Sustainable Land Use Planning for El-Daba'a Region, Egypt Using Multi Criteria / Multi Objective Spatial Analysis

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Abstract

For many decades, El-Daba'a region had been eliminated from the development plans of the western north coast of Egypt. Fortunately, this situation helped El-Daba'a region to preserve the coastal ecosystem of the western north coast, which has disappeared from many locations along this coast as a result of aggressive unsustainable development.

This situation has changed now; El-Daba'a region has been chosen by the Egyptian Government to be the site of the first Egyptian Nuclear Power Station. This decision is accompanied with strong trends to develop El-Daba'a region and its local community.

This paper introduces a framework for sustainable land use planning, considering the special ecological aspects of El-Daba'a region and the role of the local community.

Using public participation, the local trends of land use development are identified and compared to the plans of the central government to formulate a set of development criteria accepted by the local community, stakeholders, decision makers and environment NGOs. Using the multi objective/multi criteria spatial approach, these criteria are used to create a general land use plan for El-Daba'a region.

Key Words: GIS, MCE, MOE, Sustainable Planning, Environmental Management, Land Use Planning.

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1 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 charged socioeconomic process involving a plurality of interests. However, the planning processes and outcomes are the domain of powerful interest groups including investors, governments, stock market and various 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 makes 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, 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 a more recent application of the same effort to incorporate new tools and technologies (Nedovic`-Budic`, 2000).

Since 1990th, the Egyptian planners used geographic information systems to enhance their planning process and to provide an objective approach to their planning decisions. For example, GIS was involved in the land inventory analysis and 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., 1999) and (Raey, et al., 2000). For integrated planning in Egypt, two master works should be considered, Lake Nasser Development Project (LNDP, 2001) and Northwestern Coast and Inland Development Project (NWCID, 2003). In these projects GIS had been used to handle large volumes of data including satellite images, vector datasets, illustrated topographic and thematic maps, pictures, videos, social and economic census and other 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 strike a balance between the development trends of official scenarios and public orientations. The handling of this situation can 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 a multi criteria decision making problem. The results of this analysis are a series of plans to meet different objectives. Producing a single overall plan from these objective oriented plans may be achieved by applying the multi objectives decision making methodology.

The objectives of this paper are (1) to illustrate a road map for applying the multi criteria / multi objectives approach in sustainable spatial planning, and (2) to produce a spatial plan for the study area to meet both official and public orientations.

2 Study Area

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

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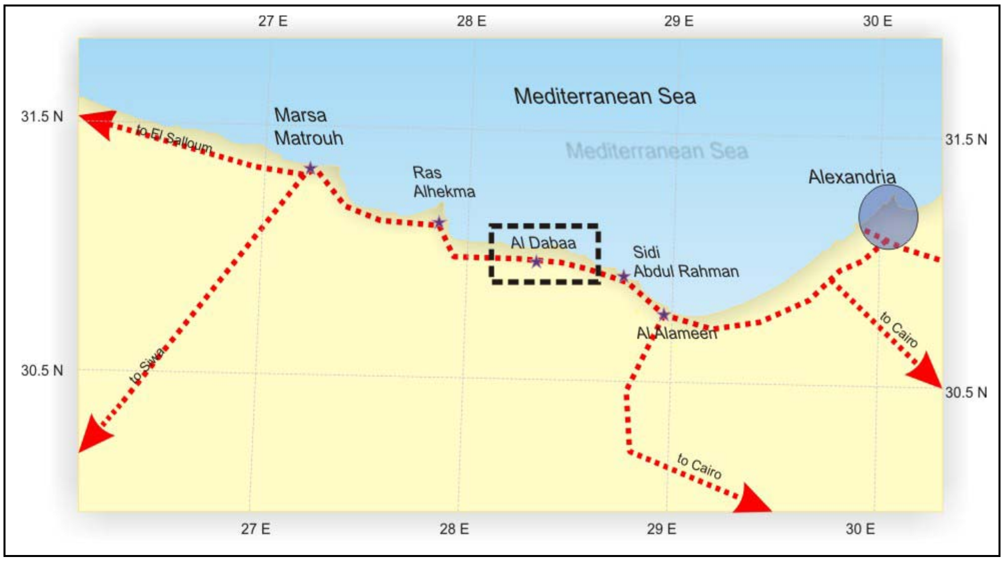

Figure 1: Location map for the El Daba'a study area

The history of land use in the study area may be illustrated by the history of land use over the northwestern coastal area. Historically, El Daba'a was an area occupied by nomadic Bedouin tribes. The basic land use in the past was grazing in the natural pasturelands in the south that are dominated by *Thymelaea hirsute* and agriculture in the coastal belt where the rainfall is estimated to be 138mm annually.

This simple land use was changed by the influences of emigrants from the other parts of Egypt in 1960^{th}. The first noticeable wave was after the launching of High Dam Project, where the Egyptian government had migrated Nubian people from their original villages that were influenced by the High Dam, to the towns of the north-western area. The second was after the 1967 war when the Egyptian government attempted to settle the war-refuges from Sinai and the Canal Zone in the small towns in the northwestern coast (NRC, 1987).

The policy of the Egyptian Government to encourage migration to the north-western coast is a basic concept to decrease the demographic rural-urban gap. This policy has ultimately been successful because the population of the Governorate of Matrouh, in which the greatest proportion of the Northwestern Coastal area is situated, is now 46 times more than in 1960. This compared to the growth of the Egyptian population of six times in the same period. The population growth rate at 3.1% is double the rate of 1.7% in 1960 (UNDP, 2004), (IDSC, 2007).

The increasing in number of emigrants leads to an increasing demand for urban growth and to develop organised agriculture in the El Daba'a area. These pressures reformulate the land use structure in the study area. It is suspected that more reformulation will occur if the Egyptian Government launches the project for a Nuclear Power Station in the area.

3 Methodology

The multi criteria approach attempts to solve the problem where the decision is formulated by a set of driving and limiting forces. It is obvious that the multi criteria approach is concerned with a single objective problem. The multi objectives approach attempts to solve the problem where many objectives need to be differentiated to varying degrees or to remove the conflict between these objectives.

Land use planning is the field where the integration between the multi criteria approach and the multi objectives 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; thus the multi criteria approach is easy to use to solve such this problem. From a different point of view, allocation of different land uses in the same area leads to conflict between these uses. The multi objectives approach solves the conflict of different land uses in the same area. For this reason, the integration between these two approaches is required in the context of sustainable spatial planning.

A decision 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 from the suitability of an area for the decision under consideration. A limitation force is a constraint that serves to limit the alternatives under consideration. The merging both of criteria and constraints requires development of an *objective function*. The 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 is expressed in the following form:

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

Or in more simple form:

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

Where

__ is the quantitative index for land suitability, it varies from 0 (not suitable) to 1 (most suitable);

__ is a driving force/criterion;

is the weight;

is the limitation force/constraint.

Driving forces can be expressed in the form of a raster map with pixel values varying from 0 to 1. Limitation forces can be expressed in the form of a binary raster map with pixel value 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) suggests the use of a matrix to illustrate the relative importance for each pair of criteria. The final weight of the criteria can deduced by calculating the weights of each column and then averaging over all columns. This method may recommend public participation in the process of formulation of the spatial decision by involving the community in the process to determine the relative importance of each of the driving forces.

The other face of the spatial decision problem is shown when many objectives should 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 solve with *maximum likelihood approximation*. As mentioned the land suitability index ranges from zero to one. For this reason, this index may handle the probability of allocation. So, 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 the following:

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

4 Data and Analysis

4.1 Data

A geographic information system (GIS) was built in this study 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 are titled El Daba'a and Ras Abu Kharouf, produced by the Military Survey Unit in 1996. Both are scale 1:50,000 and projected to Universal Transverse Mercator *UTM* – Zone No. 35N with World Geodetic System (WGS) datum for 1984.

A 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) is used in this study. The image is dated 4 September 2002 and has been rectified to UTM 35N/WGS84 by the provider. The image includes six bands of 28.5m spatial resolution and single panchromatic band of 14.25m spatial resolution (Aljenid & Mohammed, 2007).

A soil map produced by the Egyptian National Research Center of 1:100,000 scale is used to identify the soil properties in the study area. It was digitised and added as a layer in the GIS. The land cover map produced by supervised classification from the Landsat 7 ETM image is recoded to identify the current land use in the study area. Figure 2 shows a composition for land use and basic man made geographic features in the study area.

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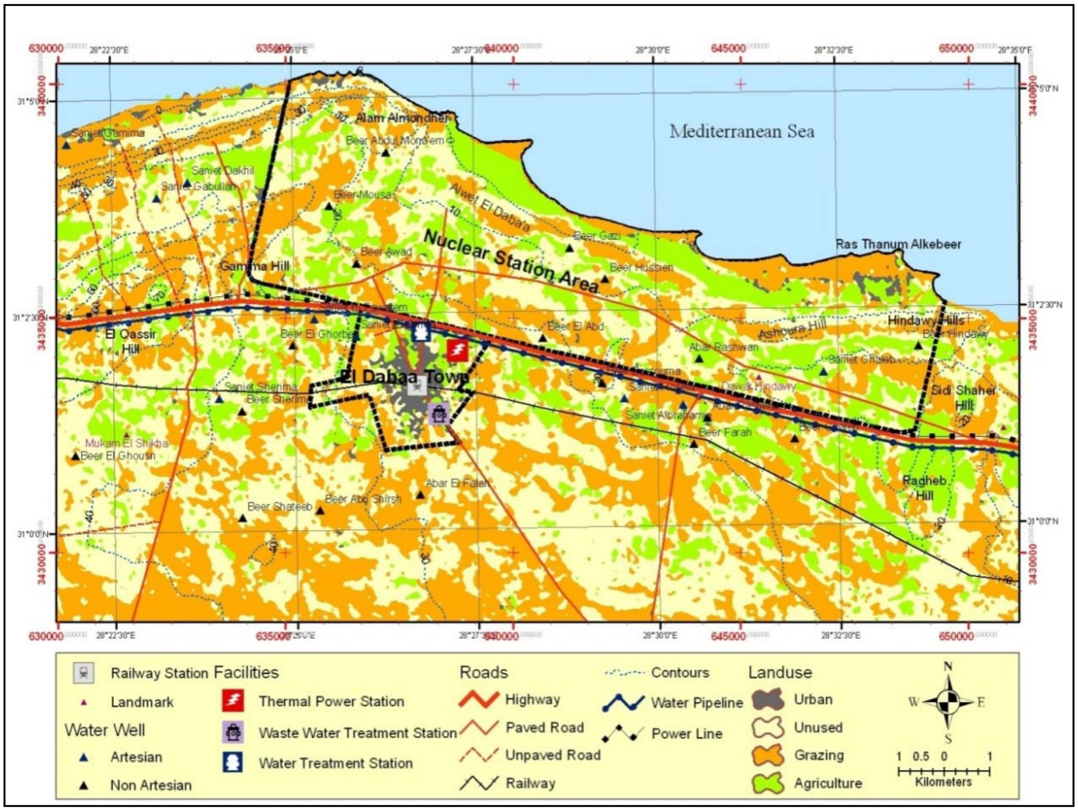

Figure 2: Land use and man-made features in the El Daba'a Study Area

4.2 Analysis

The proposed land uses in the study area are agriculture, grazing and urban respectively. The objective of this analysis is to map a proposed sustainable land use to meet both official and public demands. For this reason, the public was involved in all processes of the planning. Public participation was achieved by the attendance of a group of ten persons in the processes. These persons are three officials; one of them belongs to the central government; two investors, two farmers and three graziers. The decision of the group considered the most frequented decision.

4.2.1 Formulating Driving and Limitation Forces

To identify the factors that enhance the allocation of different land uses in the study area, a list of twenty-five factors were prepared by planning experts and discussed by the public participation group. Twelve factors were chosen as being the most influential factors in the study area. These factors are listed in **Table 1**. The signs of (✓) and (✗) show if the factor had an influence on the land use or not.

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Table 1: Driving Forces in the Study Area

Driving Forces	Agriculture	Grazing	Urban
1. Proximity to El Daba'a Town	✓	✓	✓
2. Proximity to Main Roads	✓	×	✓
3. Proximity to Waterline	×	×	✓
4. Proximity to Powerline	×	×	✓
5. Proximity to Water Facility	✓	×	✓
6. Proximity to Power Facility	×	×	✓
7. Proximity to Waste Water Facility	×	×	✓
8. Proximity to Water Wells	✓	✓	
9. Proximity Current Landuse	✓	✓	×
10. Slope	✓	×	✓
11. Aspect	×	×	✓
12. Soil Type	✓	×	×

The influence of any additional factors in the location of the facilities inside El Daba'a Town have been ignored. The influence of slope in the allocation of urban land use is limited to areas less than 5% slope, where the influencing aspect is the north, north eastern and north western respectively. For agriculture, the soil type dramatically enforces or limits agriculture allocation.

The limitation forces are identified by the most noticeable ownership in the area, the land assigned for establishment of the national nuclear power station.

4.2.2 Mapping Driving and Limitation Forces

The driving forces chosen by the public participation group were mapped using three GIS functions. The first function is the linear proximity function. This function creates a raster image where each pixel value denotes the linear distance between the centre of the pixel and the closest considered feature. The second function is the normalization function. It is used to unify the proximity index to be one for the closest pixel and zero for the furthest pixel. The normalization function is easy to illustrate using the following equation:

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

Where

__ is the new normalized pixel value;

__ is the original pixel value;

____ and ____ are the minimum pixel value in the original raster

The third function is the recoding function that is used to convert the values of driving forces such as slope to the values ranging from zero to one.

Limitation forces are mapped in binary form of zero or one where zero illustrates the allowed areas and one illustrates the restricted areas. Figure 3 shows some examples for geographic distribution of driving forces where dark colour

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denotes reduced suitability and light colour denotes greater suitability according to the considered driving force.

4.2.3 Estimating the Weights of the Driving Forces

To estimate the weight of driving force, the relative importance matrix is used. The relative importance matrix is a square array for the diving forces; each cell of this matrix represents the importance of the line heading to the column heading. See for example, tables 2, 3 and 4 that show the relative importance matrices for agriculture, urban and grazing respectively. If a cell in row i and column j contains two, this means the driving force in line i has double the importance of that in column j. For this reason, all the cells along the diagonal are equal to one.

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 represents the weight of the driving force in this line. This method provides that the sum of all weights is equal to one.

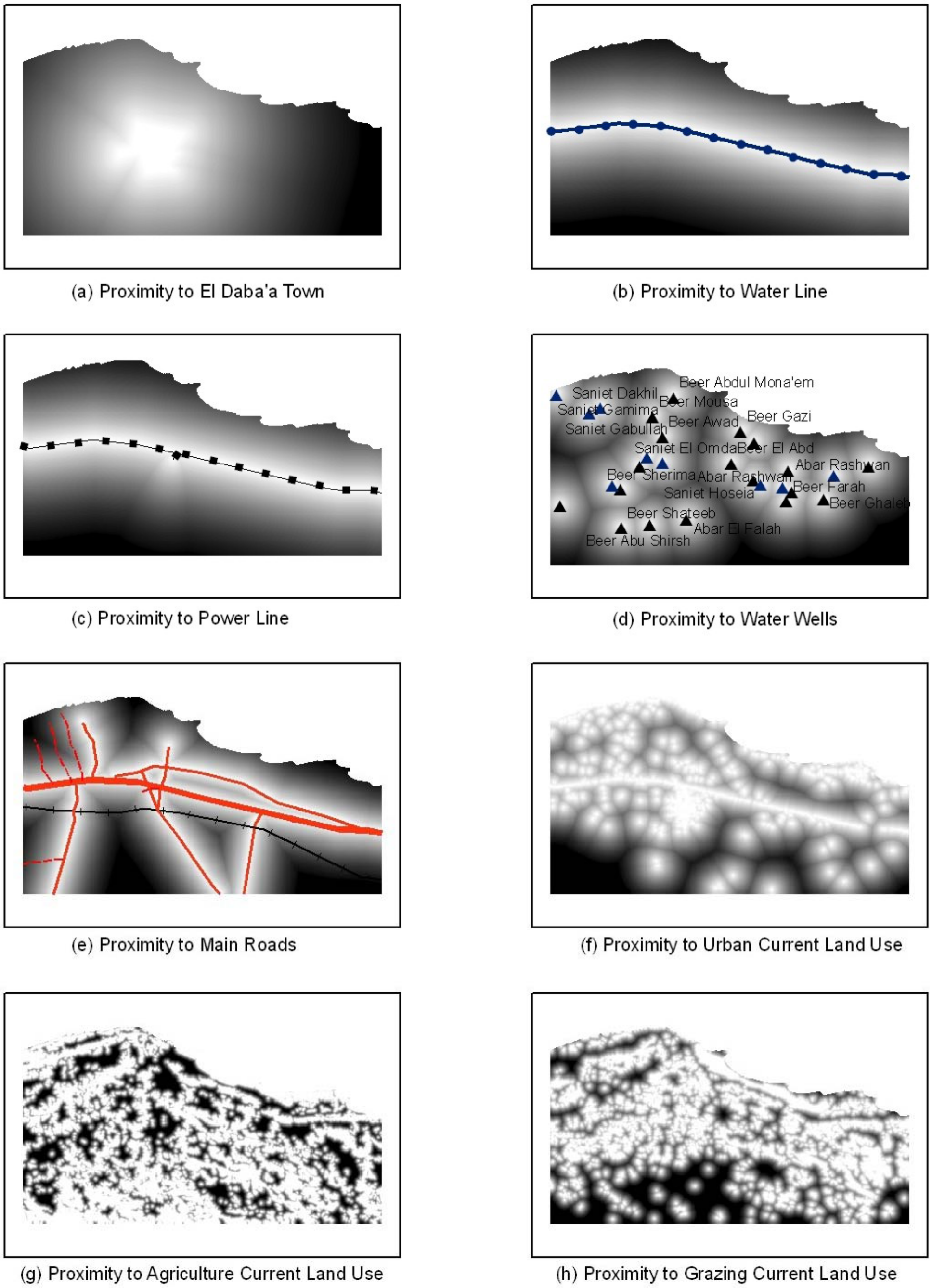

Figure 3: Examples of Geographic Distribution of Driving Forces

Table 2: The relative importance matrix for agriculture (as proximity)

	El Daba'a Town	Main Roads	Water Wells	Slope	Current Landuse	Soil Type
El Daba'a Town	1.00	0.50	0.33	1.00	1.00	3.00
Main Roads	2.00	1.00	0.33	1.00	1.00	0.33
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 urban (as proximity)

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

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Table 4: The relative importance matrix for grazing (as proximity)

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

The following equation which presents the suitability index for each proposed land use, was used to calculate the weight for each driving force.

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$$
\begin{aligned}
\textit{Agriculture Suitability} = {} & \textit{Proximity to El Daba'a Town} * 0.155093551 \\
& + \textit{Proximity to Main Roads} * 0.102795724 \\
& + \textit{Proximity to Water Wells} * 0.192007802 \\
& + \textit{Slope} * 0.125753711 \\
& + \textit{Proximity to Current Landuse} * 0.079495124 \\
& + \textit{Soil Type} * 0.322190717
\end{aligned}
$$

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$$
\begin{aligned}
\textit{Urban Suitability} = {} & \textit{Proximity to El Daba'a Town} * 0.158295771 \\
& + \textit{Proximity to Main Roads} * 0.147915013 \\
& + \textit{Proximity to Waterline} * 0.230418617 \\
& + \textit{Proximity to Powerline} * 0.189418613 \\
& + \textit{Proximity to Water Wells} * 0.074720598 \\
& + \textit{Slope} * 0.099615694 \\
& + \textit{Aspect} * 0.099615694
\end{aligned}
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$$
\begin{aligned}
\textit{Grazing Suitability} = {} & \textit{Proximity to El Daba'a Town} * 0.169432523 \\
& + \textit{Proximity to Water Wells} * 0.443061516 \\
& + \textit{Current Landuse} * 0.387505961
\end{aligned}
$$

By applying these three equations, three suitability maps were produced to show the proposed agriculture, grazing and urban land uses. These maps are shown in Figure 4.

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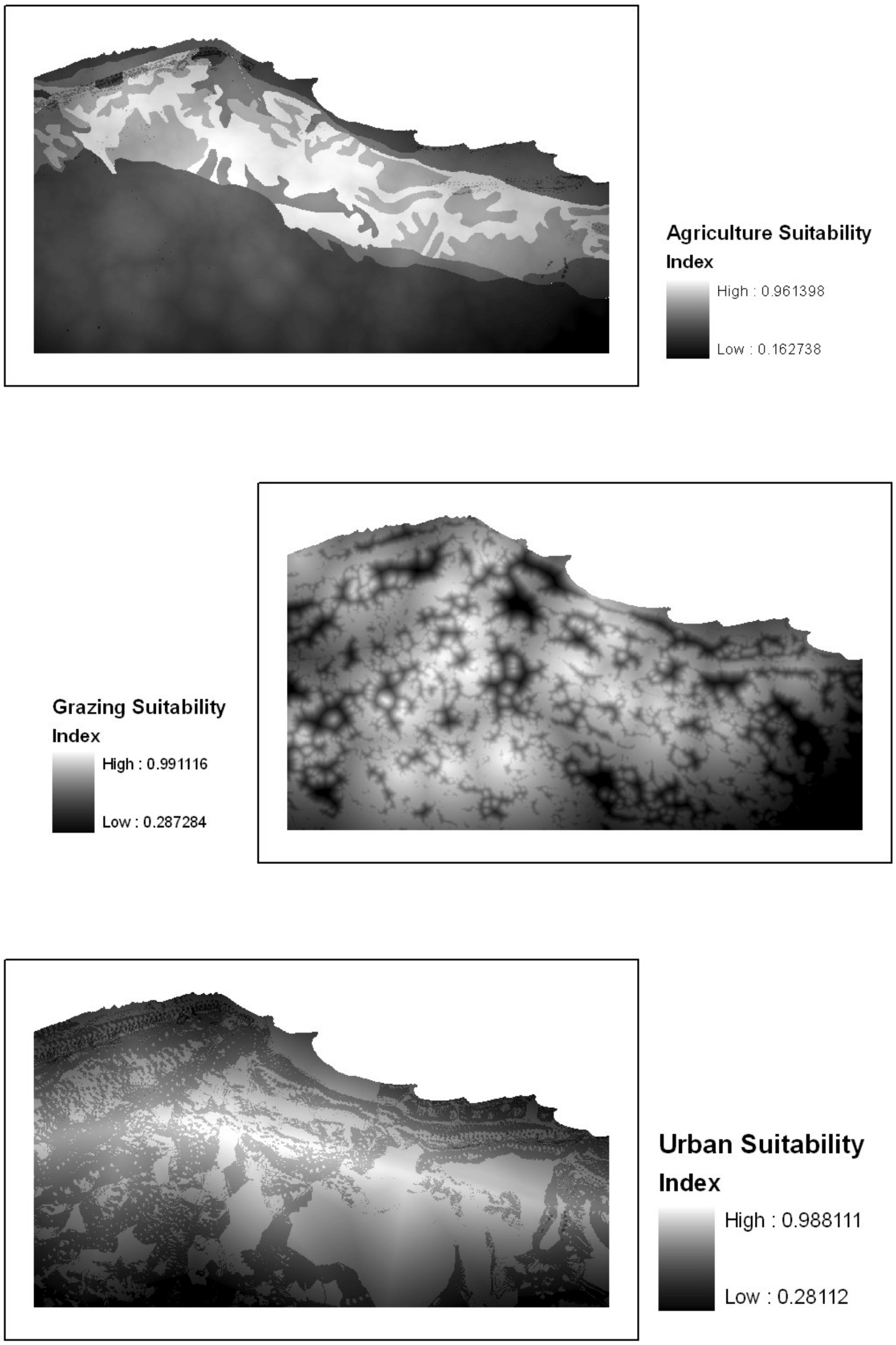

Figure 4: Suitability maps

4.2.4 Land Use Suitability Map

These three suitability maps were used to produce the final suitability map for the study area. To produce this map simple comparison rules were used 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 was greater than or equal to the suitability indices of grazing and urban, and labelled pixels as proposed grazing land use if the grazing suitability index was greater than the agriculture suitability index and greater than or equal to the urban suitability index. Pixels were labelled as proposed urban land use if the urban suitability index was greater than the suitability indices of both agriculture and grazing.

Applying these rules to the three suitability maps produced the final land use plan in the study area which is shown in **Figure 5**.

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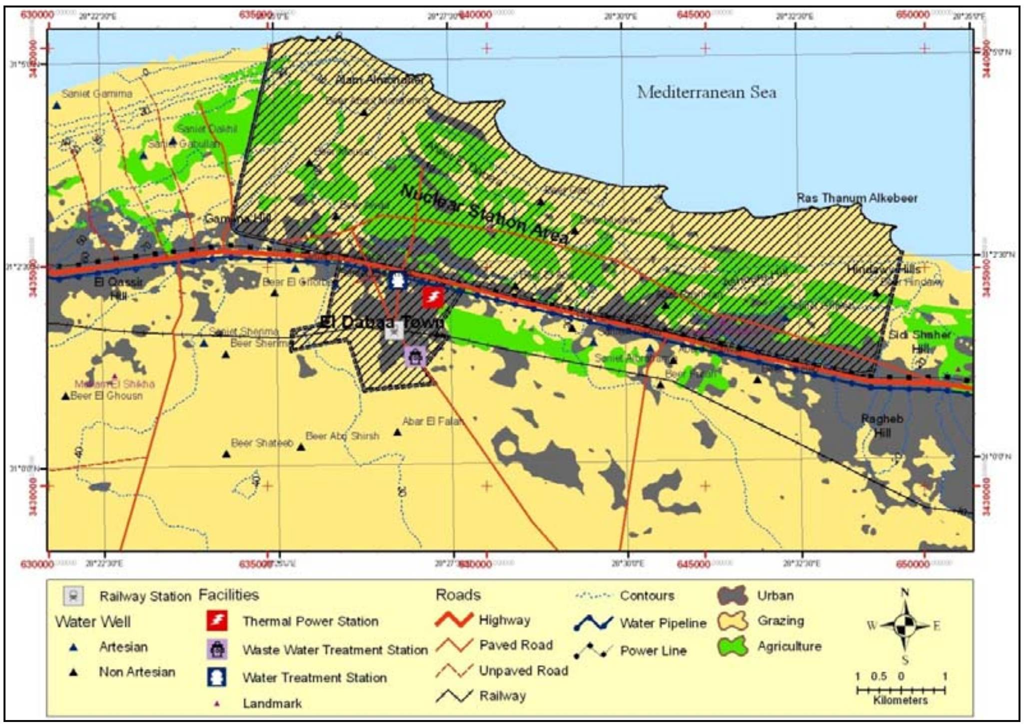

Figure 5: Final Land Use Plan

5 Conclusions

As shown in **Figure 5**, an extensive area suitable for agriculture land use is located within the restricted area of the proposed nuclear power station. This situation may vary the development in the study area. **Table (5** and **Figure (6** show the area of each proposed land use in and out the restricted area – area occupied by the nuclear power station project – and the total area.

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Table (5): Area (in hectares) of proposed land uses

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

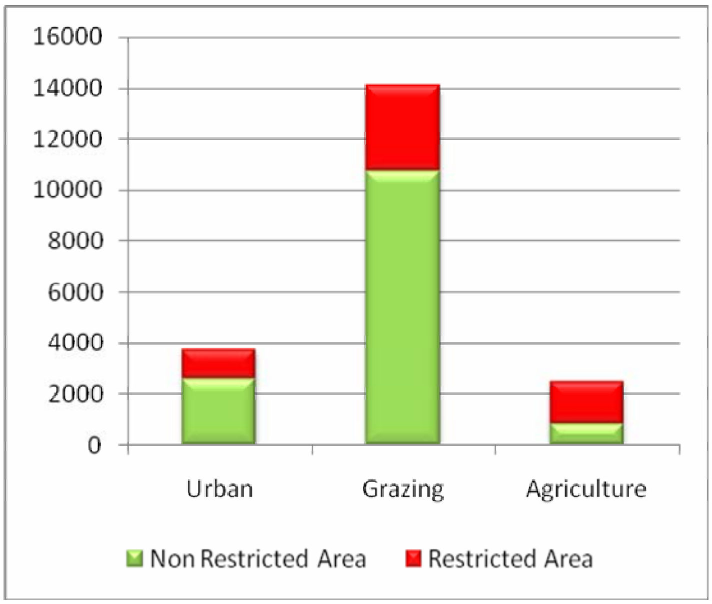

Figure (6): Areas (in hectares) of proposed land uses in the study area

As shown in **Table (5** and **Figure (6**, the agriculture land use – which is supposed to support the most important activity in the study area, would lose an area about 66% of the total agriculture suitable area for the nuclear power station.

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According to the new allocation – considering only the area not restricted by the nuclear power station project – the largest proportion is to be assigned for grazing (about 10724 hectares). The next largest allocation is urban land use which would occupy about 2600 hectares. Finally the lowest allocation would be for agriculture land use which would occupy an area estimated to be 850 hectares.

Based on the previous conclusion, it is recommended to establish two settlements in the east and the west of El Daba'a town to be settlements for farmers and graziers. These people would use the available area for agriculture and grazing in the coastal plain northward of the highway. El Daba'a Town is thus proposed to be an urban centre for the study area to provide professional services for the study area and housing services for the nuclear power station employees.

References

Aljenid, S., & Mohammed, W. (2007). Developing a GIS to Assess the Ecological Characteristics of El-Daba'a Region – Egypt. *4th Middle East Spatial Technology Conference* .

CAPMAS. (2006). *Egypt in Figures-2006.* Cairo: Central Authority for Public Mobilizing and Statistics CAPMAS.

Eastman, J. (1993). Decision Theory and GIS. *Africa GIS '93.* Geneva: UNITAR.

Friedmann, J. (1987). *Planning in the Public Domain: From Knowledge to Action.* Princeton, NJ: Princeton University Press.

IDSC. (2007). *Census Survey for Matrouh Governorate.* Marsa Matrouh, Egypt: Information & Decision Support Center.

Klosterman, R. (1990). Microcomputers in Urban and Regional Planning: Lessons from the Past, Directions for the Future. *Computers, Environment, and Urban Systems , 14* (3), 177-185.

Lein, J. (2003). *Integrated Environmental Planning.* Blackwell Science Ltd.

LNDP. (2001). *Strategy for the Development of Lake Nasser Area.* Aswan, Egypt: LNDP.

Mandelbaum, S. (1996). Making and Braking Planning Tools. *Computers, Environment and Urban Systems , 20* (2), 71-84.

Nedovic`-Budic`, Z. (2000). Geographic Information Science Implications for Urban and Regional Planning. *URISA Journal , 12* (2), 81-93.

NRC. (1987). *Encyclopedia of Western Desert.* (A. A. Shata, Ed.) Cairo: National Research Center - Minisery of Scientific Research.

NWCID. (2003). *The Strategic Development Plan for North Western Coast and Inland.* Matrouh, Egypt: NWCID.

Raey, M., Nasr, S., Abdraboh, M. E., Elkaffas, S., Hattab, M., Shalaby, A., et al. (1999). *Integrated Coastal Area Management for Fuka-Matrouh, Egypt.* Dopervenk, Croatia: PapRak.

Raey, M., Nasr, S., Frihy, O., Abdul Qader, F., Bahanasy, M., Hattab, M., et al. (1998a). *Geographic Information System to Land Inventory Assssment for Fuka-Matrouh Region.* Dopervenk, Croatia: PapRak.

Raey, M., Nasr, S., Frihy, O., Bastaweisy, I., Hattab, M., Dawidar, K., et al. (1998b). *Tourism Carrying Capacity Assessment for Fuka-Matrouh Area.* Dopervenk, Croatia: PapRak.

Raey, M., Nasr, S., Hattab, M., Abdraboh, M., Elbastawisy, I., Mohammed, W., et al. (2000). *Strategic Environmental Assessment for Integrated Coastacl Area management Plan of Fuka-Matrouh.* Dopervenk, Croatia: PapRak.

UNCED. (1993). *Programme of Action for Sustainable Development.* New York: United Nations.

UNDP. (2004). *Egypt Human Development Report 2003.* Cairo: United Nations Development Program (UNDP).

Voogd, H. (1983). *Multicriteria Evaluation for Urban and Regional Planning.* London: Pioneer Press.

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