Environmental Vulnerability Mapping in the Suez Governorate, Egypt Using SRTM Data and GIS

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Abstract. Land use planning decisions have to deal with large volumes of basic data where technical knowledge must be co-coordinated with the decision maker's views of society. Understanding of the natural environment leads to rational and sustainable land use decisions. Site selections have to avoid hazardous zones that may result from misallocations. This makes spatial planning quite a complex process. Remote sensing and geographic information systems have been used efficiently as tools for risk assessment related to land use decision making. In Egypt, the desert occupies almost 96% of the territory. The Eastern Desert has a variety of risk issues related to sand dunes encroachments, flash flood hazard and rock collapse. Shuttle Radar Topography Mission (SRTM) DEM data integrated with geographic information system (GIS) to study the terrain characteristics and model the vulnerable lands in El Suez Governorate. The study included the elevation, slope, aspect and drainage network and extraction of the land relative moisture index. A Spatial model is applied on part of the Eastern Desert, the Suez Governorate to identify the risk facing the Development corridors and road network. A ranking was performed to identify the most vulnerable road sectors subjected to each type of risk. The methodology resulted in two risk index maps namely sand dunes encroachment risk and land collapse risk index. Such indices were classified and combined in a multi-risk map. The model was verified using a high resolution image for sand dunes encroachment and field investigations for potential rock collapse. SRTM DEM integrated with GIS provided a comprehensive tool for environmental vulnerability mapping, and produced a constraints map which is a pre-requisite for land use planning

Keywords: remote sensing, GIS, model, decision support, natural hazard, risk index.

1 Introduction

Land collapse has been studied by several scientists**.** *ComegnaL. et al 2007* studied the undrained-drained deformation. Undrained conditions are established as a consequence of landslides mobilization or reactivation. *Mitchell W.A. et al 2007* describes the geomorphology of rock avalanche deposits that resulted from a major mountain slope failure at Keilong Serai on the north slope of the Indian high Himalaya**.** Fourniadis I.G. et al 2007 focused on the hazard impact of landslides in the three Gorges, and represents the progression of on regional land instability assessment in the area using imagery data from the ASTER data. They established a model that integrates land instability with several factors that can relate hazard to human life. Sand encroachment and dust storms are some of the geologic hazards found in arid lands associated with Aeolian systems, hazards which are increasing due to climate change and anthropogenic *activity Nicholson et al., 1998; Veron et al., 2006*. There has been an extensive history of studies of the migration rates of sand dunes and their orientation using a variety of methods. *Del Valle et al., 2006; Pease, 1999 and Robinson et al., 2007; Embabi 1998; 2000; 2004). Embabi (2000***)** studied the sand dunes distributions in Egypt, he concluded that there exist six sand seas and eight dune fields in Egypt, except for the North Sinai sand sea, it can be noticed that the other five sand seas are developed in the Western Desert. *(Embabi 2000*). *Rubin et al (2007)* studied the lateral migration of sand dunes in the Sinai Desert focusing on the wind conditions and possible occurrences that would influence the rate of migration (*Rubin et al., 2007*). *Livingstone et al. (2007)* concluded that dune migrations studies have shifted from empirical studies to modeling approaches. However, models will continue to require accurate field observations to fully develop an understanding of desert sand dune geomorphology *(He et al.,* *2005; Sanchez-Flores et al., 2008)*.The Suez Governorate is one of the governorates located in the northeastern part of Egypt figure 1. The governorate covers an area of 9002.21 km². It represents 0.9% of the total area of Egypt. According to the preliminary results of the 2006 census, population is 511,000 with a population growth rate amounting to 19.9 per thousand capita. The governorate is well known for its industrial potentials and resources, rich in Limestone, Dolomite, Coal and Petroleum. The main industries include petroleum exploration, cement industry, glass industry, and chemical and fabrics industry in addition to port-based activities. Lying on the Red Sea coast and encompassing the Suez Canal, the governorate has potentials for both tourism and logistical activities. The governorate is therefore, has development plans that are in need for suitability studies. The objective of this study is to develop a comprehensive methodology (model) using remotely sensed data and geographic information system for exploring and mapping vulnerable zones to the land collapse hazard and sand dunes activities in the Suez Governorate. This map is an important input to all land suitability analysis which, are an essential component for land allocation decisions and future development plans.

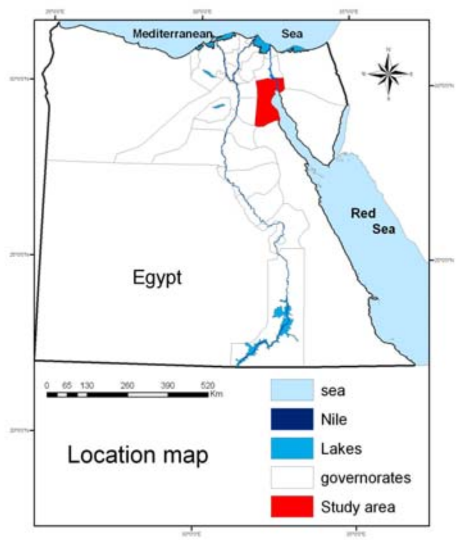

Figure (1): Location map of the Study area

2. Materials and methods:

The primary datasets for this study incorporated:

- Shuttle Radar Topography Mission (SRTM) DEM data.
- The geological map was used to delineate the rock type and fault distribution map.
- Seismic maximum intensity zones map was converted to a grid.
- Food and Agriculture Organization of the United Nations (FAO) (2002). Egypt Multipurpose Land Cover Database (Africover).
- Meteorological data for wind speed and wind direction

2.1 Risk Assessment of Land Collapse

Cartographic modeling is an example of an advanced method of GIS analysis. It is a methodology for structuring a GIS analysis scheme Heywood 2002 and Belka 2005. It consists of data pre-processing, graphical representation of the process of modeling as a flowchart, and execution of the model using GIS operations. Cartographic modeling applies map algebra tools together with other basic analysis operations in GIS. It has graphical environment in most of commercial GIS systems.

Shuttle Radar Topogrphy Mission (SRTM) was used to derive the elevation zones grid for the Egyptian terrain. Using ArcGIS 9.2 software, the slope angle was derived. The lithology (rock type) and the faults distribution were derived from the geological map of Egypt. The seismic maximum intensity donation map was converted to a grid. Effective parameters for land slides studied in this paper are lighology, elevation zones, slope angles, geologic structure (faults). These layers were used as input for the landslide cartographic model as illustrated in figure (2).

A multi-criteria evaluation model was used that standardizes the various layers into a standard measuring scale. These layers were reclassified according to the contribution of every factor and its impact on the land collapse phenomenon to a measuring scale. The elevation zone map was reclassified to depict the effect of elevation on the land collapse vulnerability, high elevation areas are more subjected to land collapse due to gravity effect. Elevation risk index grid is shown in figure (4).The slope grid was produced as shown in figure (4). The continuous slope grid was reclassified into a risk index grid according to the conditions. Steep slopes are vulnerable to land collapse more than gentle slope areas. Various rock types have different vulnerability for land collapse due to their physical characteristics including hardness. The lithology map was reclassified according to their vulnerability to land slide as shown in figure (4). Fault map has been reclassified to a fault density map, high fault density areas are more subjected to land collapse. Seismic intensity zones map were reclassified into a vulnerability scale, Zones with higher intensity scores are more vulnerable to land collapse. The above mentioned five layers (variables) were input into a cartographic model in ArcGIS 9.2 software using the weighted overlay module. For the weighted overlay module all input grids must be integers. A floating-point raster must first be converted to an integer raster before it can be used in Weighted Overlay. Using the reclassified above mentioned parameter grids, different scenarios were applied to produce different output. Equal weights (Unity weight) were given to the input grids. The five variables produced the vulnerability map for land collapse. Changing the map assignment evaluation scale value or the percentage influences can change the results of the weighted overlay analysis. The second scenarios maximized the weights of the slope and fault density grids. The output risk map is shown in figure (5a and 5-b).

Table 1: Parameters for mapping of the risk of collapse risk

Parameter (variable grid)	**Parameter contribution to rock collapse**
Elevation zone	Higher elevation zones are more vulnerable to land collapse.
Slope	Steeper slope angles are more risky.
Rock type	Different rock type have different response to land collapse
Fault density	Higher fault density is more vulnerable to land collapse
Seismic maximum intensity zones	Higher seismic magnitudes are more vulnerable to land collapse

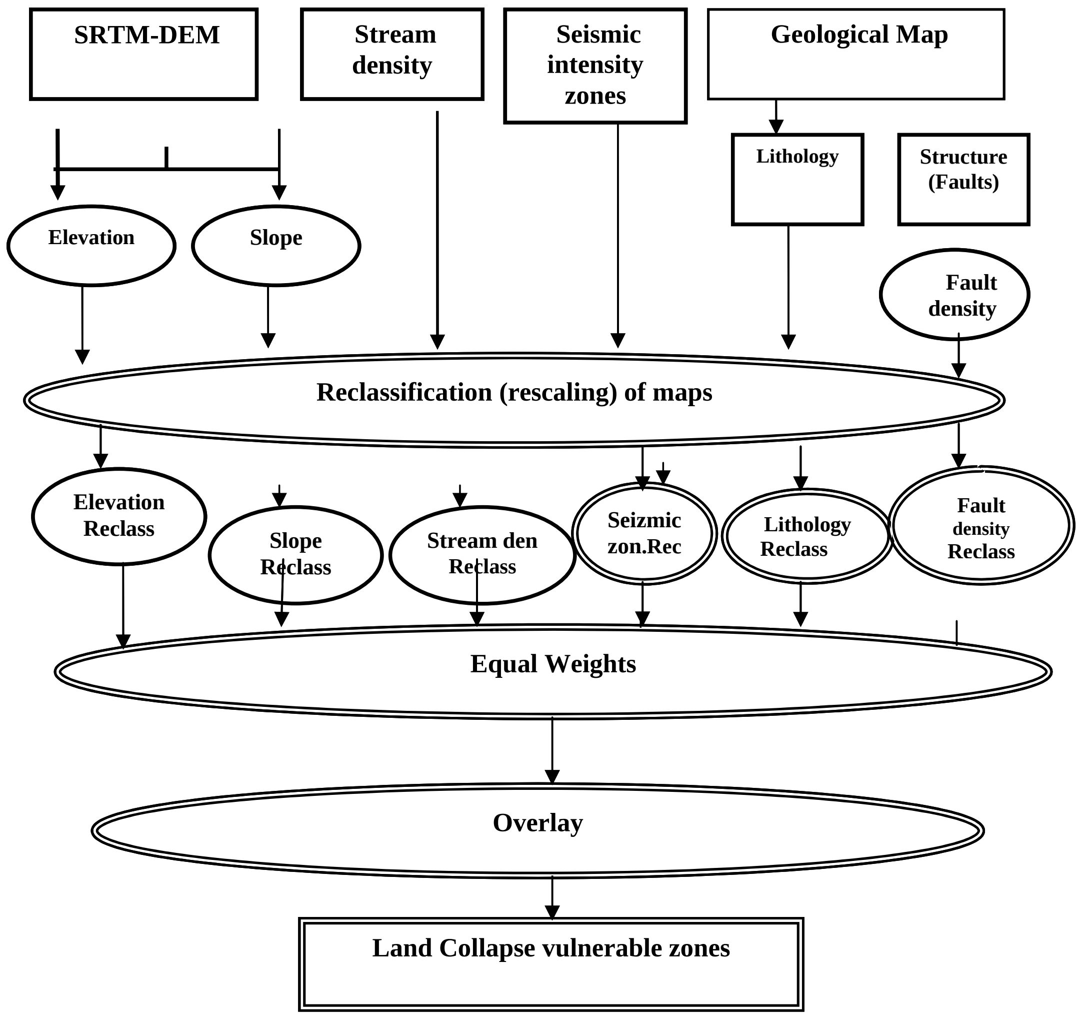

Figure (2): Flow chart for the methodology of mapping the Land collapse vulnerable zones

2.2 Risk assessment of Sand Dunes Movement

Six parameters affecting the sand movement are modeled. A land cover map produced by the Food and Agricultural Organization (FAO) of the United Nations (2002) from Landsat Thematic Mapper satellite images was first used to identify the area of sand dunes in the Suez Governorate. For this region, the six model parameters of terrain surface elevation, slope angle, slope angle direction (aspect), relative moisture index, prevailing wind direction and wind speed were developed from an existing Digital Elevation Model (DEM) and meteorological information. It is essential to mention that the sand grains size is an effective parameter in sand dunes movement yet, this parameter is not considered in this study due to lack of data.

Table 2: Parameters for mapping of the risk of sand dunes movement

Parameter (variable grid)	Parameter contribution to sand dunes activity
Dune Elevation	Higher elevation zones are more subjected to wind effects.
Slope angle	Steeper slope angles are more risky.
Dune Aspect	Dunes aspect facing the prevalent wind direction are more subjected to its effects
Prevailing wind speed	Wind speed plays a crucial role in sand dunes activities
Prevailing wind direction	Prevalent wind directions affect sand dunes most.
Relative moisture index	The drier the sand dunes body the most vulnerable it becomes to wind effects.

The dunes elevations were reclassified into five risk classes. Zones with the highest relief were given the maximum risk value and vice versa. The slope was reclassified into first class ranged from 0-10 degrees. The second class ranged from 10-20 degrees, the third class ranged from 20-30 degrees as medium risk while more than 40 degrees were classified as highest risk dunes. The aspect map was reclassified according to the prevalent wind direction. The most prevalent wind directions had the maximum risk while the least prevalent wind directions had the minimum risk value. Wind speed data were derived from the meteorological atlas of Egypt. Wind Intensity read from the various wind stations were presented as a point vector map. These values were interpolated to create a surface for the wind intensity values. The wind direction vectors were presented in azimuth angles measured from the North direction.

The six parameters were used to run the designed cartographic model as shown in figure (3). The wind direction surface was reclassified according to the prevalent wind directions hierarchy distributions.

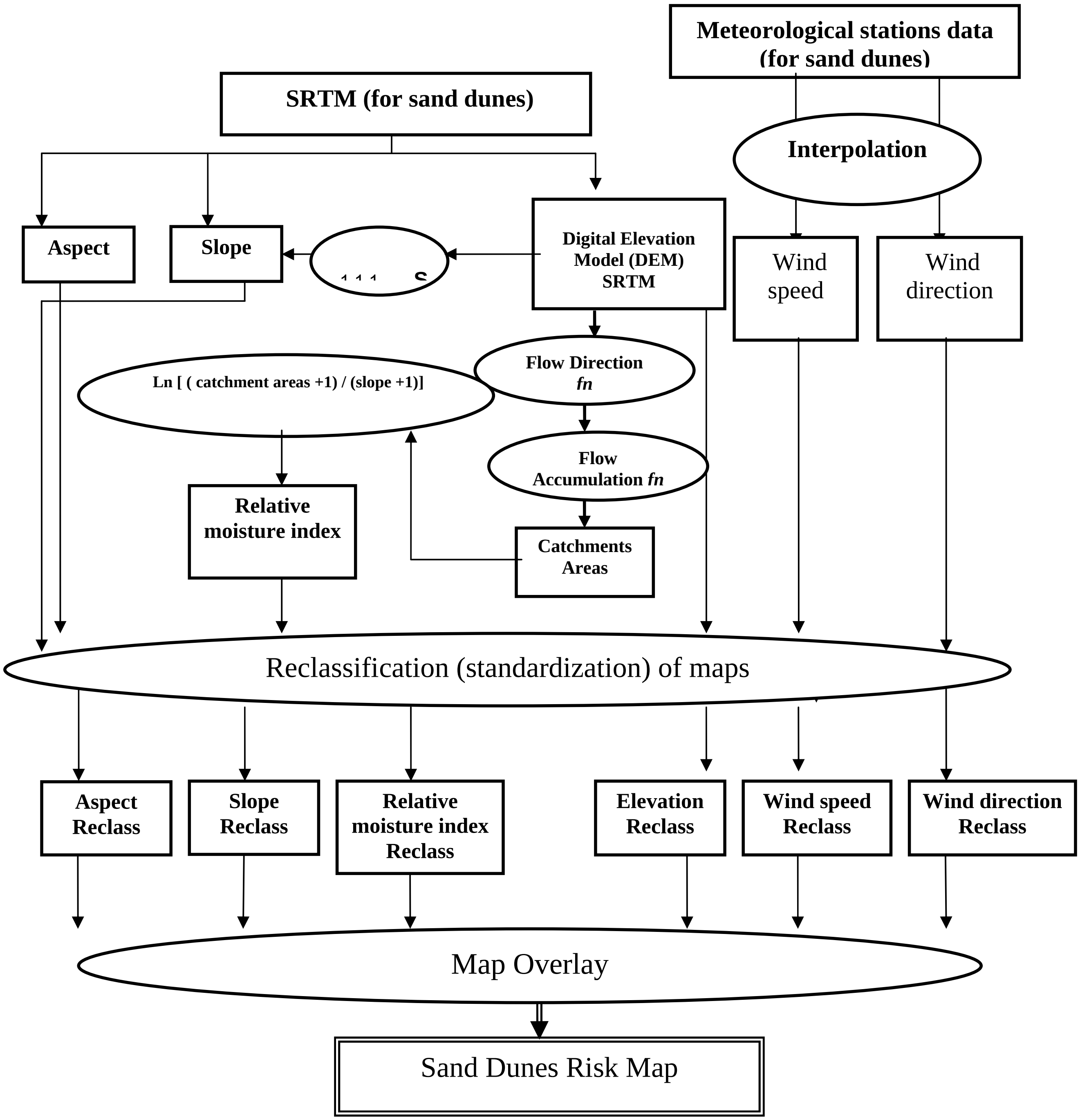

Figure (3): Flow chart for the cartographic model for sand dunes risk assessment

3. Results and Discussions

Results of exploring the various effective parameters in risk mapping of the Suez Governorate revealed the following facts:

The Elevation zones map (figure 4-a) shows that the distributions of high relief exist in the south zones. The lithology map shows the sand dunes to exist in the Eastern part with some sand gravel and sand dunes in the Western part (figure 4-b). Stream density map shows the spatial high values distribution in the investigated area (figure 4-d). Aspect angles depict the slopes direction in azimuth. Such distribution is shown in (figure 4-e). The high slopes exist in the south with some distributions in the middle showing most lands with relatively high slopes due to the existence of mountains (figure 4-g).

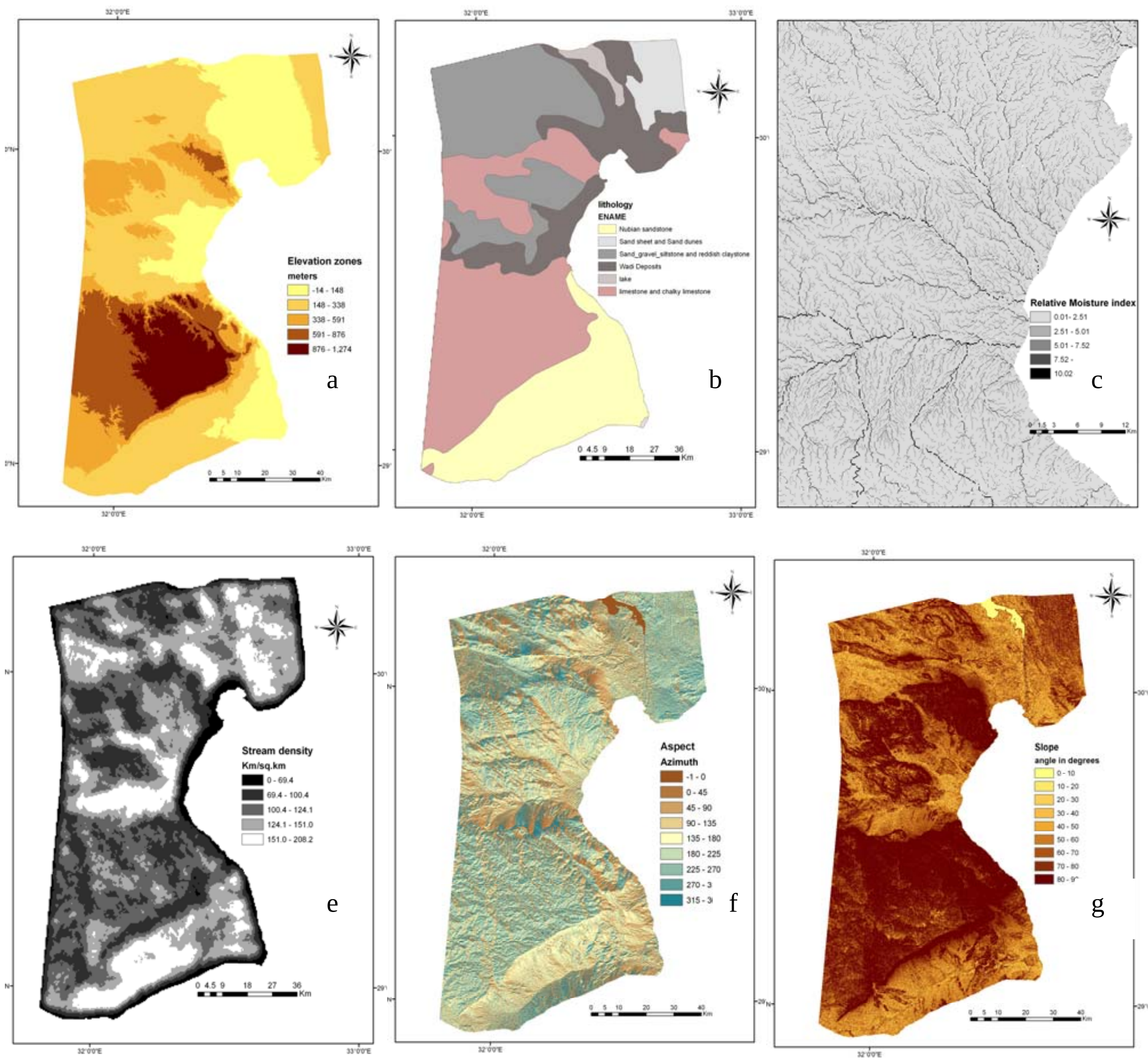

Figure (4): some parameters used for cartographic modeling of the terrain risk map for Suez Governorate. (a) Elevation zones map. (b) Litholgy map. (c) Relative Moisture index map. (e) Stream density map. (f) Aspect map. (g) Slope map.

Combining the results of the cartographic models resulted in the final risk map. This map shows the sand dunes classifications. The massive sand dune bodies existing in the Eastern part of the governorate show low risk classes, while the sand dunes in the lower half of the governorate have high risk classes indication a high possibility of sand encroachment. Dunes distributions in the northern parts have some high risk values indicating a relatively high risk. The results of the landslide cartographic risk indicate areas of relatively high risk of land collapse in the southern part with some distribution in the northern part figure (5). Overlaying the railroads in Suez Governorate with the resultant risk map facilitates the assessment of the environmental conditions of the railroad. The western sector of Cairo-Suez rail road passes through a relatively high zone of possible land collapse. The same sector is in proximity to a sand dunes body. The two eastern sectors (Suez-Port Saied and Rafah-Port Tawfik) pass by a medium risk of collapse zone as well as being in proximity to sand bodies with minimum risk of encroachment. Overlaying the map with the urban areas show an optimum location and a minimum risk of land collapse figure 5-a. Overlaying the risk map with the road network figure 5-b reveals
that most of the roads run through a low to medium risk of land collapse zones. An exception is few sectors of the northern roads which need more detailed soil investigations.

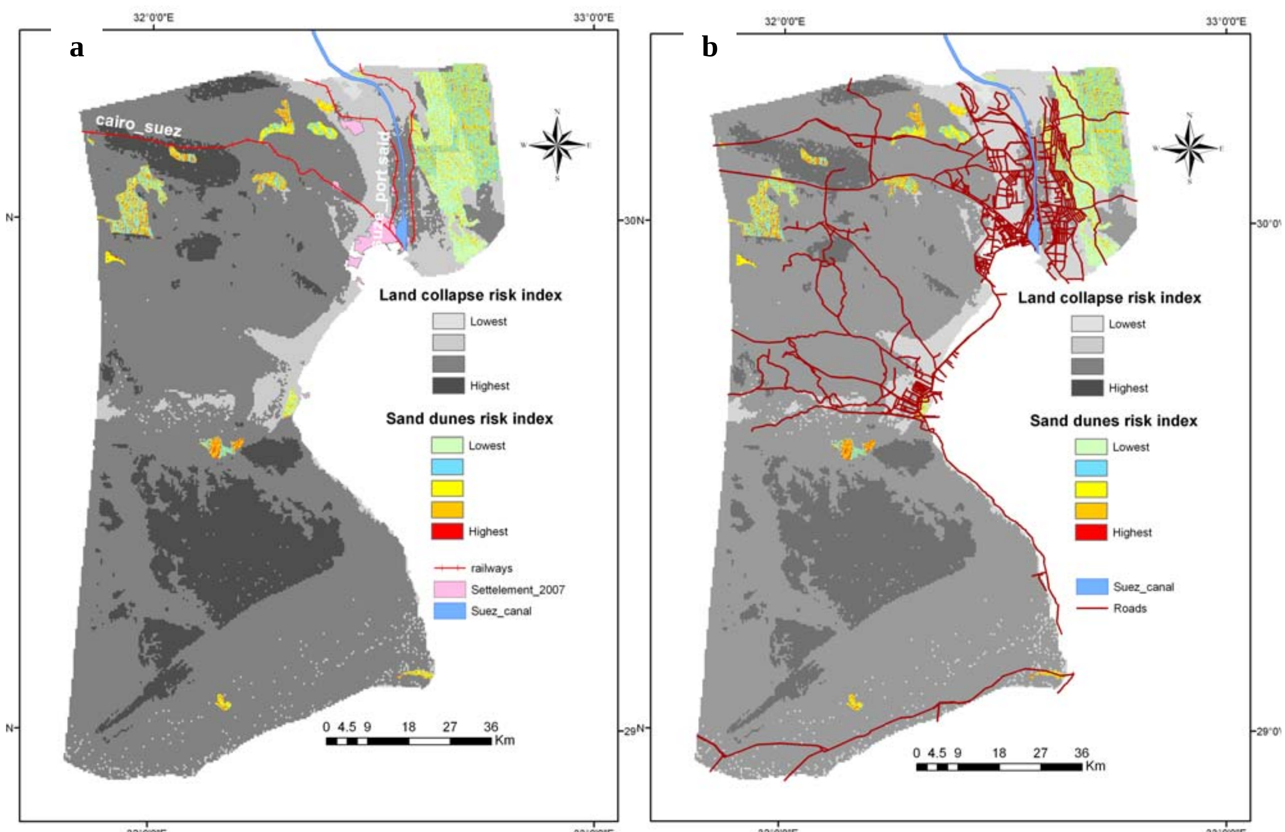

Figure (5): Composite risk index map for sand dunes and land collapse in Suez Governorate.
(a) Overlay of the railroad and urban features on the risk map.
(b) Overlay of the road network on the risk map.

Risk Map Verification

A planned field investigation is being undertaken in addition to higher resolution images (IKONOS) for some chosen locations with relatively high risk to assess the reliability of the resultant maps. The research is on-going in this stage of analysis for the identified road sectors.

4. Conclusion

Cartographic modeling provided a multi-disciplinary approach for exploring land constraints. In this study, the use of cartographic modeling produced a land risk map. Such risk map can be useful as guidelines for more detailed studies in environmental impact assessment and environmental management plans. It can be useful in establishing and reviewing building codes for construction in the various zones. It is also helpful in land suitability analysis and land allocation in urban planning decisions.

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