institute for Environmental Studies, Vrije Universiteit Amsterdam, R-01/01; 2001
- Jiang-Jiang, W., You, L. J., Chun, F. Z., & Jun, H. Z. (2009). Review on multicriteria decision analysis aid in sustainable energy decision-making. *Sustainable Energy Reviews*, 13(9), 2263–2278.
- Lee, J., & Stucky, D. (1998). On applying viewshed analysis for determining least-cost paths on digital elevation models. *International Journal of Geographical Information Science*, 12, 891–905.
- Leung, L. C., & Cao, D. (2000). On consistency and ranking of alternatives in fuzzy AHP. *European Journal of Operational Research*, 124, 102–113.
- Van Leusen, M. (2002). Pattern to Process: Methodological Investigations into the Formation and Interpretation of Spatial Patterns in Archaeological Landscapes, PhD Dissertation, Groningen University.
- Lewis, J. (2017). *The suitability of using least cost path analysis in the prediction of roman roads in the highland and lowland zones of Roman Britain*. Leicester University, Department of Geography.
- Madinet Madi, (2013). Archaeology Site. Online report cited on 7 March 2022 at <https://fayoumegypt.com/medinet-madi-narmouthis/>
- Ramzy, Y. (2017). Managing Egyptian tourism through tourism governance. *Journal of Social Sciences (COES&RJSS)*, 6(2), 196–210.
- Saaty, T. L. (1980). *Multicriteria decision making: the analytic hierarchy process, 1988* (p. 1980). Revised and published by the author; Original version published by McGraw-Hill.
- Saaty, T. L. (2000). *Fundamentals of Decision Making and Priority Theory with The Analytic Hierarchy Process*. Pittsburgh: RWS Publications.
- Saaty, T. L. (2008). Decision making with the analytic hierarchy process. *International Journal of Services Sciences*, 1(1), 83–98.
- Saaty, T.L. (1990). How to make a decision: The analytic hierarchy process. *European Journal of Operational Research* 48, 9–26, North-Holland
- Sadasivuni, R., O'Hara, C. G., Nobrega, R., & Dumas, J. (2009). A transportation corridor case study for multi-criteria decision analysis. In *Proceeding of ASPRS 2009 Annual Conference. Baltimore, Maryland: USA*.
- Schild, A. (2016). *Archaeological least cost path modeling : A behavioral study on the middle bronze age merchant travel routes Across the Anamus Mountains*. Faculty of the USC graduate school university of Southern California.
- Seifrieda, R. M., & Gardnerb, C. A. M. (2019). Reconstructing historical journeys with least-cost analysis: Colonel William Leake in the Mani Peninsula Greece. *Journal of Archaeological Science. Reports*, 24(2019), 391–411.
- Singh, M. P., & Sing, P. (2017). Multi-criteria GIS modeling for optimum path alignment planning in outer region of Allahabad City. *India. Arabian Journal of Geosciences*, 10(294), 1–16.
- Song, T., Pu, H., Schonfeld, P., Zhang, H., Li, W., Peng, X., Hu, J., & Liu, W. (2021). GIS-based multi-criteria railway design with spatial environmental considerations. *Applied Geography*, 131(2021), 102449.
- Vaidya, O. S., & Kumar, S. (2006). Analytic hierarchy process: an overview of applications. *European Journal of Operational Research*, 169, 1–29.
- Wahdan, A., Effat, H., Abdallah, N. & Elwan, K. (2019). Design an optimum highway route using remote sensing data and GIS-based least cost path model, Case of Minya-Ras Ghareb and Minya-Wahat-Bawiti Highway Routes, Egypt. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS)* 56(1), 157–181.
- Yakan, F., & Celik, F. (2014). A highway alignment determination model incorporating GIS and Multi-criteria decision making. *KSCE Journal of Civil Engineering*, 18(6), 1847–1857.