Sustainable Planning for Environmental Sensitive Area using Multi Criteria\Multi Objective Spatial Analysis: Case Study El-Dabaa, Egypt

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ABSTRACT

Planning for a sustainable development of land use requires a set of factors that represent technical, bio-geophysical and socioeconomic aspects. Maintaining balance between society's demands and environmental conservation requirements is the core issue of sustainable planning of land use. Many tools have been developed to aid in the implementation of such balance, including linear programming, computer simulation and other analysis support tools. Most of these tools are suitable for the economic analysis of sustainable planning in many fields, but in the field of land use allocation, the spatial approach is considered as the key player in academic research and executive proceedings. In this paper, a methodology is developed to solve the problem of land use allocation considering both bio-geophysical and socioeconomic aspects in a pilot area – El Daba'a Region in the north western coast of Egypt. This methodology attempts to develop a set of criteria for each land use by the stakeholder participation. It was used to map the suitability of each land use activity using a multi-criteria approach. The priorities of land use activities were defined by the stakeholder participation and then used to create a multi-objective land use allocation map. The developed map is considered as a base map for sustainable land use processes.

KEYWORDS

GIS, multi criteria, multi objective, sustainable land use planning, public participation

Introduction

Planning is a future-oriented activity, strongly conditioned by the past and present. It links *"scientific and technical knowledge to actions in the public domain"*(Friedmann, 1987). Ideally, it happens via public discourse between all groups and individuals interested in and/or affected by urban development and management activities pursued by the public or private sector. In practice, such comprehensive sharing of information and decision making is rarely found. At their best, urban and regional planning agencies are rich, dynamic arenas where many societal problems and solutions are explored and addressed in a direct and tangible way.

Decision-making has been defined as a process by which a person, group, or organization identifies a choice or judgment to be made, gathers and evaluates information about alternatives, and selects from among those alternatives (Lein, 2003). Planning-related decisions are made daily through a complex, often socioeconomic charged process involving a plurality of interests. However, the planning processes and outcomes are the domain of powerful interest groups that include investors, governments, stock market and different other players. Land use planning should be a decision-making process that "facilitates the allocation of land to the uses that provide the greatest sustainable benefits" - *Agenda 21, Paragraph 10.5* (UNCED, 1993).

The role of widely disseminated accurate geographic information is imperative to the planning process. Moreover, the implementation of planning decisions leaves a long-term imprint on the structure, functionality, and quality of life in urban environments. While most urban and regional planning occurs at the local level, the national and state policies and legislation often influence the planning activities (Nedovic`-Budic`, 2000).

Planners have always sought tools to enhance their analytical, problem-solving, and decision-making capabilities (Mandelbaum, 1996). Beginning in the late 1950s, planners started to develop and use computerized models, planning information systems, and decision support systems to improve performance (Klosterman, 1990). The adoption of geographic information systems (GIS) is the most widely application of the same effort to incorporate new tools and technologies (Nedovic`-Budic`, 2000).

Since 1990, Egyptian planners have used geographic information systems to enhance their planning process and to produce objective approach to their planning decisions. For example, GIS was utilized in the land inventory analysis, beach carrying capacity assessment for tourism and strategic environmental assessment in the context of integrated coastal zone management of Fuka-Matrouh area in the Northwestern Coast of Egypt (Raey, *et al.,* 1998a; Raey, *et al.,* 1998b; Raey, *et al.,* 2000). For integrated planning in Egypt, two main works can be cited; Lake Nasser Development Project (LNDP, 2001) and Northwestern Coast and Inland Development Project, (Wisam & Sabah, 2007) where GIS was used to handle large volume of data that included satellite images, vector datasets illustrated topographic and thematic maps, pictures, videos, social and economic census and another forms of spatial and aspatial data to support the planning decisions.

In this paper, the problem of sustainable planning is treated in a spatial context. The challenge facing the planners is how to balance between different developmental trends of official scenarios and public orientations. Handling this situation should be approached in the form of multi criteria and multi objective problem solving. In this context, the planning decision may be introduced as a weighted series of preferences that create the spatial distribution. This approach is easy to handle in the form of multi-criteria decision making problem. The results of this analysis are a series of plans designed to meet different objectives. Producing the overall plan that merged from these objective oriented plans into one plan may be achieved by applying multi-objectives decision making methodology.

The objectives of this paper are to two-folds. One is to illustrate a road map for applying multi-criteria / multi objectives approaches in spatial sustainable planning. The other is and to produce a spatial plan for the study for both official and public orientations and interest.

Study Area

The study area El Daba'a area, shown in Figure 1 is located approximately 160Km from Alexandria Metropolitan in Matrouh Governorate in the Northwestern coast region of Egypt, and Marsa Matrouh city the capital of Matrouh Governorate. It extends from 28° 21' 33'' E to 28° 35' 11'' E and from 30° 58' 50'' N to 31° 5' 22'' N. It is about 21.5 kms in length and 11.8 kms in width, occupying an area of approximately 254 km^2.

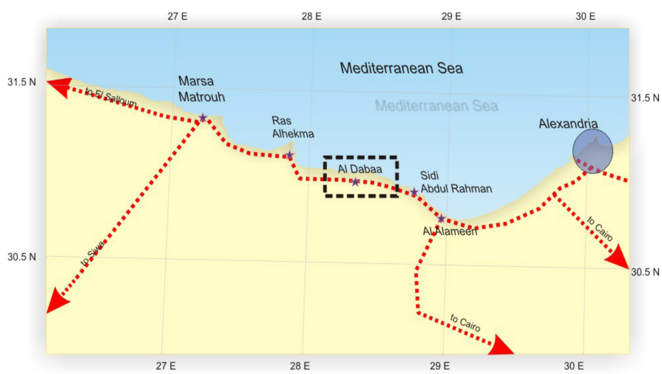


Figure 1: Location map for the study area

The history of land use in the study area can be used to illustrate the history of land use over the northwestern coastal area. Historically, El Daba'a area is characterized as a nomadic area occupied by the Bedouin tribes. The basic land use in the past was grazing in the natural rangelands of the south that was dominated by *Thymelaea hirsute* and agriculture in the coastal belt where the rainfall recorded at roughly 138 mm annually.

This simple land use was changed by the emigrants from the other parts of Egypt in the 1960s. The first noticeable wave was after the launching of High Dam Project, where the Egyptian government had displaced Nubian people for their original villages influenced by it to the towns of the northwestern area. The second wave was after the 1967 war when the Egyptian government attempted to settle the war-refugees from Sinai and Canal Zone in the small towns of the northwestern coast (NRC, 1987).

The policy of the Egyptian Government in encouraging the emigration to the northwestern coast has been used to bridge the demographic rural-urban gap. This policy ultimately has been successful because the population of the Governorate of Matrouh, where the greatest portion of the Northwestern Coastal area is, has multiplied 46 times than it was in 1960 compared to the overall Egyptian population increase of six times for the same period, with a current population growth rate of 3.1% compared to 1.7% in 1960 (UNDP, 2004), (IDSC, 2007).

The increasing of emigrants flow leads to an increasing demand for urban expansion and developing organized agriculture in El Daba'a area. These pressures reshape the land use structure in the study area. It is suspected that more reformulation will occur if the Egyptian Government launch the project of Nuclear Power Station in the area (Al-Jenaid and Mohammed, 2008).

In general multi-criteria approach attempts to solve the problem in which the decision is formulated by a set of driving and limiting forces. It is obvious that multi-criteria approach is concerned with a single objective problem. Moreover, multi-objective approach attempts to solve the problem where many objectives need to be differentiated to decrease or remove the conflict between these objectives.

Methodology

Land use planning is a field where the integration between multi-criteria approach and multi-objective approach is required to solve the problem of land use allocation. Each land use may be defined through a set of driving and limiting forces. Multi-criteria approach is easy to use to solve such a problem. From a different point of view, allocation of different land uses in the same area leads to conflict between these uses. Multi objective approach is employed to solve the conflict of land use in the same area. For this reason, the integration between these two approaches is required in context of sustainable spatial planning.

Decisions may be expressed as a complicated form of driving forces (criteria) and limitation forces (constraints). A driving force is a criterion that enhances or detracts the suitability of an area for the decision under consideration. A force is a constraint that serves to restrict the alternatives under consideration. Merging both criteria require the developing of an *objective function*. An objective function contains a procedure for combining driving forces into a single composite index and a statement of how alternatives are to be compared using this index. The objective function expressed in equation (1).

$$P_a = (x_1 w_1 + x_2 w_2 + \cdots + x_n w_n) l_1 . l_2 \ldots . l_m$$

Or in a more simple form:

$$P_a = \sum_{i=1}^{n} x_i w_i \prod_{j=1}^{m} l_j$$

p_a is the quantitative index for land suitability, and varied between 0 (not suitable) to 1 (most suitable);

x_i is a driving force/criterion

w_i is the weight;

l_j is the limitation force/constraint.

Driving forces are expressed in the form of raster map with pixel values varying from 0 to 1, while forces are expressed in the form of a binary raster map with pixel value of 1 for allowed areas and zero for forbidden areas. The main problem in this approach is how to identify the weights of the criteria objectively. This problem is discussed by Voogd (1983) and Eastman, (1993). Eastman (1993) suggested the use of a matrix to illustrate the relative importance of each pair of criteria. The final weight of a criterion can be deduced by calculating the weights in each column and then averaging over all columns. This method may be recommended provided that stakeholders participate in the process of formulation of spatial decision by involving the community in the identification process of the relative importance of the driving forces.

The spatial decision problem occurs when many objectives need to be implemented in the plan. For example, an allocation study for urban and agriculture will create conflicts for some areas. Handling this problem is easy to be solved with *maximum likelihood approximation*. As indicated above, the land suitability index ranges from 0 to 1. For this reason, the index may be considered as the probability of allocation. Therefore, if there are two (or more) conflicting decisions a, and b, where the priority of a is greater than b, illustrated by the two indices and, the allocation role can be expressed as indicated in the equation (2).

$$Pixel\ label = \begin{cases} a & if \quad p_a \geq p_b \\ b & if \quad p_a < p_b \end{cases}$$

Data and Analysis

Data

A geographic information system (GIS) was built for the study area using spatial data including maps and satellite images. Two topographic maps were used to create the base map features such as power lines, railroads, and roads. These two maps were titled El Daba'a and Ras Abu Kharouf, produced by the Military Survey Unit in 1996. Both were scaled to 1:50,000 and projected to the Universal Transverse Mercator *UTM* – Zone No. 35N with the World Geodetic System *WGS* datum for 1984.

Satellite image produced by Landsat 7 Enhanced Thematic Mapper *ETM* Sensor, located in path No. 178 and row No. 39 on Worldwide Reference System *WRF* was used in this study. The image dated 4 September 2002. The image was rectified to UTM 35N/WGS84 by provider. The image included six bands of 28.5 m spatial resolution and single panchromatic band of 14.25 m spatial resolution (Al-Jenaid and Mohammed, 2008).

Soil map produced by the Egyptian National Research Center of 1:100000 scale was used to identify soil properties in the study area. It was digitized and added as a GIS layer. The land cover map produced by supervised classification for Landsat 7 ETM image was re-coded to identify the current land use in the study area. Figure 2 shows a composition of land use and basic man made geographic features in the study area.

Analysis

The proposed land uses in the study area are for agriculture and grazing and urban respectively. The objective of this analysis was to map a proposed sustainable land use to meet both official and public demands. For this reason, the stakeholder participation was involved in all of the processes of the planning. This stakeholder participation was achieved by creating a group of 10 individuals. There were three officials; one of them came from the central government, two investors, two farmers and three shepherds. The decision of the group was considered the most trusted decision.

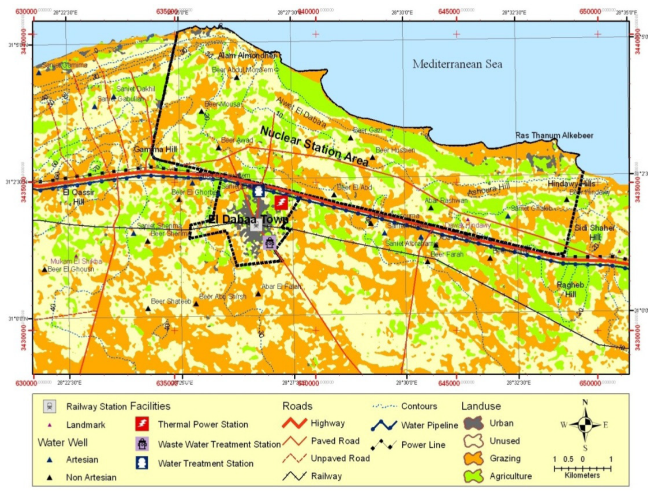


Figure 2: Land use and man-made features in the El-Dabaa study area.

Formulating Driving and Limitation Forces

To identify the factors that enhance the allocation of different land uses in the study area, a list of 25 factors were outlined by the planning experts and discussed by the public participation group. Twelve factors were chosen as the most influential factors in the study area. These factors are listed in Table 1. The indicators (ü) and (û) show whether any factor influences or not as regards the land use.

The influence of different facilities is ignored from this list as a reason for the location of the facilities inside El Daba'a Town. The influence of slope in the allocation of urban land use is limited to areas of less than 5% slope, while the influence aspect is the North, Northeastern and Northwestern. For agriculture, the soil type dramatically enforces or limits agriculture location. The limitation forces are identified by the most noticeable ownership in the area, the land assigned for launching of the national nuclear stations.

Table 1: Driving force in the study area

Driving Force	Agriculture	Grazing	Urban
Proximity to El Daba'a Town	✓	✓	✓
Proximity to Main Roads	✓	✗	✓
Proximity to Waterline	✗	✗	✓
Proximity to Powerline	✗	✗	✓
Proximity to Water Facility	✓	✗	✓
Proximity to Power Facility	✗	✗	✓
Proximity to Waste Water Facility	✗	✗	✓
Proximity to Water Wells	✓	✓	
Proximity Current Landuse	✓	✓	✗
Slope	✓	✗	✓
Aspect	✗	✗	✓
Soil Type	✓	✗	✗

The driving forces chosen by the public participation group were mapped using three GIS functions. The first function was the linear proximity function. This function creates a raster where each pixel value denotes the linear distance between the center of this pixel to the closest considered features. The second function is the normalization function. It is used to unify the proximity index which is 1 for the closest pixel and 0 for the farthest pixel. Normalization function can be illustrated using the following equation:

$$v_n = 1 - \frac{v_o - v_{min}}{v_{max} - v_{min}}$$

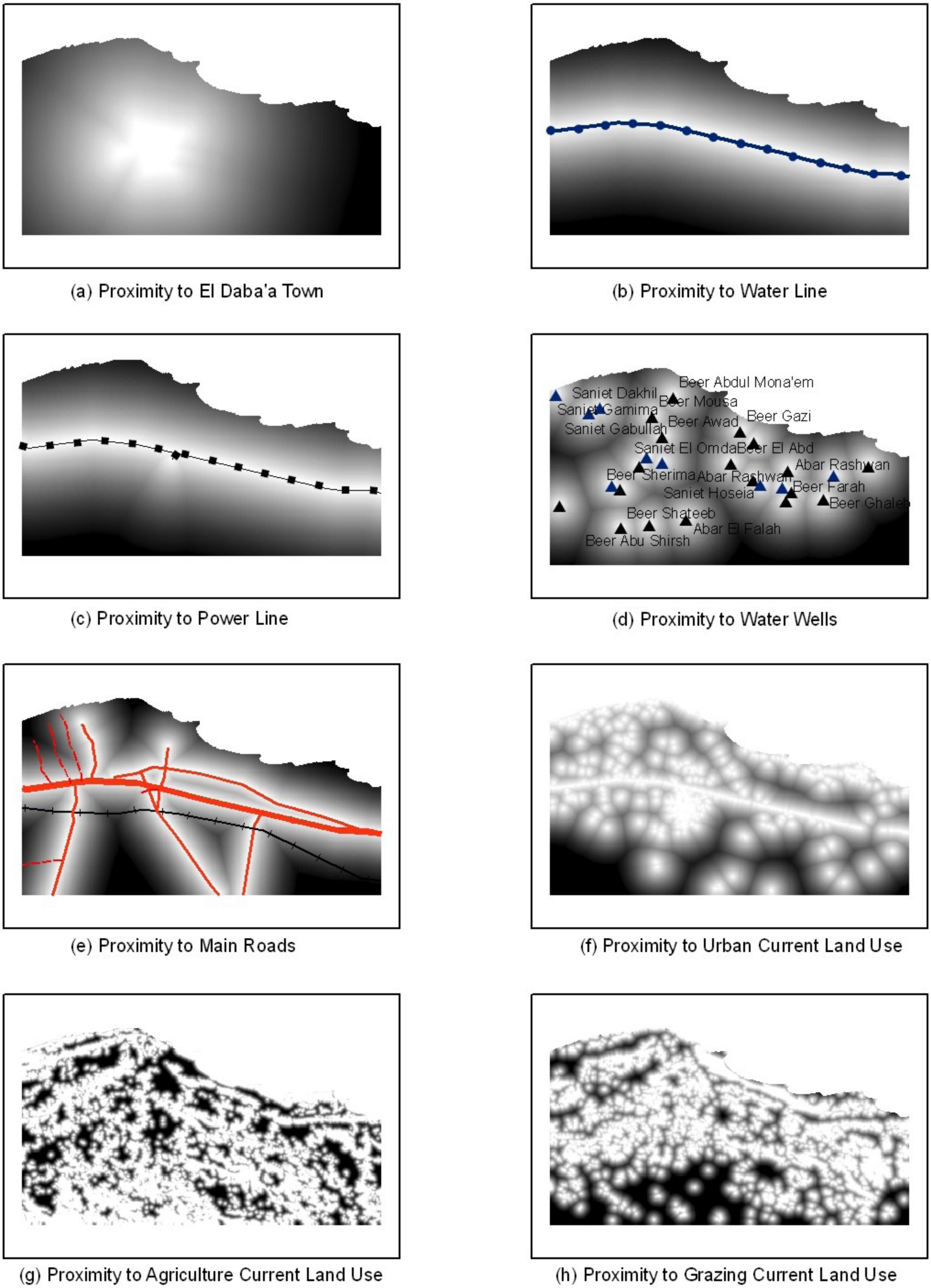
Where
v_n new normalized pixel value;
v_o original pixel value;
v_{min} minimum pixel values in the original raster
v_{max} maximum pixel values in the original raster

The third function is the recoding function used to convert the values of the driving forces such as slope to the values ranging from zero to one. Limitation forces are mapped in binary form of 0 and 1 where a value of 0 illustrates the allowed areas and a value of 1 illustrates the restricted areas. Figure 3. shows some examples of geographical distribution of the driving forces where dark color denotes less suitability and light color denotes areas of less suitability, light color denotes area of more suitability, according to the considered driving force.

Estimating the Driving Forces Weights

The relative importance matrix, which is asquare array, is used to estimate the driving forces. Each cell of this matrix presents the importance of the row heading to the column heading. For example, if a cell in a row *i* and column *j* contains two, this means that the driving force in line *i* is twice in importance as compared to that in column *j*.

To calculate the weight of each driving force, the vertical sum was calculated, then the ratio of each cell to its column sum was calculated and presented in another matrix, the average of each line in the new array represented the weight of the driving force in this line. This method provides the sum of all weights which is equal to 1. Tables 2, 3 and 4 show the relative importance matrices for agriculture, and urban and grazing respectively.



(a) Proximity to El Daba'a Town

(b) Proximity to Water Line

(c) Proximity to Power Line

(d) Proximity to Water Wells

(e) Proximity to Main Roads

(f) Proximity to Urban Current Land Use

(g) Proximity to Agriculture Current Land Use

(h) Proximity to Grazing Current Land Use

Figure 3. Examples for geographic distribution of the driving forces.

Table 2: The relative importance matrix for agriculture

	to El Daba'a Town	to Main Roads	to Water Wells	Slope	Current Landuse	Soil Type
to El Daba'a Town	1.00	0.50	0.33	1.00	1.00	3.00
to Main Roads	2.00	1.00	0.33	1.00	1.00	0.33
to Water Wells	3.00	3.00	1.00	2.00	1.00	0.33
Slope	1.00	1.00	0.50	1.00	3.00	0.33
Current Landuse	1.00	1.00	0.50	0.33	1.00	0.33
Soil Type	3.00	3.00	3.00	3.00	3.00	1.00

Table 3: The relative importance matrix for grazing

	to El Daba'a Town	to Main Roads	to Waterline	to Powerline	to Water Wells	Slope	Aspect
to El Daba'a Town	1.00	1.00	1.00	1.00	3.00	1.00	1.00
to Main Roads	1.00	1.00	0.50	0.50	2.00	2.00	2.00
to Waterline	1.00	2.00	1.00	2.00	3.00	2.00	2.00
to Powerline	1.00	2.00	0.50	1.00	3.00	2.00	2.00
to Water Wells	0.33	0.50	0.33	0.33	1.00	1.00	1.00
Slope	1.00	0.50	0.50	0.50	1.00	1.00	1.00
Aspect	1.00	0.50	0.50	0.50	1.00	1.00	1.00

Table 4: The relative importance matrix for urban

	to El Daba'a Town	to Water Wells	Current Landuse
to El Daba'a Town	1.00	0.33	0.50
to Water Wells	3.00	1.00	1.00
Current Landuse	2.00	1.00	1.00

By calculating the weight for each driving force, the following equation – which presents the suitability index for each proposed land use were derived.

*Agriculture Suitability = Proximity to El Daba'a Town * 0.155093551*
*+ Proximity to Main Roads * 0.102795724*
*+ Proximity to Water Wells * 0.192007802*
*+ Slope * 0.125753711*
*+ Proximity to Current Landuse * 0.079495124*
*+ Soil Type * 0.322190717*

*Urban Suitability = Proximity to El Daba'a Town * 0.158295771*
*+ Proximity to Main Roads * 0.147915013*
*+ Proximity to Waterline * 0.230418617*
*+ Proximity to Powerline * 0.189418613*
*+ Proximity to Water Wells * 0.074720598*
*+ Slope * 0.099615694*
*+ Aspect * 0.099615694*

*Grazing Suitability = Proximity to El Daba'a Town * 0.169432523*
*+ Proximity to Water Wells * 0.443061516*
*+ Current Landuse * 0.387505961*

By applying these three equations, three suitability maps were produced to show the agriculture, and grazing and urban land uses. These maps are shown in figure 4. Then, the three suitability maps were used to produce the final suitability map for the study area. To produce this map simple comparison rules were applied to express the priorities of these different land use types for the local community. These comparison rules labeled pixels as proposed agricultural land use if the agriculture suitability index is greater than or equal to the suitability indices of grazing and urban, and labeled pixels as proposed grazing land use if the grazing suitability index is greater than the agriculture suitability index and greater than or equal to the urban suitability index, and labeled pixels as proposed urban land use if the urban suitability index is greater than the suitability indices of the agriculture and grazing.

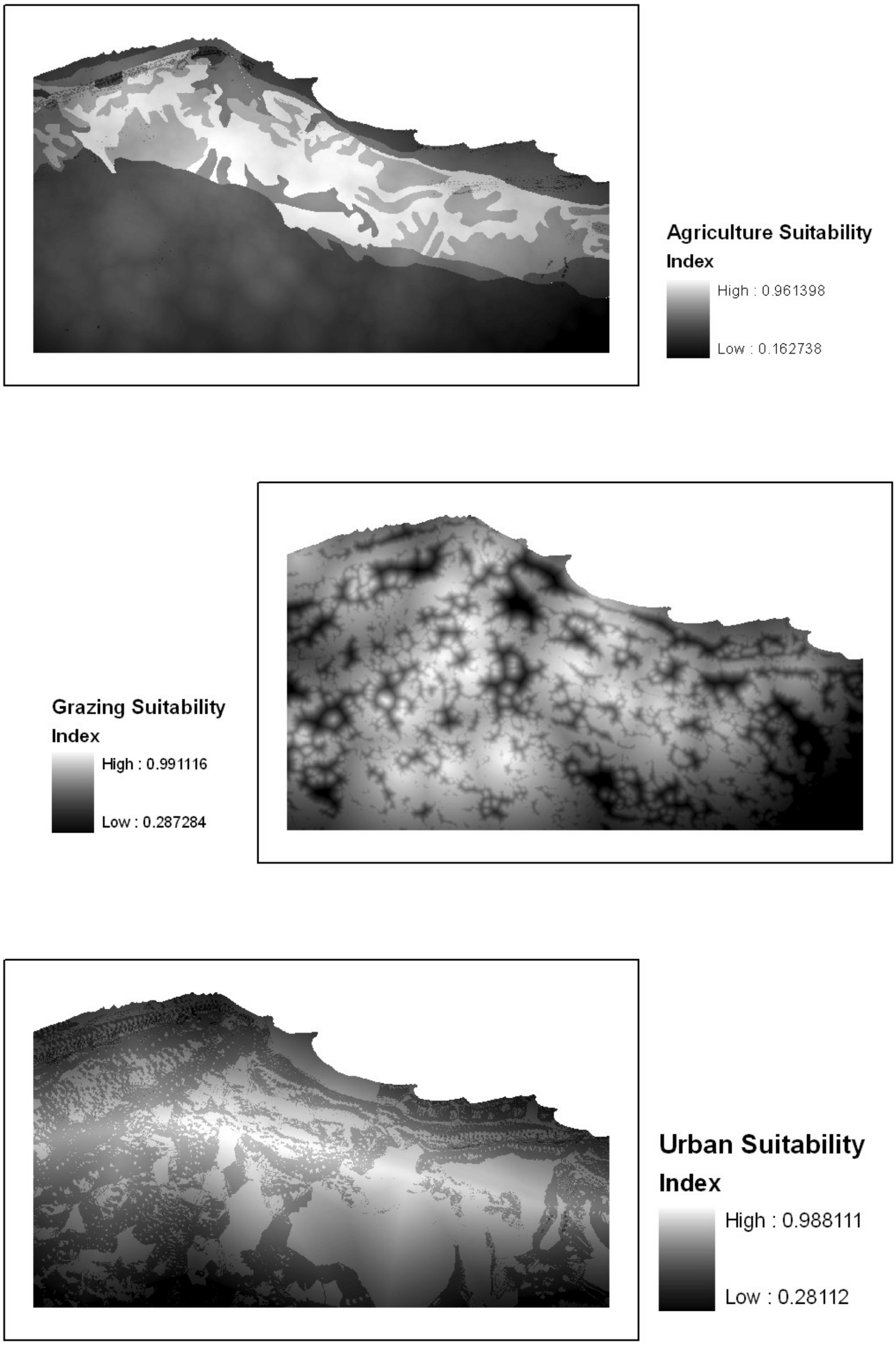


Figure 4: Suitability maps, *(agriculture suitability, grazing suitability, & urban suitability).*

Results

Application of the above indicated methodology to the three suitability maps produced the final land use plan in the study area, as shown in Figure 5.

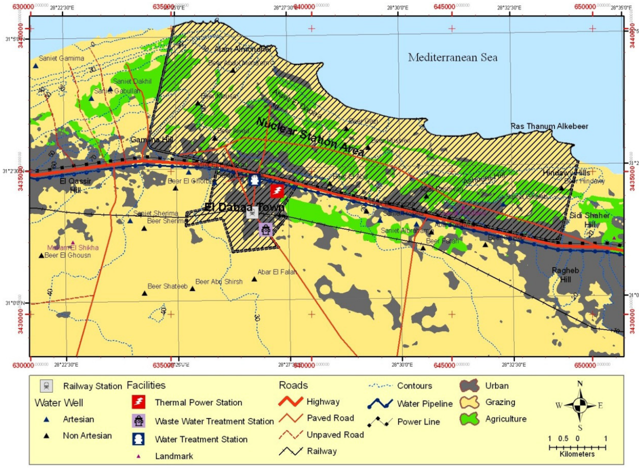


Figure 5: Final land- use plan.

As noted in the map, a wide area for the agricultural land use is located inside the restricted area by the proposed nuclear power station. This situation may cause variation in the development of the study area. Table 5**.** and Figure6 show the area of each proposed land use in and outside the restricted area – area occupied by the nuclear power station project - and total area. As shown in the table and the figure, the agriculture land use which is supposed to support the most important activity in the study area lost about 66% of total agriculturally suitable area for the planned nuclear power station.

Table 5: Areas of proposed land- uses in the study area (Hectares)

Land Use	Urban	Grazing	Agriculture
Non Restricted Area	2605.10	10724.03	856.07
Restricted Area	1143.40	3340.98	1652.40
Total Area	3748.51	14065.02	2508.47

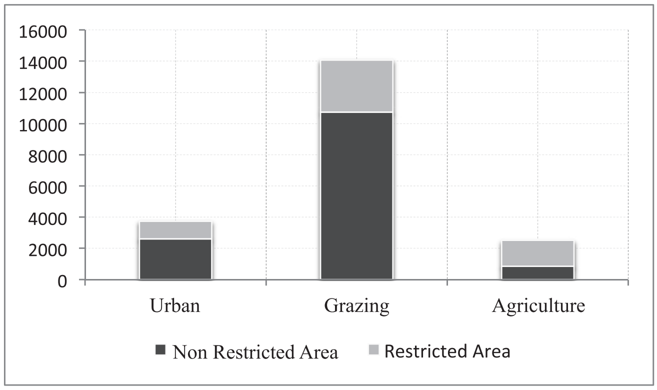


Figure 6: Areas of proposed land- uses in the study area (Hectares)

Conclusion and Recommendation

A methodology is developed to solve a problem of land use allocation considering both bio-geophysical and socioeconomic aspects in El-Daba'a Region, located in the Northwestern coast of Egypt. The methodology is based on modeling the driving forces and limitation forces. The multi-criteria and multi-objective analyses with the stakeholder's participation were utilized to allocate the main land use type in the study area under the circumstances of launching the nuclear station activities in the region.

According to the new allocation, the removal of the area restricted by the nuclear power station project will result in the following distribution: the largest area is assigned for grazing (about 10724 Hectares). then urban land use which is supposed to occupy about 2600 hectares, and finally agriculture land use which is supposed to occupy an area estimated to be about 850 hectares.

Based on this calculated allocation, it is recommended to establish two settlements in the east and the west of El Daba'a town as settlements for farmers and pastures who will use the available area for agriculture and grazing in the coastal plain northward the highway, where the proposed El Daba'a Town urban center provides the provisional services for the study area and housing services for the nuclear power station employee.

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