Towards a good urban development plan in Sinai through land site suitability maps

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Abstract:

Urban developments are considered of high priority in Egypt. This research investigates the site suitability for urban developments using multi-criteria analysis. The study area, Sinai Peninsula, is one of the most promising areas for urban developments in Egypt, which is located in the northern east of Egypt. Weighted multi-criteria analysis approach has been applied tointegrate different data sources. These data sources include: geological data; slope percent; received flow rate; rain ratio; and water accessibility. As a result of this study, the most suitable areas for urban developments were identified. The suitability map for urban development was produced by weighted overlay of the five data sources. The most suitable zones for urban development in Sinai Peninsula amounted to 37% of total area. Therefore, decisions can be made early in the planning process before significant money and design efforts are being invested.

Key words: Suitability map, Factors, Urbanization, Remote Sensing, GIS, multi-criteria analysis.

1. Introduction

Urban development is a global phenomenon. Small population centers are rapidly changing into large cities and hence the conversion of natural land to urban use is quite obvious [Hauser *et al.*, 1982]. According to United Nation's Population Division report published in 1975, about 38% of the earth's population is living in urban areas and by 2025; this proportion is expected to rise to 61% [UNPD, 1995; http://www.wri.org/wri/wr-96-97]. This rapid increase of urban population lead to many problems such as: unplanned sprawl, inadequate housing facilities, traffic congestion, insufficient drainage, sewerage facilities and lack of other amenities [Liu, 1998].

Site suitability is the process of analyzing existing site qualities and factors in order to determine the most suitable location of a particular activity. The selection of a suitable site is based upon a specific set of local criteria. The characteristics of a site (e.g., present land use, slopes, geology, etc.) influence its suitability for a specific land use type. To assess the overall suitability a scoring and weighting system is applied to the various aspects of suitability [Hofstee and Brussel, 1995].

Shan [1999] applied remote sensing and GIS technologies for analyzing the dynamics of the urban spatial structure in Shanghai. Multi-temporal land use information was obtainedfrom aerial photos. Sao [2000] prepared location map of urban facilities and services using GPS technology, which will be applied as inputs for comprehensive development plan of the city.

Amarsaikhan and Ganzorig [2000] investigated the urban changes that have occurred in central part of Ulaanbaatar area, Mongolia over the past few decades and describe the socio-economic reasons for the changes. Ashraf [2001] described the historical urban development of Kharga city, Egypt and used it for defining the main direction of city's development. A survey of the literature review showed that the multi-criteria based approaches are most often used in site suitability analysis [Malczewski, 2006].

Youssefet al., [2011]assessed site suitability for rating the different environmental, geological, and geotechnical conditions facing civil engineering projects using a geographic information system (GIS) multi-criteria approach at the NW coast of the Gulf of Suez in Egypt. As a result, areas of potential geotechnical and geo-environmental hazards that could impact the design and construction of civil projects were identified. Cerreta and Toro [2012] proposed an approach for developing a Dynamic Spatial Decision Support System (DSDSS), denominated Integrated Spatial Assessment (ISA), supported by Geographical Information Systems (GIS) combined with the Analytic Hierarchy Process (AHP). The approach helps produce urbanization suitability maps which proved to be useful for both facing the main issues relating to land consumption as well as minimizing environmental impacts of spatial planning.

Effat and Hegazy [2013] mapped potential urban development zones in Sinai Peninsula in Egypt using Remote Sensing and GIS. Five sub-models were created for five themes, using Spatial Multi-criteria Analysis (SMCA), and used as inputs to the final suitability model. These themes are: land resources, land stability, accessibility, cost of construction and land protection. A GIS-based model was designed following a sustainable development approach. Economic, social and environmental factors were introduced in the model to identify land suitable zones for urban development using Analytical Hierarchy Process (AHP). The most suitable zones for urban development in Sinai Peninsula amounted to 17% of total area.

The objective of this paper is to develop a suitability map for lands that are best suited for urbanization. This objective has been achieved by integrating different data sources which include: geological data; slope percent; received flow rate; rain ratio; and water accessibility. In the illustration below, a solution to the multi-criteria problem is presented.

2. Study area and data sources

2.1 Study area

Sinai Peninsula which is located in the northerneast of Egypt was chosen as a study area. It extends between 32º E and 35º E, and between 27.5º N and 31.5º N. Sinai Peninsula includes not only narrow ravines and steep ridges, but also exhibits coastal plain topography along its edges as shown in Figure 1. The Peninsula contains several mountain ranges with summits reaching up to 2,647m above sea level.

2.2 **Data sources**

As data preprocessing step, DEM, slope percent, received flow rate, water accessibility, geological features and rain ratiosare all obtained from the analysis and interpretation from satellite images and maps covering Sinai Peninsula at different scales as shown in table 1 and figure 1:

Table 1: Data sources and derived factors which have been applied as inputs for the multi-criteria analysis process.

Remotely Sensed Data	**Derived Item**
Landsat ETM satellite images (acquired in 2015)	Regional investigation of the whole Sinai Peninsula.
Shuttle Radar Topography Mission (SRTM)	DEM - Slope percent - received flow rate - water accessibility.
Geologic maps scale 1:4000, 000 prepared by the soil survey institute, Wageningen, the Netherlands and generalized by the geological survey of Egypt, 1975.	geological features
Rain Ratio map	Rain ratio

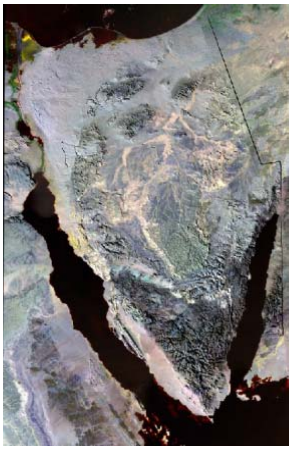
It is worth mentioning that various maps have been collected in hard copies, scanned, rectified using the 1st order polynomial geometric model and saved as classified images for further analysis.

For clarity, the flow image records the flow direction out of each pixel. The output values are not continuous, but rather indicate which neighboring pixel receives the flow. The direction assigned to each cell is established by examining all eight neighboring pixels and choosing the direction of the steepest slope. If more than one direction has identical steepness, a look up table is called to pick a flow direction closest to the average. In the case of flat areas, the 3 x 3 kernel is enlarged.

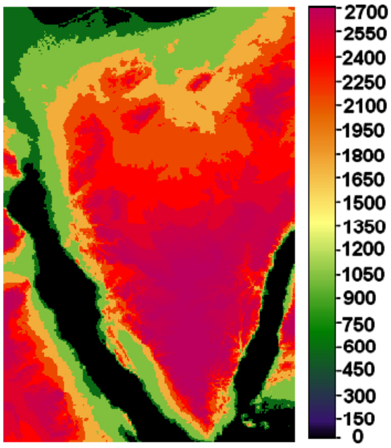
On the other hand, slope is calculated from a continuous surface image, such as a digital elevation model. The slope for a cell based on the cell resolution and the values of the immediate neighboring cells to the top, bottom, left and right of the cell in question. This is known as a rook's case procedure. The slope is calculated as the resultant vector of the slope in X and the slope in Y:

$$tan\_slope = \sqrt{\left(\frac{right-left}{res*2}\right)^2 + \left(\frac{top-bottom}{res*2}\right)^2} \quad (1)$$

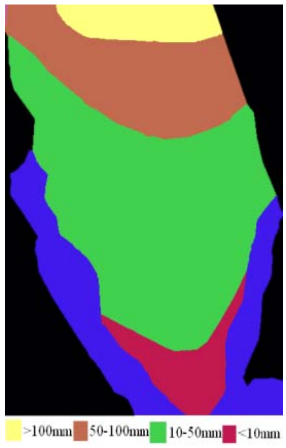
Where *tan_slope* is the tangent of the angle that has the maximum downhill slope; *left*, *right*, *top*, *bottom* are the attributes of the neighboring cells; and *res* is the cell resolution. *Tan_slope* multiplied by 100 produces the output as % gradient.



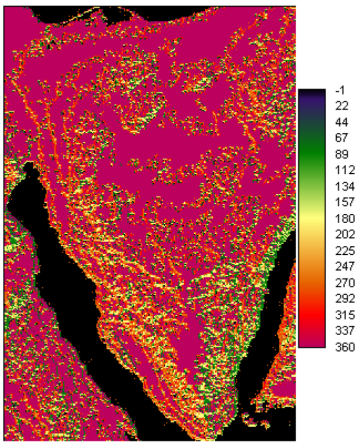
Landsat ETM satellite image



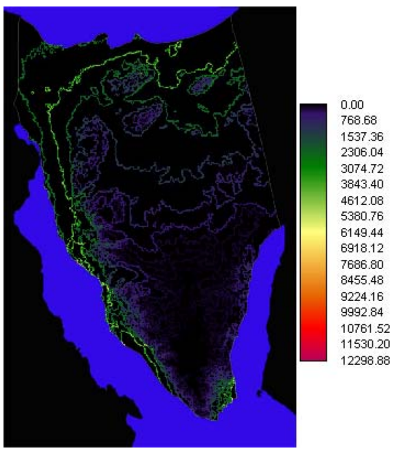
SRTM DEM



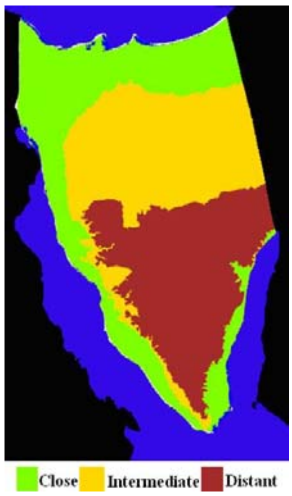
Rain ratio



Received flow rate

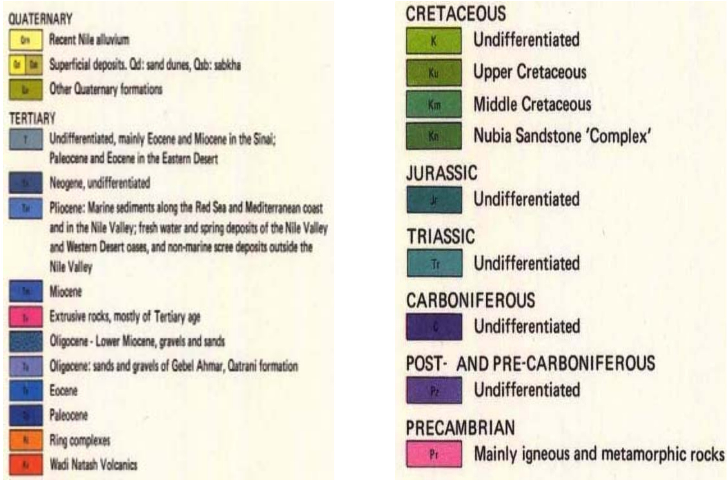


Slope percent



water accessibility

Geologic map



Geologic map legend

Figure 1: Data sources applied as inputs for the multi-criteria analysis process.

3. Methodology

For suitability analysis, different parameters such as: DEM, slope percent, received flow rate, water accessibility, geological features and rain ratios are considered and categorized with various attribute. Methodology is shown as flow diagram, in Figure2.

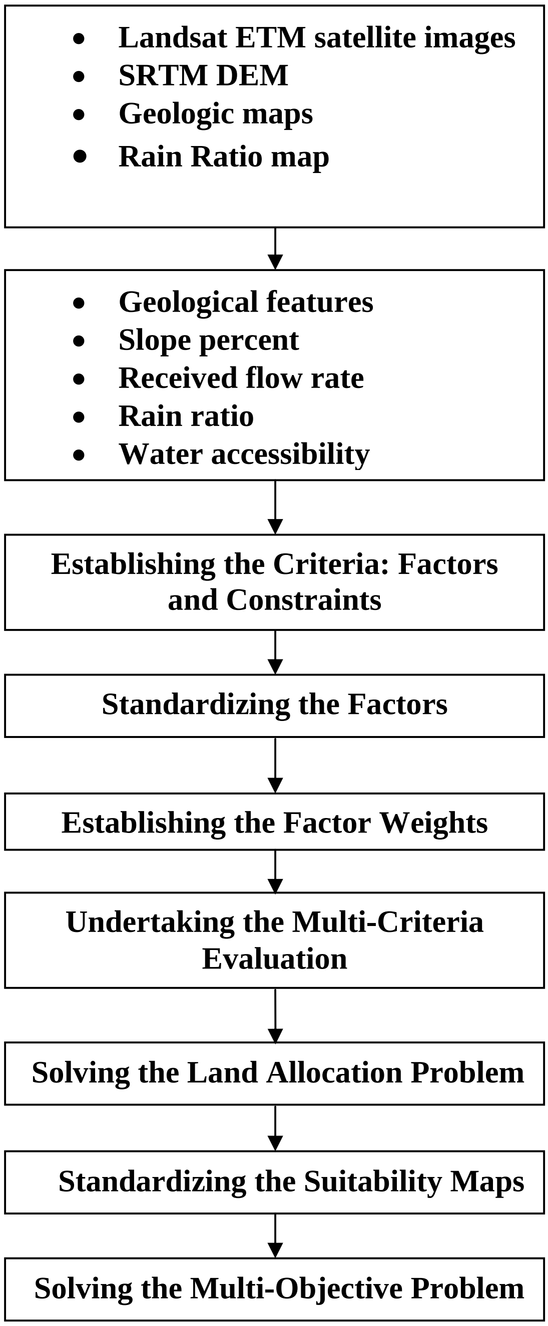


Figure 2: Flowchart for the applied methodology.

4. Processing Strategy, Results and Analysis

4.1 Establishing the Criteria: Factors and Constraints

Criteria may be of two types: factors and constraints. Factors are generally continuous in nature such as the slope gradient; they indicate the relative suitability of certain areas. Constraints, on the other hand, are always Boolean in character (such as the reserved lands constraint). They serve to exclude certain areas from consideration. Factors and constraints can be combined in the Multi-Criteria Evaluations process. Five factors were identified as being relevant to the sitting of the urbanization process: geological features; slope percent; received flow rate; rain ratio; and water accessibility. The constraints are identified as follows: the allocation would be limited to areas of igneous and metamorphic rocks, land with slope gradients less than 5%, land with received flow rate less than $20m^3$, land with rain ratio more than 50mm/year and flat areas within50km distance to water.

4.2 Standardizing the Factors

Each of the constraints was developed as a Boolean map while the factors were standardized so that the results represent fuzzy membership in the decision set. For example, the slope factor map was standardized using a *sigmoidal monotonically decreasing* fuzzy membership function with control points at 5% and 10%slopes. Thus, areas less than 5%slope were assigned a set membership of 255 (on a scale from 0-255), those between 5% and 10%slopes were assigned a value which progressively decreased from 255 to 0 in the manner of an s-shaped curve, and those beyond 10% slope considered to be very rugged (i.e., they were assigned a value of 0). Figure 3 is a typical example illustrates the slope factor standardized result and the constraint for urban areas allocation with zeros excluded from considerations.

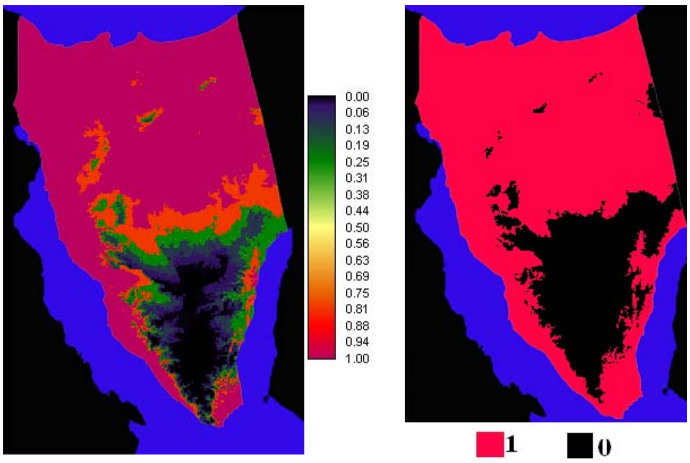


Figure 3: Slope factor standardized result (left) and the constraint (right) for urban areas allocation.

4.3 Establishing the Factor Weights

The next stage was to establish a set of weights for each of the factorsto identify inconsistencies and develop the best fit weights. Table2 shows the factor weights evaluated for the suitability for carpet industry development.

Table 2: Suitability factor weights as applied for the urban development.

Factor	Factor Weight
Rain zone category	0.10
Slope percent category	0.25
Geology	0.25
Received flow rate	0.25
Water accessibility category	0.15

4.4 Undertaking the Multi-Criteria Evaluation

Once the weights were established, the factors and constraints were combined in the form of a weighted linear combination. The procedure is optimized for speed and has the effect of multiplying each factor by its weight, adding the results and then successively multiplying the result by each of the constraints. Since the weights sum to 1.0, the resulting suitability maps have a range from 0-255. Figure 4 shows the result of the multi-criteria evaluation process to derive suitability map for the urbanization.

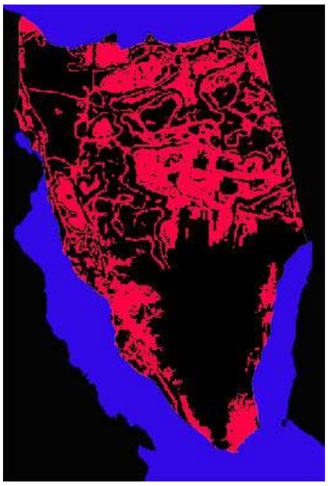


Figure 4: Composite Suitability images for urban areas.

Once the multi-criteria suitability maps have been created, the decision problem can be approached.

4.5 Standardizing the Suitability Maps

The first step was to rank order the cells in the suitability map. This has the effect of standardizing the suitability map using a nonparametric histogram equalization technique. Ranks were developed in descending order (i.e., the best rank was 1). Tied ranks were resolved by examining the other suitability map and ranking in reverse order to the suitability on that map. This preserves the basic logic of the uncorrelated ideal points for conflicting objectives that is used in the resolution of conflicts. Figure 5 shows the results of this process.

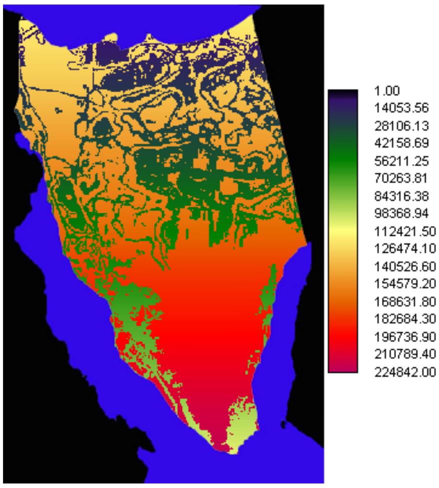


Figure 5: Cell ranks derived from multi-criteria evaluation process.

4.6 Solving the Decision Making Problem

The second step was to submit the ranked suitability maps to a single-objective decision making process. This requires the name of theobjective, areas suitable for urbanization. The process then undertakes the iterativeprocedure of allocating the best ranked cells to the objective based on the weighed minimum-distance-to-ideal-point logic. Figure 6 shows the final result,achieved after 10 iterations.

It is worth mentioning that the same area has been evaluated for urbanization using different factors and constraints in Effat and Hegazy [2013]. They used many more factors as shown in table 3. Some factors such as distance to roads, distance to ports, distance to airports, distance to water supply, distance to power supply, etc, have reduced the suitable zones for urban development since the lands with these constraints were omitted from the study area. As a result, the most suitable zones for urban development were amounted to only 17% of the total area. This reflects how far the selected factors and constraints can affect the obtained results. However, these constraints are not critical and can be treated in a future step by constructing new roads, ports, airports, water networks and electricity networks and so on. By cancelling these constraints, the suitable zones for urban development have been extended to 37% in our research. In conclusion, the 37% resultant map can be used as guidelines providing a base for any future land development. On the other hand, the 17% can be used as guidelines for current land developments since it is obtained based on the current status of utilities networks.

Table 3: Factors applied for multi-criteria evaluation in (Effat and Hegazy) as compared to (Shaker and Salah)

Effat and Hegazy	Shaker and Salah
1. Underground water	1. Rain ratio
2. Sea/ Lakes	2. Slope percent
3. Mines/Quarry	3. Geology
4. seismic zone	4. Received flow rate
5. fault zone	5. Water accessibility
6. Geology	
7. high order streams	
8. Elevation	
9. Roads	
10. Ports	
11. Airports	
12. Land Cover	
13. Distance to water supply	
14. Distance to Power supply	
15. Slope	
16. Protectorates	
17. Archeology	

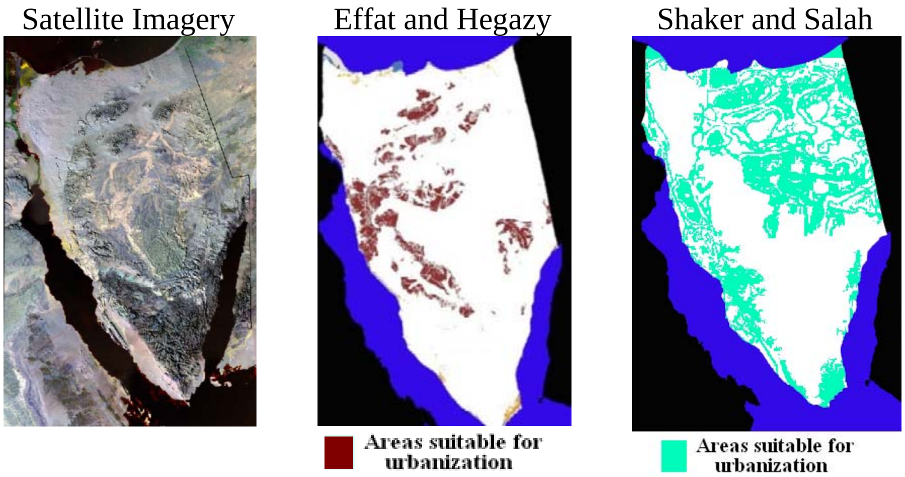


Figure 6: Final suitable areas for urbanization as obtained by (Effat and Hegazy) and (Shaker and Salah)

Conclusions

Land use suitability analysis for urban development is necessary to overcome the problems associated with limited land availability against growth of urbanization in Egypt. This research investigates the suitability of lands in Sinai Peninsula in Egypt for urban developments using weighted multi-criteria analysis. The proposed approach integrates data from different sources which include: Satellite imagery, geological maps, and rain ratio maps. The suitability map for urban development was produced by weighted overlay of five factors derived from the original data sources. The factors include: geological data; slope percent; received flow rate; rain ratio; and water accessibility. The process can be implemented in a simple manner making the decision early in the design process before significant design efforts are being invested.The suitability map shows that almost 37% of Sinai Peninsula is valid for urbanization. This study will help urban planners and decision makers to plan development of the Sinai. It is worth mentioning that the same area has been evaluated for urbanization using different factors and constraints in Effat and Hegazy [2013] and the most suitable zones for urban development was amounted to 17% of the total area. This reflects how far the selected factors and constraints as well as the scale of the data sources can affect the obtained results.

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