Mapping of Land Collapse Susceptibility Using SRTM and Geographic Information Systems – Case of Greater Cairo Region, Egypt

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Abstract. Geohazard information is an important input to strategic land use planning. Land collapse susceptibility map is crucial to land use planning and decisions, yet such map is often lacking or incomplete in most developing countries. Many reasons contribute to this some of which are lack of qualitative data related to hazard, lack of awareness between some decision makers and planners as well as time limitations. This paper is an attempt for an understanding of some criteria indicators triggering land collapse and susceptibility through cartographic modeling. Such studies are crucial for setting an early warning system using remotely sensed data and geographic information system. Multicriteria evaluation was used for mapping zones that are prone to future land collapse hazard in Cairo region, Egypt on a regional scale. Using shuttle radar topography mission (SRTM) data to analyze the terrain characteristics layers such as the elevation, land slope and streams network maps. The geological map of Egypt was used to identify the rock types and to delineate the lineament structures in addition to the seismic intensity zones map. Criterion maps were created for the mentioned parameters and combined into a composite index map for land collapse susceptibility zoning map. The resultant map was overlaid with the main corridors and new cities in greater Cairo region to point out zones at risk of such a hazard. It also highlighted the fact that there is a lack of awareness of land vulnerability in the early stages of land use planning (zoning). Resultant map can help in managing and mitigation of the environment of the urban areas and infra structure prone to such risk and should be used in the earliest stages of regional urban planning and for strategic environmental assessment of future development plans.

Keywords. Vulnerability, geohazard, elevation zones, slopes, fault density, seismic intensity, multicriteria evaluation, srtm data, egypt.

1. Introduction

The term landslide includes a wide range of ground movement, such as rock falls, deep failure of slopes, and shallow debris flows. Although gravity acting on an over-steepened slope is the primary reason for a landslide, there are other contributing factors: and slides may involve movement of natural rock or soil, artificial fill, or a combination of such materials. They are triggered by many factors, exogenic, endogenic or man induced. According to U.S. Geological Survey (USGS) excess weight from accumulation of rain or snow, stockpiling of rock or ore, or from man-made structures may stress weak slopes to failure and other structures. Earthquakes create stresses that make weak slopes fail.
“Ground failure” is the term used to describe zones of ground cracking, fissuring, and localized horizontal and vertical permanent ground displacement that can form by a variety of mechanisms on gently sloping valley floors. Ground failure may be caused by surface rupture along faults, secondary movement on shallow faults, shaking-induced compaction of natural deposits in sedimentary basins and river valleys, and liquefaction of loose, sandy sediment (USGS, 2005). Such hazard has been studied by several scientists. Luca C. et al 2007 studied the undrained-drained deformation as 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 on regional land instability assessment using imagery from the ASTER data. They established a model that integrates land instability with several factors that can relate hazard to human life. Landslide can be classified into different types on the basis of the type of movement and the type of material involved. The purpose of this research paper is limited to the terrain-related triggering parameters rather than the types of landslides. In recent years, computer modeling of landslides has been to study landslide phenomenon over time. Promising methods are being developed that use digital elevation models (DEMs) to evaluate areas quickly for their susceptibility to landslide/debris-flow events. Hazard maps used in conjunction with land-use maps are a valuable planning tool. Commonly, there is a three-stage approach to land failure hazard mapping. The first stage is regional or reconnaissance mapping, which synthesizes available data and identifies general problem areas. This regional scale mapping is usually performed by a Provincial, State, or National geological survey. The next stage is community-level mapping, a more detailed surface and subsurface mapping program in complex problem areas. Finally, detailed site-specific large-scale maps are prepared. Regional or reconnaissance mapping supplies basic data for regional planning by providing baseline information for conducting more detailed studies at the community and site-specific levels and for setting priorities for future mapping. Such maps are usually simple inventory or susceptibility maps and are directed primarily toward the identification and delineation of regional landslide problem areas and the conditions under which they occur. They concentrate on those geologic units or environments in which additional movements or ground failure is most likely. The geographical extent of regional maps can vary from a map of a State or Province to a national map, which delineates an entire country. Map scales at this level are typically at scales ranging from 1:10,000 down to 1:4,000,000 or even smaller (Highland et al, 2008).

Vulnerability to land slide hazards is a function of a site’s location (topography, geology, and drainage), type of activity and frequency of past landslides. Yet, some triggering mechanisms occur sporadically and have a gradual and cumulative effect and are not readily obvious (Highland et al, 2008). An early warning system can start early from the land use assessment before the decision making and site selection. This paper attempts to produce a susceptibility map for Greater Cairo region prone zones for land collapse/failure due to existence of both natural and anthropogenic factors. Past actions of quarrying and mining activities caused several cracks and faults in the region. Such regional scale assessment provides a quick and general map that synthesizes available
data and identifies problem areas. It is meant to provide guideline to land use planners and environmental managers.

**Cairo Region Case**

Cairo metropolitan region is located between 27 30 00 and 30 20 00 North and 27 00 00 and 31 40 00 East. The region covers a total area of 41.34 square kilometers. The investigated area consists of four neighboring administrative divisions namely; Helwan, El Giza, Kalyoub and Six October divisions. The land cover features vary between the Nile River and its Delta rich cultivated land, sand dunes, bare land and rocky hilly zones. Extending East and West the lithology in the investigated region consists of a variation of basement rocks, clay and sandy clay, Nile deposits, Wadi deposits, sandstone, sand gravel siltstone and clay stone in addition to vast zones of limestone and chalky limestone. Most of the rocks consist of limestone and chalky limestone with medium vulnerability. Least vulnerable rock units consisting of some Nubian Sandstone units while marginally vulnerable units extend toward the South Western zone consisting of Dolomitic limestone and clastic deposits and phosphate hard Paleozoic and Mesozoic The highly populated megacity of Cairo is sited within a diffuse zone of faulting that transfer’s extension from the Gulf of Suez Rift to the Manzala rift beneath the Nile delta. (Bosworth et al. 2005). The Egyptian Governorate had started an ambitious plan for Cairo city decentralization since the seventies. The plan is meant to re-habitat people from the overcrowded city to new and near-by towns in both Eastern and Western Cairo vicinity. Eastern part of Cairo is occupied by Helwan Division where the lithology is mainly limestone and a mixture of limestone and chalky limestone. The region had been the home for heavy industries that started in the sixties of the last century. Excavations for mining and quarry activities took place heavily in the region and caused severe soil erosions, cracks and faults.

![Figure 1: Location and boundary of the Greater Cairo Region](image)

Rock collapse events occurred in Cairo in Mokattam mountainous area three times during last two decades. The most recent occurring as a crashed rock slide in 2008 on a shantytown resulting in almost 70 victims killed or and 130 injured and lost home.
2. Materials and methods

The study follows a sequential method that starts by data extraction and multicriteria evaluation methodology. Data extraction from Shuttle Radar Topography Mission (SRTM) of a resolution of 3 Arc second = 90 meters was used to derive the elevation zones grid in the study area using ArcGIS 9.2 software, the slope angle and the drainage network. The rock type and the faults distribution were derived from the Geological map of Egypt, EGPC-CONOCO-Coral (1987). The seismic intensity zones derived from the National Research Institute of Astronomy and Geophysics, (NRIAG 2003).

2.1. Identifying the criteria and decision rules

Selecting a proper set of evaluation criteria can be done by means of literature study, analytical studies or survey of opinions (Belka, 2005). Such criteria were used as indicators for pointing out lands that are prone to a future land collapse hazard. Such geohazard can be a result of either or both natural and anthropogenic factors. A set of six selected criteria and decision rules are derived from remotely sensed data and cartographic maps and literature review. Such criteria were classified into geological and terrain characteristics. The selected geological criteria are the rock type and the faults. The terrain characteristics criteria are represented by the elevation zones, the slope and the stream network. The selected set of criteria and decision rules are explained in Table 1.

<table>
<thead>
<tr>
<th>Evaluation Criteria</th>
<th>Condition / Rule</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rock type (lithology)</td>
<td>Different rock type have different response to land collapse</td>
</tr>
<tr>
<td>Fault density</td>
<td>Higher fault density is more vulnerable to land collapse.</td>
</tr>
<tr>
<td>Seismic maximum intensity zones</td>
<td>Higher seismic magnitudes are more vulnerable to land collapse.</td>
</tr>
<tr>
<td>Stream density zones</td>
<td>The higher the stream density the more vulnerable to land collapse.</td>
</tr>
<tr>
<td>Slope</td>
<td>Steeper slope angles are more vulnerable to land collapse.</td>
</tr>
<tr>
<td>Elevation zone</td>
<td>Higher elevation zones are more vulnerable to land collapse.</td>
</tr>
</tbody>
</table>

2.2. Standardization and weighting of the criteria maps

Due to the different measuring units of the criteria maps, (example rock class is a qualitative measure, while the slope is an angle in degrees), they had to be standardized into a common scale. A constructed risk scale was created for comparing the attributes of each criteria map that ranges from 1 indicating a least risk to 7 indicating a highest risk. Such process known as map standardization was performed in ESRI ArcGIS 9. Criterion weights are usually determined in the consultation process with decision makers, which results in ratio values being assigned to each criterion map. They reflect the relative preference of one criterion over another. The straight rank sum weighting of criteria has been described by McHarg (1969), Jankowski and Richard (1994), Malczewski (1999), Malczewski, (2004). The method was selected for this study due to its simplicity that promotes its applicability by the decision makers. In straight ranking, factors are ranked in order, from most to least relative important in the selected criteria list. After the ranks
were established, weights were assigned to the factors, a table was constructed to weight every criterion and then the total score for each alternative was calculated see Table 1 and equation (1).

\[ w_j = \frac{(n - r_j + 1)}{\text{SUM}(n - r_k + 1)} \]  

(1)

Where \( w_j \) is the normalized weight for the jth factor, \( n \) is the number of factors under consideration, \( r_j \) is the rank position of the factor. \( r_k \) is the factor number.

Table 2: Deriving relative weights of Criteria

<table>
<thead>
<tr>
<th>Rank</th>
<th>Criteria Layer</th>
<th>Weight ((n - r_j + 1))</th>
<th>Normalized weight (\frac{(n - r_j + 1)}{\text{SUM}(n - r_k + 1)})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Seismic intensity zones</td>
<td>6</td>
<td>0.286</td>
</tr>
<tr>
<td>2</td>
<td>Fault density</td>
<td>5</td>
<td>0.238</td>
</tr>
<tr>
<td>3</td>
<td>Rock type (lithology)</td>
<td>4</td>
<td>0.190</td>
</tr>
<tr>
<td>4</td>
<td>Stream density</td>
<td>3</td>
<td>0.143</td>
</tr>
<tr>
<td>5</td>
<td>Slope angle</td>
<td>2</td>
<td>0.095</td>
</tr>
<tr>
<td>6</td>
<td>Elevation</td>
<td>1</td>
<td>0.048</td>
</tr>
<tr>
<td></td>
<td>Total weight</td>
<td></td>
<td>1.000</td>
</tr>
</tbody>
</table>

2.3. Weighted overlay of the standardized criteria maps

Raster overlaying is known as scalar overlaying because it uses such mathematical operations as addition, subtraction, multiplication and division. It is described as map algebra (Belka 2005). The standardized maps were multiplied by their relative weights and input to the map overlay in ESRI ArcGIS 9.2 Spatial Analyst raster calculator. In such model, a weighted overlay summation function was used which sums up each of the products of the criterion multiplied by its relative weight as explained in equation 1 (Jankowski 1995 and Belka 2005).

\[ V \left( \sum_{i=1}^{n} \frac{W_i \times V_{ij}}{\sum_{i} W_i} \right) \]  

(2)

Where \( V \) is the weighted average vulnerability score, \( W_i \) is weight for ith map, and \( V_{ij} \) is score for jth class of the ith map. The assigned importance weight \( W_i \) depends on the variable significance with respect to the land vulnerability \( V \).
3. Results and discussions

The elevation zones in Cairo metropolitan ranges between 1-818 meters above sea level (abs). Such wide range is distributed in a pattern where the Eastern zones being part of the Eastern Desert are highly elevated. The elevated lands range between 325 to 818 meters abs. The middle parts which consist of the Nile Delta and Valley are low elevated ranging between 1-107 meters abs. For the Western regions, the elevation range between 107-325 meters with few zones reaching 1 meters abs (Fig. 3-a). Creating the fault density map, revealed a higher density in the Eastern zones resulting from anthropogenic factors of mining and related excavation works. Faults and linear features exist along such zones reaching 0.26. Another faulted zone exists in the South moving towards the West where fault density reaches 0.15 for some zones (Fig. 3-b). Rock vulnerability varies for the study region. Most vulnerable zones are represented by the Nile Delta.
and Valley due to their friable materials cover. The Eastern part of the study region has a relatively high vulnerability value. The stream density map shows a relatively higher density of streams in the Eastern zones due to the elevated lands and higher slopes of the Eastern Desert. This phenomenon reaches its maximum ranging from 0.39 to 0.60 in the Nile Valley and Delta (Fig. 3-c). The land slope angles map shows the high slopes land to exist in the Eastern parts (Helwan region) where some slope angles reach 45 degrees. For the western parts of the investigated area, land slopes range from zero to 15 degrees (Fig. 3-d).

Figure 3: Criteria maps: a- Elevation. b- Fault density. c- Rock vulnerability. d- Seismic intensity zones. e- Stream density. f- Slope map

The map weighted overlay resulted in a land vulnerability index map (Fig. 4). Such vulnerability index map shows most vulnerable zones to exist in the Eastern part (Helwan). Such zones extend along the Eastern part parallel to the Nile Valley, while other zones extend from North West to South East following the frequent faults trend in the region. A fourth zone extends towards the Northern part of Helwan. In the Eastern zones, three vulnerable zones extend longitudinally once more following the main faults trend in such zone. Least vulnerable zones, which are the most stable lands, exist in the Western region of the Nile Delta and Valley. The overall results indicates that the western part of the Cairo Metropolitan have the most suitable lands for locating new settlements. Such land which is mostly virgin deserts with minimum linear
features and suitable base rocks of sandstone, gravel and siltstone in addition to some patches of clay and sand clay and basement rocks.

Figure 4: Vulnerability composite index map result of multicriteria evaluation model.

The results also pointed out that; most of the new cities located in Helwan region might be exposed to a risk of future land collapse (Fig. 5 and Table 3). Such risk increases in case of an Earthquake event or water accumulations and long term seepages. Such issues have to be studied in more details for the new proposed and the semi-constructed settlements. Exiting towns have to maintain efficient environmental management plans and programs for maintaining efficient sewage and drainage networks to protect the limestone and chalky limestone rocks. Care has to be taken in foundation construction as well as the selection of vegetation with least water requirements such as cactus and desert plants.
Table 3: Preliminary assessment for the locations of the new towns in Helwan region.

<table>
<thead>
<tr>
<th>New towns</th>
<th>Vulnerability Scale</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>10th of Ramadan</td>
<td>6-9</td>
<td>Medium to highly vulnerable lands.</td>
</tr>
<tr>
<td>Badr</td>
<td>5-8</td>
<td>Medium to highly vulnerable lands</td>
</tr>
<tr>
<td>El Sherouk</td>
<td>4-5</td>
<td>Low vulnerability to land collapse.</td>
</tr>
<tr>
<td>New Cairo</td>
<td>5-8</td>
<td>Medium to low vulnerability in middle zones with highly vulnerable zones in the Eastern and Western zones</td>
</tr>
<tr>
<td>El Amal</td>
<td>5-8</td>
<td>High vulnerability in the northern zones, highly vulnerable zones in the south.</td>
</tr>
<tr>
<td>15th May city</td>
<td>7-8.9</td>
<td>Highly vulnerable lands.</td>
</tr>
</tbody>
</table>
4. Model validation

The city of 15 May was used for validation of the model result. The results of this study revealed that the location of such city shows a highly vulnerable site with vulnerability values 7, 8 and 9. The geological map for 15 May city, scale of 1:5,000 was used for model validation. Examination of such map shows the existence of a drainage course running from north-west to south-east. Quarry sites exist in the Southern zones. Three Graben zones (mixture of gypsum and sand) exist in the Southern zones extending towards east and west. Such zones are assumed not suitable for construction works. Faults (thrust fault, concealed faults and normal faults) extend from north-west to south-east. Steep slopes exist in the Northern zones extending from north-east to south-west.

5. Conclusion

The result of this study concludes that based on the evaluated criteria, vast zones in Eastern part of Cairo Region; namely Helwan are relatively vulnerable to land failure. Despite this fact, some of such zones have been planned or consumed for constructing new towns. In order to minimize such risk, care has to be given to engineering and construction of buildings and extension of water pipelines. Capacity building and awareness between stakeholders and decision makers is crucial. Efficient maintenance plans for the built up areas and utility networks should be set in parallel with development and physical plans.

References

Effat, H. A.: Mapping of land collapse susceptibility using SRTM and Geographic Information Systems


