Application of Multi Criteria Evaluation in GIS Environment for an Agricultural Development Scenario in the Egyptian Deserts

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Abstract
The land use decisions and planning processes deal with large volumes of basic data where technical knowledge must be coordinated with the decision makers' visions of society. This fact makes spatial planning quite a complicated process. This study addresses a regional scale zoning issue through cartographic modeling using Multi Criteria Evaluation in a geographic information environment through a case study. The main objectives of this research are to explore the model potential of providing an answer to the suitability of the desert lands in Egypt for an agricultural development strategy and to provide a decision support tool for land use planners. A geographic database was established at a national scale. Multiple Criteria Evaluation techniques were used in a geographic information system environment to produce the land suitability index for agriculture development. Lands with constraints were omitted from the study area. Factors needed for land cultivation were identified, ranked, weighted and overlaid in a cartographic model. The product of the model was a suitability index map which was further classified into zones according to the suitability index range of values. A five phase strategy was proposed based on the suitability classes. The resultant map can be used as guidelines providing a base for land reclamation and development. This methodology can be applied on other locations at regional planning levels, and can provide what-if scenarios based on the objectives and relative importance of the selected criteria sets.

Keywords: Land use strategy, multi criteria evaluation, remote sensing, geographic information system, cartographic models, geographic database, decision support systems.

1. Introduction

Despite the close relationship between geographic information sciences and land-use studies, there has been little constructive dialogue on the relationship between its theories, land-use analysis and practical applications. Spatial decision support system (SDSS) is an interactive, computer-based system designed to support a user or a group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem. It lies at the intersection of two major trends in the spatial sciences: geographic information sciences (GIS) and spatial analysis (1). According to (2), a SDSS should provide mechanisms for the input of spatial data, allow representation of spatial relations and structures, and include the analytical techniques of spatial analysis, and finally provide output in a variety of spatial forms, including maps. Multi criteria spatial decision support systems (MC-SDSS) can be viewed as part of the broader fields of SDSS. Spatial multi criteria decision making refers to the use of multi criteria analysis (MCA) to spatial decision problems. (3) MCA is a family of operations research tools that have experienced very successful applications in different domains since the 1960. It has been coupled with geographical information systems (GIS) since the early 1990s for an enhanced decision making. Remotely sensed data together with geographic information systems have been recently used in land use decision analysis. Cartographic modeling and suitability mapping of land in accordance to its potentials and constraints using multiple criteria evaluation techniques have been broadly applied. (4) explain that in order to define the suitability of an area for a specific practice, several criteria need to be evaluated. Multi Criteria Evaluation (MCE) has been developed to improve spatial decision making when a set of alternatives need to be evaluated on the basis of conflicting and incommensurate criteria (5) MCE is an effective decision-making tool for complex issues that uses both qualitative and quantitative information. It has been utilized around the world for Land Suitability Modeling and is concerned with how to combine the information from several criteria to form a single composite index of evaluation. A criterion may be a factor providing suitability of phenomenon of continuous measure or may be a constraint to limit the alternatives under consideration .The MCE in its Weighted Linear Combination (WLC) method introduces a soft or “fuzzy” concept of suitability in standardizing criteria. It is scaled to a particular common range where suitable and unsuitable areas are continuous measures. The aggregation method uses weighted linear combination, which retains the variability of continuous criteria and allows criteria to trade off with each other **(6).** *Reference (7)* explains that the Multi-criteria evaluation is primarily concerned with how to combine the information from several criteria to form a single index of evaluation. As the criteria are measured at different scales, they are standardized and transformed such that all factor maps are positively correlated with suitability. Reference **(8)** explains that the weighted summation allows for evaluation and ordering of all alternatives based on the criteria preferences by decision-makers.

The Study Area:

The geographic location of Egypt lies between longitudes 22° and 32° North and latitude of 24° and 37° East (figure 1). The lands cover an area of one million square kilometers in North Africa and Western Asia. Deserts occupy almost 96% of the Egyptian land cover. The vast majority of its 78 million populations for 2006 are mainly concentrated in the Nile Valley and the Delta as well as in the coastal zone along the Mediterranean Sea. Inhabited area resembles only 4% of the total territory. Rich in unexplored potentials, the vast desert zones are being joined and accessed by development corridors linking the Egyptian towns. This study attempts to apply the MCE theory and technique in a GIS environment on a national scale for exploring the agricultural potentials of the desert lands surrounding the development corridors in Egypt.

Objectives of the Study

The main objective of this study is to explore the potentials of remotely sensed data and geographic information sciences in linking the gap between this geo-science and the land use decisions and applications in the field of regional planning. The study attempts to apply the MCE theory and GIS techniques using maps and remotely sensed data for producing a suitability index map for identifying potential zones for agricultural development in the Egyptian deserts. The study also aims at exploring the land resources, potentials and constraints that need to be considered in sustainable land use plans in Egypt.

2. Materials and Methods

Several datasets were acquired for this study considering the heterogeneity of the area under investigation, an integrated database was established. The Primary data sets used for this study are Shuttle Radar Topography Mission (SRTM) 90 meters (9) resolution was used to derive the slope, aspect, catchments areas and drainage basins. The derived topographic grids were imported into the database. The FAO land cover map produced by the FAO organization from Landsat TM data was used (10). Hydrogeological maps scale 1:2,000,000 were obtained from the National Water Resources Center Research Institute for Groundwater (11). The exiting and future protectorates maps after the Egyptian Environmental Affairs Authority (EEAA) (12) were rectified and digitized, in addition the topographic base map scale 1:1000,000 obtained from the Egyptian Survey Authority (ESA) (13) was used. The analysis started by data acquisition and conversion of the acquired maps from the analogue to the digital format. These maps were rectified and digitized using on-screen digitizing and saved as ESRI format shape files (.shp). The datasets were all projected to the Universal Transverse Mercator UTM, WGS84. The shape files were imported into feature datasets or stand-alone feature classes in a geodatabase using ArcGIS9.2 (14) software. Tables from reports were converted to digital and imported into the database. Shuttle Radar Topography Mission (SRTM) -90 meters resolution was used to derive the slope, aspect, catchment areas and drainage basins. The derived topographic grids were imported into the database. The data acquisition, rectification and establishment of the database were followed by the identification of the suitability criteria for agriculture development, an essential step for land suitability models.

Identification of the essential criteria for agricultural development in the desert was done through literature review. The set of constraints consisted of the protected areas including the natural protectorates, river Nile and lakes, cultivated areas, natural vegetation and sand dunes, figure 3. The constraints layers were masked out from the study area resulting in a map of potential sites for zoning as shown in figure (1).

Factors contributing to the land suitability for adopting new policies for land reclamation and agricultural development was identified by experts, literature review and decision makers. The most significant factors were classified into natural factors and feasibility factors. The natural factors having the most impact are; the availability of water resources, soil classes, land slope angles and precipitation. Due to the absence of soil maps that cover the vast desert zones, therefore the rock type and surficial deposits maps (lithology) were used instead, to provide approximate soil classes for the vast desert zones. Feasibility factors such as the availability of power supply and suitable accessibility through the desert roads were considered for this analysis. As the natural factors are the main motivation for agricultural development, these were given higher weights compared to the economic feasible factors. .

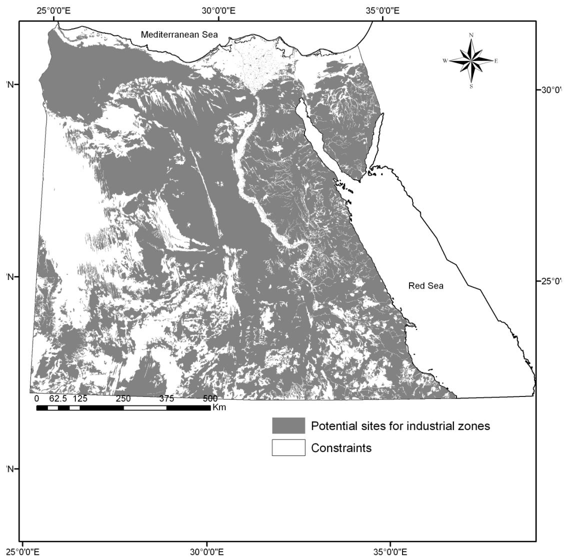

Figure 1: Map showing the potential zones and the constraints mask.

The factor maps were rescaled to a standard suitability scale and the maps were ranked according to their relative importance. Finally a cartographic model based on multi criteria evaluation was run to produce the land's suitability indices. The objectives for criteria selection are diagramed in figure (2). The methodology is diagramed in figure (3) and explained in the following section:

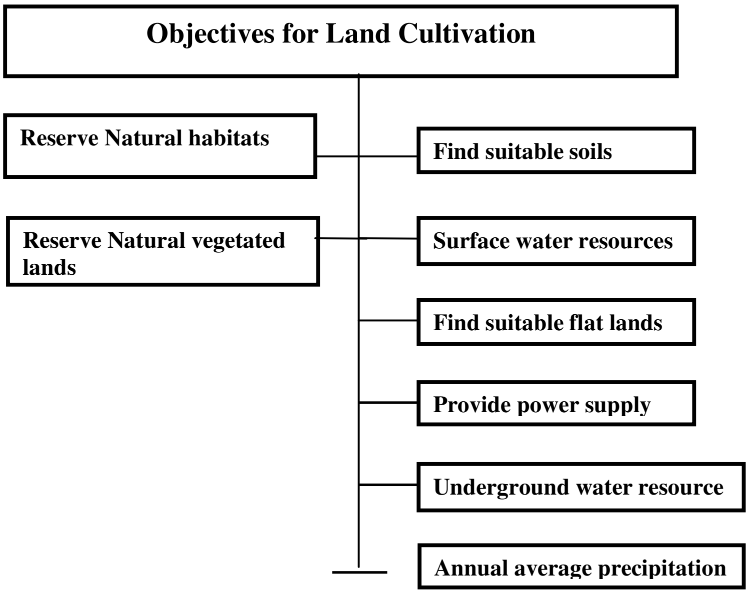

Figure 2: Agricultural development parameters.

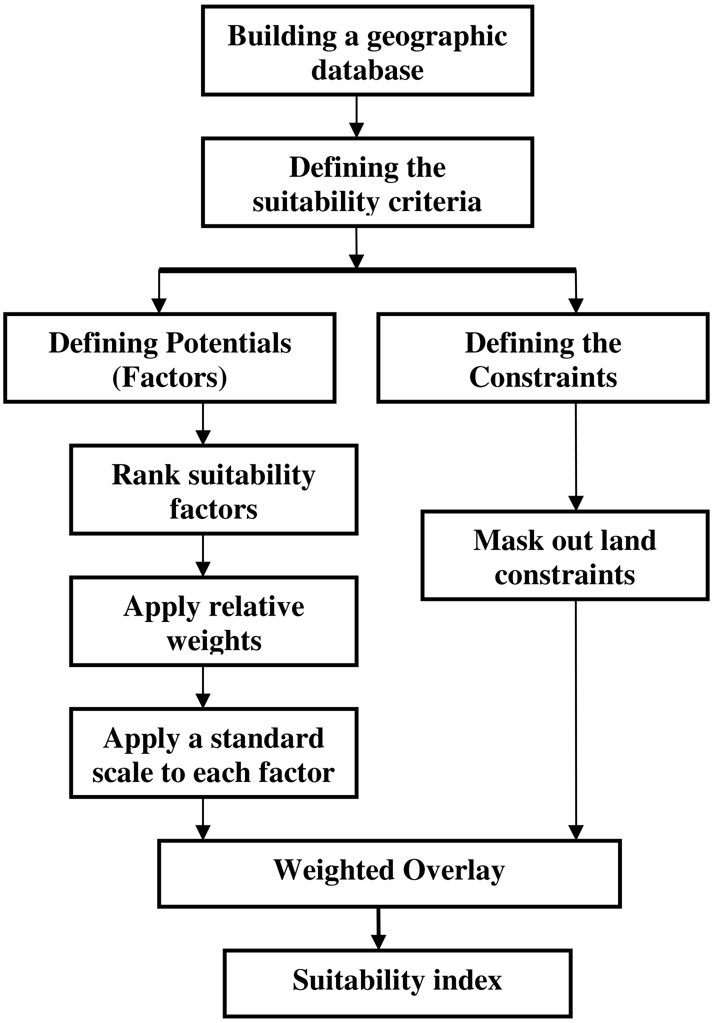

Figure 3: Flow chart for deriving the suitability index for agricultural development

Ranking of the factor maps is a step prior to applying their relative weighs. The straight raksome method was selected for this study. The method is one of the simplest criterion weighting techniques though criticized for its lack of theoretical foundations in interpreting the level of importance of a criterion (15). It is selected here for being a straight forward method that can be used with least confusion to the decision makers. In straight ranking, criteria are ordered from most to least relative important factor in accordance to the decision makers' point of view. After the ranks are established, relative weights are assigned to the factors, using the straight rank-sum method as explained in equation 1:

$$w_j = (n - r_j + 1) / SUM(n - r_k + 1) \quad \ldots\ldots\ldots\ldots\ldots\ldots \textbf{(1)}$$

where **wj** is the normalized weight for j^{th} factor , **n** is number of factors under consideration , **rj** is the rank position of the factor.

Several raster layers can constitute a set of criteria where every cell value is assigned a criterion score. Since the criteria attributes differ in evaluation, (example lithology units describe rock types, while the distance maps measure distance) therefore, a common scale had to be applied, namely a suitability scale. Accordingly, each of the attributes was rated to a suitability scale that ranges from zero to nine. The higher the value the more suitable and vice versa. Standardization values of the lithology and aquifer maps are shown in table (1).

Table 1: Suitability values used for rating of some factors

Standardization of Factors Map Units (suitability scaling)	
Lithology Units	
Rock type	Suitability rate
Basement rock	0
Clay and sand clay	5
Dakhla shale	3
Dolmitic lime stone and clastic	2
Lime stone and Marley lime stone	1
Mainly lime stone with interactions of shale	1
Nile deposit	7
Nubian sandstone	1
Sabkha deposit and gypsm clay	2
Sand sheets and sand dunes	3
Wadi deposits	6
Lime stone and chalky lime stone	1
Sand gravel silt stone	3
Aquifers Units	
Extensive and highly productive aquifers continuous	8
Extensive and highly to moderately productive aquifer	7
Extensive and moderately to low productive aquifers with paleo	6
Local and highly to moderately productive aquifers	5
Local and moderately to low productive aquifer insignificant surface	4
Local and very low productive aquifers formed from intercalations	3
Local ground water occurrences in fissured rocks and withered zones in hard rocks	2
Non aquifers	1
Slope in degrees	
0-10	6
10-20	5
20-30	4
30-40	3
40-50	2
Greater than 40	1

The straight rank sum method was used to obtain a relative importance weight for the suitability factors as shown in table 2.

Table 2: Relative weights applied for the Agricultural suitability factors

Criteria	Straight Rank (rj)	Weight (n – r j + 1)	Normalized Weight (n – r j + 1) / SUM(n – r k + 1)
Water resource Aquifers Surface water (Nile, lakes and canals)	1	6	25
Lithology	2	5	19
Slope	3	4	15
Precipitation	2	5	18
Power Supply Power Stations High Electric line	3	4	8 7
Road network	4	3	7
Sum	15	27	100

2.4 Cartographic Modeling for Land Suitability Analysis:

The next phase is conducting the land suitability analysis to identify concentrated areas of potentials and limitations to development. The standardized criteria maps, given relative weights are then incorporated into a GIS- overlay model. For each location, the average suitability score is calculated as:

$$\overline{S} = \frac{\sum_{i=1}^{n} (W_i \times S_{ij})}{\sum_{i}^{n} W_i} \qquad \textbf{\dots\dots\dots\dots(2)}$$

Where S^{-} is the weighted average suitability score, Wi is weight for i^{th} map, and Sij is score for j^{th} class of the i^{th} map. The assigned importance weight Wi depends on the variable significance with respect to the land suitability S^{--} for a studied activity.

3. Results and Discussion

The constraints of the lands were reflected by the sand dunes spatial distributions, the cultivated lanes in the Nile Delta and Valley, the natural protectorates and the natural vegetation in addition to the river Nile and lakes. The sand dunes propagate in the desert specifically in the Western Desert where the great sand sea exists. Masking out all the identified land constraints produced the suitable zones map for agriculture development. These zones vary in their suitability scale according to their realization of the defined set of factors. The potentials and constraints sites map is shown in figures (4) and (5). The suitability factors maps provided a new vision for the spatial distributions of essential parameters for land use decisions. Running the model resulted in the suitability index for the most favorable agricultural development zones. The index map shows the spatial distribution of the lands in a graduated scale for its suitability for cultivation. The scenario revealed that there exist suitable lands for agricultural development around the Nile Valley and delta extending in the Northern lands parallel to the Mediterranean Sea. Suitable lands extend in Sinai Peninsula especially in the northern and mid-area. Lowest suitability scores were found to cover the remote zones of the Western Desert. Moderate scores are shown to be distributed around the corridors buffers as shown in figure (6). These suitability scores are the result of the selected criteria and their relative weights. These highest suitability scores are found to be spatially distributed among eleven governorates. These governorates are North Sinai, Marsa Matrouh, Aswan, El Giza, El Beheira, South Sinai, El Esamilia, El Suez, Beni Suief, El Menia , Qena and El Wadi El Gedid.

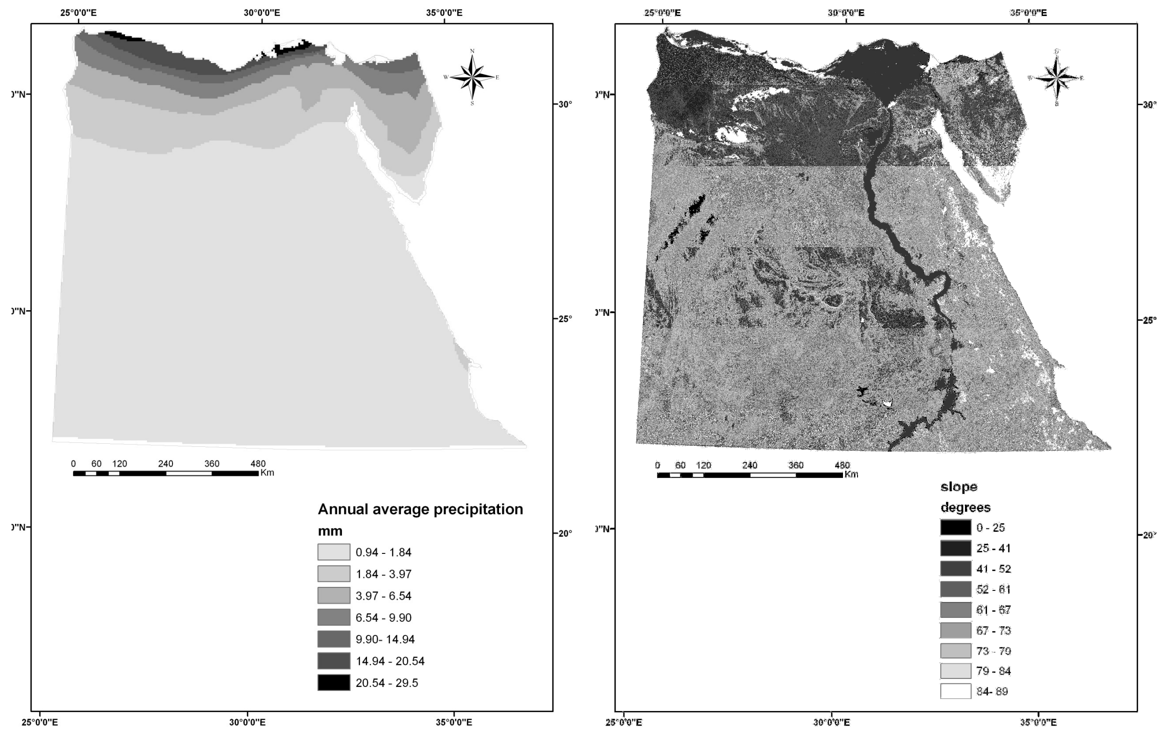

Figure 4: Factor maps: *Left* Annual average precipitation map. *Rig*ht Slope angles map

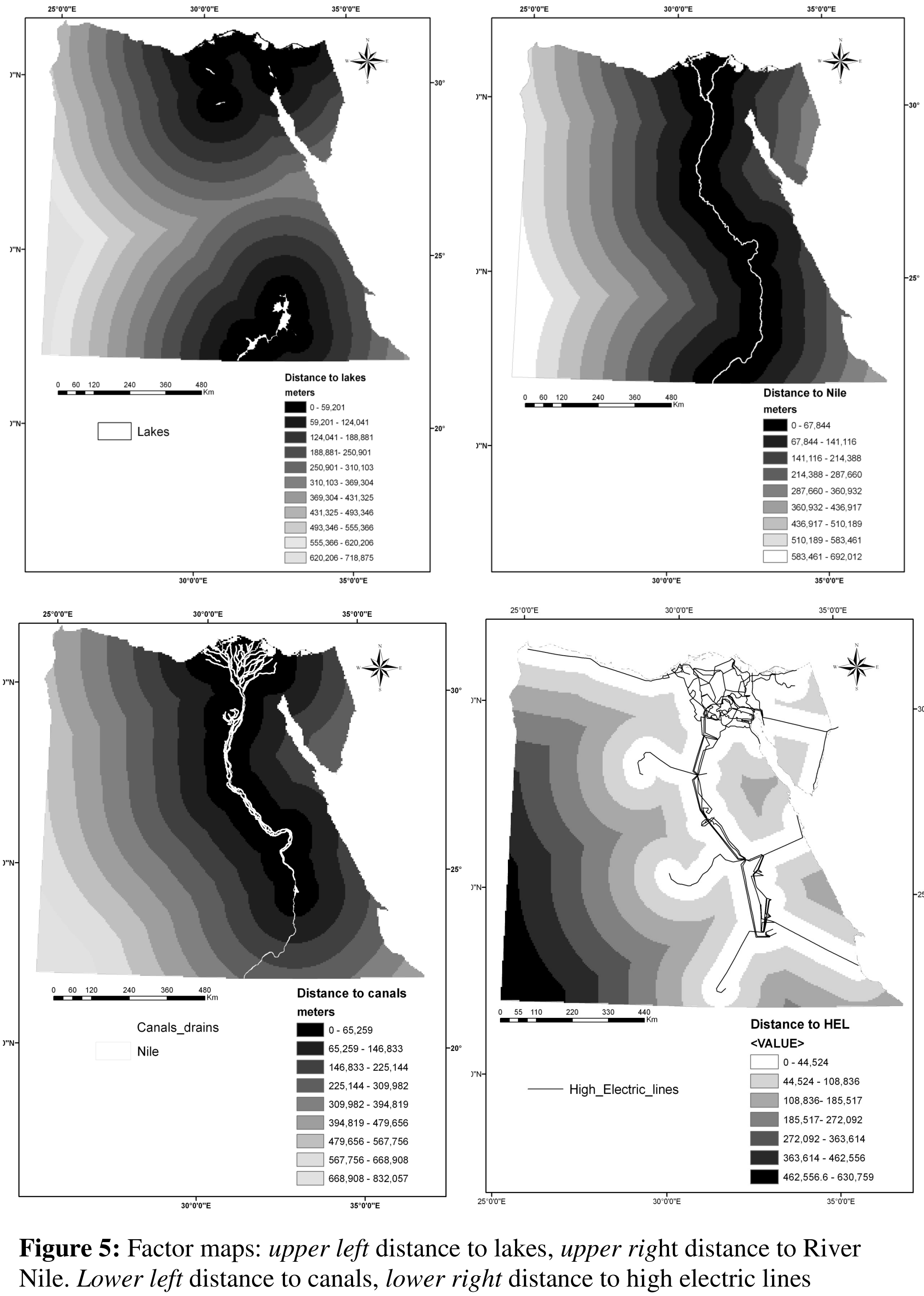

Figure 5: Factor maps: *upper left* distance to lakes, *upper rig*ht distance to River Nile. *Lower left* distance to canals, *lower right* distance to high electric lines

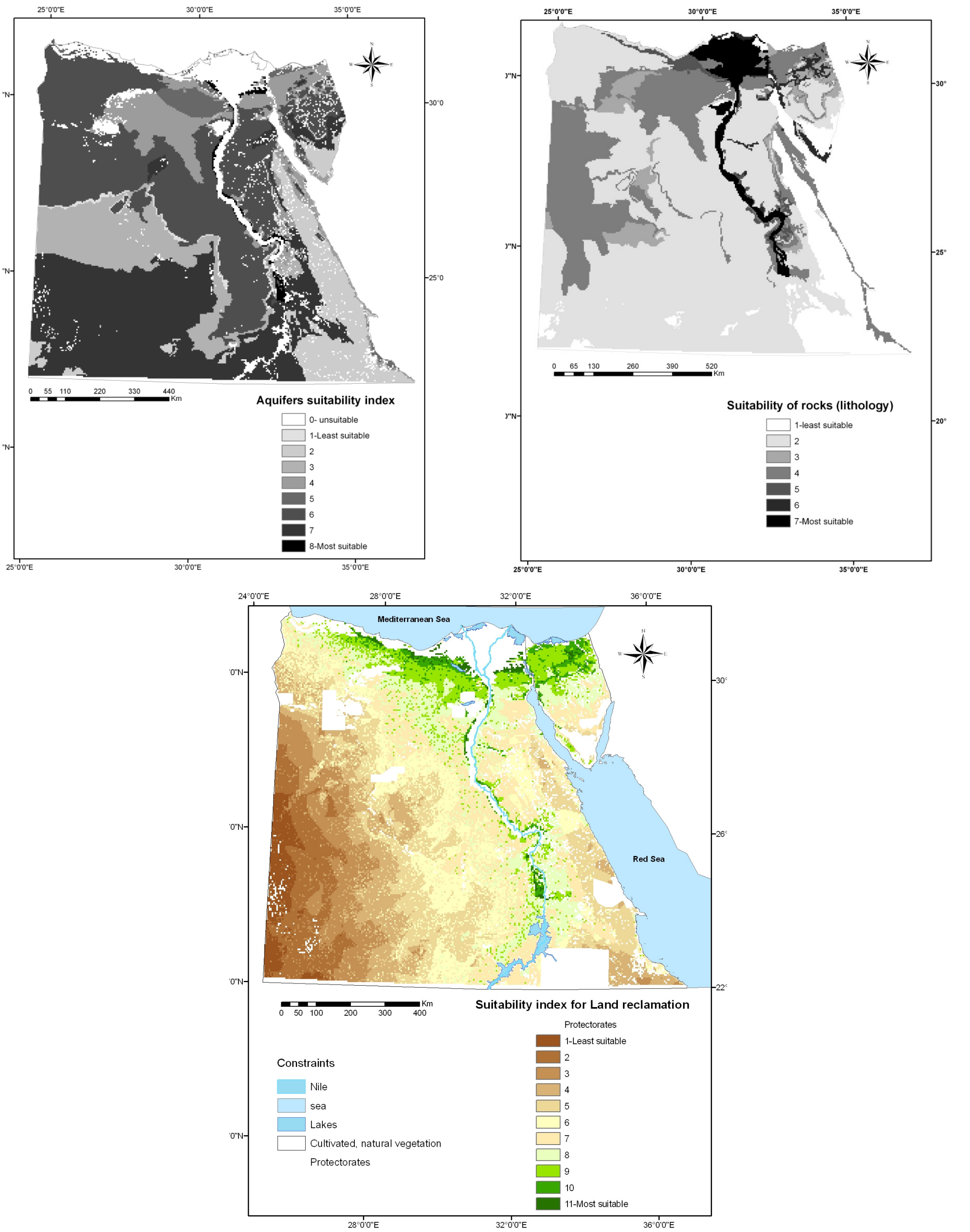

Figure 6: *Upper Left* aquifers suitability map. *Upper Right* rock type suitability map.
Bottom final suitability index map

4. Conclusion and Recommendation

Multi-Criteria Evaluation theory (MCE) applied in this study provided unlimited possibilities to create scenarios based on a selected set of criteria. This technique can be time and cost saving for land use decision makers. Prioritizing and emphasizing criteria is done by the assignment of weights. Also combination of different attributes criteria is made possible by the standardization or normalization the criteria suitability scores. An example of this is the combination of the precipitation map and the slope degree map.

It is recommended to adopt the Multi Criteria Evaluation technique by land use decision makers. This technique can bridge the gap to a multi-disciplinary approach for land use planners on all levels of land use planning. Applying the technique on a national scale provides indicator maps that despite its need for further screening and enhancement by with detailed local analysis, it can be used as a guide for the local scale, zoning plans and land use strategies. It is also recommended to conduct further studies for applying this technique on the different land use planning levels.

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