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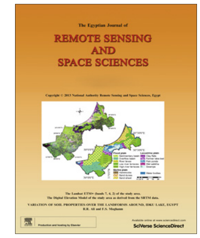

RESEARCH PAPER

Designing and evaluation of three alternatives highway routes using the Analytical Hierarchy Process and the least-cost path analysis, application in Sinai Peninsula, Egypt

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Abstract Land use planning in a remote desert zone is usually dependent on an efficient corridor and main road network system. In this paper, Geographic Information System (GIS) tools were used to develop a least-cost path for a corridor to link three cities in Sinai Peninsula desert environment. It is supposed to create a backbone for developing the middle part of peninsula by facilitating the transport of mineral resources and accessibility to such region and encourage populating the remote desert city of Nekhel and the coastal cities of Taba and El Shatt. Therefore, such a route should have the least cost and should be protected from the negative impacts that may be caused by the surrounding environment. Environmental and economical factors were integrated through a spatial multicriteria model using the Analytical Hierarchy Process. Cost factors were identified and a cost surface was created for each factor, standardized, weighed and aggregated. Three visions were modelled: an engineering vision, an environmental vision and a hybrid vision. A multicriteria evaluation was used to compare the three routes. The hybrid route was finally recommended.

1. Introduction

Least-cost path analysis (LCPA) allows designers to find the "cheapest" way to connect two locations within a cost surface which can be computed by combining multiple criteria, and therefore by accounting for different issues (environmental impact, economic investment, etc.). There are a number of basic steps in finding a minimum cost path over a surface partitioned into regions of different resistances to movement (Collischonn and Pilar, 2000; Douglas, 1994). This procedure can be easily implemented with modern Geographic Information System

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(GIS) technologies, and consequently it has been widely employed to support planning and designing of different types of linear infrastructures, ranging from roads to pipelines. In route planning generally one or a few alternative routes are proposed, often representing the interest of the proponent(s). The generation of alternatives, which is at the heart of Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA), is perhaps the most underdeveloped part of the assessment processes (Glasson et al., 1994; Sadler and Verheem, 1996; Niekerk and Voogd, 1999; Treweek, 1999; Steinemann, 2001; IAIA, 2007). Keshkamat (2007) concludes that a rational, transparent stakeholder-based process for the generation of alternatives is required to be able to improve EIA and SEA and thence decision-making. There have been several recent applications of least-cost path methodologies which involve: selecting an all-weather road (Atkinson et al., 2005). Selecting the fastest path with the least slope based on elevation data (Stefanakis and Kavouras, 1995) selecting the best route for a pipeline based on land use and land cover data (Feldman et al. 1996). Now, the computation of least-cost paths is considered the most useful tool available for determining the optimal path from one or more origin points to one or more destination points (Lee and Stucky, 1998). The methodology for the calculation of an accumulated-cost surface is well documented in commercial GIS packages and in Collischonn and Pilar (2000), Douglas (1994), and Lee and Stucky (1998). Routes for features such as roads, railways, or pipelines are often constrained by physical, environmental, political, social, economic, and regulatory factors. A system that can optimize relationships among these factors and identify trade-offs can produce a wide range of alternatives (Motemurro et al., 1998). Spatial Multicriteria Evaluation (SMCE) as a technique has been used to solve routing problems in utility infrastructure, such as for pipeline routing (Bagli et al. 2011; Rescia et al., 2006; Yusof and Baban, 2004), transmission line routing and in telecommunication network design (Paulus et al., 2006).

Atkinson et al. (2005), Collischonn and Pilar (2000), and Douglas (1994) applied the following basic steps: (a) a friction surface is created for each evaluation criterion, where each cell in the grid is assigned a value based on the relative cost of traversing that cell. The methodology utilizes a GIS to prepare, weigh, and combine construction factors. (b) Multiple friction surfaces are weighed and combined to create a cost-of-passage surface, representing the total cost associated with traversing each cell. (c) A spreading function combines two separate grids representing source points and destination points with the cost-of-passage grid to calculate an accumulated-cost surface. (d) The lowest cost line is traced down the accumulated-cost surface from an origin point to a destination.

2. Purpose of the study

The purpose of our research is to develop a model utilizing GIS techniques to design a least cost route for a highway that crosses central Sinai region. The highway is supposed to link the city of Nekhel in the central zone to the coastal city of Taba located on Gulf Aqaba and the city of Shatt located on the Gulf Suez. Such a highway can be the backbone of a new development corridor improving the accessibility to the central zone of Sinai Peninsula. The path can be adapted for a railway route in the future. Therefore, such a route should have the least negative impacts on the environment and should also be protected from the negative effects that may be caused by the surrounding environment.

3. Description of the study area

Sinai Peninsula is situated between Gulf of Aqaba and Gulf of Suez, and is bounded from north by the Mediterranean Sea. The region has rich geological resources reflected in extensive mines and quarry sites. Sinai is popular for its unique historical sites such as Holly Mountain of Moses and Saint Catherine monastery in addition to unique ecological sites such as Lake Bardawil and Zaranik protectorates and rare coral reefs along the Red Sea costs. The peninsula is divided into two administrative governorates, North and South Sinai.

The central zone of Sinai Peninsula is the least developed. Cities are located along the sea cost with least development in the middle desert zones. Three towns are located in the central zone and have the least population densities among cities of Egypt. Such cities are described in this section (Fig. 1).

Geomorphologically, Sinai can be divided broadly into the following main units, namely (Hassan, 2000): (1) Mountainous basement terrain, (2) Upland plateaux, (3) Folded Hilly terrain (4) Mediterranean coastal plain belt, and (5) Pediplains. Central table lands, an extensive stretch of flat-topped plateau, cover most of central Sinai (Ashmawy et al., 2000). The general surface of the plateau slopes gently northward, where it merges into Central Sinai pediplain near Thamada-Nakhl stretch. The plateau is bounded on its east, south and west by vertical scarps. The northern boundary is marked by large east–west faults that cross almost the entirety of Sinai. This central table lands consist of two plateaus. The southern plateau (El Tih Plateau), and El-Egma Plateau is to the north. El Tih is a horseshoe shaped (concave to the north) series of connected topographic hights (cuestas) (maximum 1600 m), which are separated from the southern mountains by the Ramlet Himeiyir Depression (El Ghazawi,1989). The plateau is composed of cretaceous limestones, with shales and sandstones at the base (Hammad, 1980). The exposures of the lower Cretaceous (Nubian type) sandstone at the base of the southern escarpments of El Tih are considered the principal recharge areas for the lower Cretaceous aquifer. On El-Egma Plateau, chalky carbonate rocks of Eocene age, containing bands of flint, are exposed in a broad zone which dips gently to the north, occupying most of the middle of the peninsula. The plateau is separated from El Tih Plateau by three tectonic depressions: Yaraqa on the west, El Aqaba on the east and Kuntilla on the northeast (Morency et al., 1998). El Egma is drained by Wadi El Arish. The tributaries of which create a well developed and very complex network of ephemeral streams. The plateau land is intensely drained by numerous dry natural water courses descending northerly towards the Mediterranean Sea through Wadi El Arish, westerly towards the Gulf of Suez, easterly towards the Gulf of Aqaba, and northeasterly towards Palestine through Wadi Garrafy.

The region has few remote towns, most of which are located around the coastal belt. Few towns and Bedouin settlements are scattered in the middle of the Peninsula (Central Sinai). Linking the centre city of Nekhel with the coastal towns Taba and El Shatt with a highway can further improve accessibility,