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Proposed Spatial Framework to Develop Land Use in an Environmentally-Sensitive Area: Case Study, El-Daba'a Region, Egypt Part I: Ecological Value Assessment Using GIS

إطار عمل مكاني مقترح لتطوير استخدام الأراضي في منطقة حساسة بيئياً: حالة دراسية، منطقة الضبعة، مصر الجزء الأول: تقييم القيمة الإيكولوجية باستخدام نظم المعلومات الجغرافية

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ABSTRACT: The aim of this study is to assess the ecological characteristics of El-Daba'a area in Egypt using GIS as a first step for the development of an environmental management plan for the area. The Absence of environmental planning in the process of land use development may cause many significant negative impacts on biodiversity, ecological value, and the general environmental conditions, and therefore, reducing such negative impacts will improve land use development. The first part of this sequel of two papers, which is part of a sustainable land use development research program, aims at designing a spatial framework to improve land use planning and development in an environmental context. The research program deals with the problem of land use planning and development in an arid coastal area under environmentally sensitive conditions. The study area is El-Daba'a region, located in the northwestern coast of Egypt, which can be described as a wild area. The approach used in this paper consists of studying the spatial ecological characteristics of El-Daba'a region using different spatial data including maps and Landsat remote sensing data. These data are used to create a series of superimposed informative layers managed by a geographic information system (GIS) to describe the spatial ecological characteristics of the study area. The developed GIS allows decision makers to handle large amounts of information simultaneously such as geology, geomorphology, land cover, wild life and many other different information layers. The system is designed to help decision makers to organize, relate, analyze, and visualize the ecological data and information in the study area. The developed GIS system might be used to determine the probable effects of building a nuclear power station on the ecosystem.

Keywords: *GIS, Ecological Value, Ecological Spatial Characteristics, Ecological Sensitivity Index.*

المستخلص: تهدف هذه الدراسة إلى تقييم الخصائص الإيكولوجيه لمنطقة الضبعة بجمهورية مصر العربية باستخدام نظم المعلومات الجغرافية، وذلك كخطوه أولى لوضع خطة إدارة بيئية للمنطقة. يؤدي عدم إدماج التخطيط البيئي في عملية

تطوير استخدامات الاراضي إلى العديد من التأثيرات السلبية على التنوع الحيوي والقيمة الإيكولوجية وحالة البيئة بشكل عام، ولذا فإن تخفيف مثل هذه التأثيرات سيؤدي إلى تحسين تطوير استخدامات الأراضي. تهدف هذه الورقة، والتي تمثل الجزء الأول من برنامج بحثي حول التنمية المستدامة لاستخدامات الأراضي، إلى تصميم إطار عمل مكاني في السياق البيئي لتحسين تخطيط وتنمية استخدام الأراضي ذات الحساسية البيئية في المناطق الجافة الساحلية. تقع منطقة الدراسة والمعروفة بالضبعة على الساحل الشمالي الغربي لمصر وتعتبر من المناطق البرية. ركزت المقاربة المستخدمة في هذه الدراسة على الخصائص الإيكولوجية المكانية لمنطقة الضبعة وذلك باستخدام بيانات مكانية (جغرافية) إشتملت على خرائط وصور القمر الصناعي Landsat. واستخدمت هذه البيانات لبناء مجموعة من الطبقات المعلوماتية المتطابقة التي وظفت لبناء نظام معلومات جغرافية لوصف هذه الخصائص في المنطقة. ويسمح نظام المعلومات الجغرافي الذي تم بناءه لمتخذي القرار بمعالجة معلومات منوعة تشمل الجيولوجيا والجيومورفولوجيا وغطاء الأرض والحياة البرية وغيرها من المعلومات في آن واحد. ولقد صمم هذا النظام بحيث يساعد متخذ القرار على تنظيم وتحليل واستكشاف العلاقات وعرض البيانات والمعلومات الإيكولوجية في منطقة الدراسة. واستخدم هذا النظام لأستكشاف الآثار المحتملة الناجمة عن إنشاء محطة للطاقة النووية على النظام البيئي للمنطقة.

كلمات مدخلية : *نظم معلومات جغرافية، القيمة الإيكولوجية، الخصائص الإيكولوجية المكانية، مؤشر الحساسية البيئية.*

INTRODUCTION

Egypt is the most populated country in the Arab League, with approximately 75 million inhabitants, representing about one-third of the total population of the Arab countries. With a growth rate of 1.87%, the population of Egypt is expected to be about 170 million inhabitants in the next four decades. More than 80% of Egypt land is classified as desert area occupied by less than 5% of the population, while 20% of the area is occupied by 95% of population (CAPMAS, 2006).

Since the first economic reform in the end of the 1970s, Egypt attempted to redraw the map of its population distribution by establishing many new settlements and supporting industrial development. This trend has been maintained through the country's second economic reform in the mid 1990s. By the eve of the new millennium, urbanization has extended to include different Egyptian frontiers such as Toshka region in the south and the Northwestern Coast. This widespread development has resulted in the increase in the demands for power energy.

For decades, the energy system in Egypt depended on the High Dam energy and the energy generated by a large network of thermal power stations. Different alternatives are proposed to extend the capabilities of the energy system. These alternatives are designed to be sustainable, economic and eco-friendly. Alternatives like wind power, tide power, nuclear power and sun power are studied. Based on these studies the nuclear power is chosen as the best alternative (SCE, 2000).

In the 1950s, researchers of the Egyptian Atomic Energy Establishment (EAEE) had identified the site of El-Daba'a as the most feasible site for establishing a nuclear power station to generate power to supply Alexandria Metropolitan and the Northwestern coast. This has kept El-Daba'a area out of the urbanization expansion that spread over the Northwestern coast. Currently, El-Daba'a area represents a model for the Northwestern coast ecosystems, of which the majority has been destructed, or at least deteriorated, as a result for the random and extensive urbanization.

It is anticipated that the increase in power demands will eventually lead to the establishment of a nuclear power station in El-Daba'a area. However, this would conflict with the national demand to maintain and preserve a model ecosystem. This study attempts to solve the paradox of the problem of development and conservation.

Ecological assessment based on spatial data analysis can provide an efficient and cost-effective approach for acquiring up to date and accurate habitat level information (Prato, 2005; Gontier, *et al.* 2006; Gontier, 2007) for use by resource planners, researchers, and conservationists. Spatial tools, namely GIS and remote sensing, have been used to map ecological characteristics in various sites and for various objectives (Zandbergen, 1998; Geneletti, 2004; Roy, *et al.* 2005; Stefanov and Netzband, 2005; Yue, *et al.* 2006; Bertazzon, *et al.* 2006; Barbour, *et al.* 2007; Wimberly and Reilly, 2007; Williams, 2007) including the Northwestern coast of Egypt (Mohammed, *et al.* 2000; Raey, *et al.* 2005; Raey and Mohammed, 2006).

The methodologies adopted by these research works typically utilizes GIS in merging topographic maps, thematic maps, remote sensing data, field survey data, and censuses to provide a comprehensive geospatial database. These are managed by a set of powerful analytical tools to identify the spatial and quantitative relations between ecological elements and socioeconomic circumstances.

The objective of this study is to assess the ecological characteristics of El-Daba'a using GIS as a first step for the development of an environmental management plan for the area. The assessment objectives is intended for 1) identifying the local species geographic distribution; 2) mapping the natural habitats of these species; and 3) identifying the spatial properties of these habitats.

STUDY AREA

El-Daba'a area (Fig. 1) is located in Matrouh Governorate in the Northwestern coast region of Egypt, about midway between Alexandria city 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 occupies an area of about 254 km² (about 21.5 km long and about 11.8 km wide)The study area northern border is the Mediterranean Sea, while its southern border is the Matrouh Plateau (Fig. 2). The basic man-made features in the study area is the "International Coastal Highway" and the "railway line", both run in the east-west direction. The International Coastal Highway divides the area into two parts. In the northern part the basic land use is agriculture, while in the southern part the main land uses, respectively in their size, are urban, agriculture and grazing. El-Daba'a Town, located

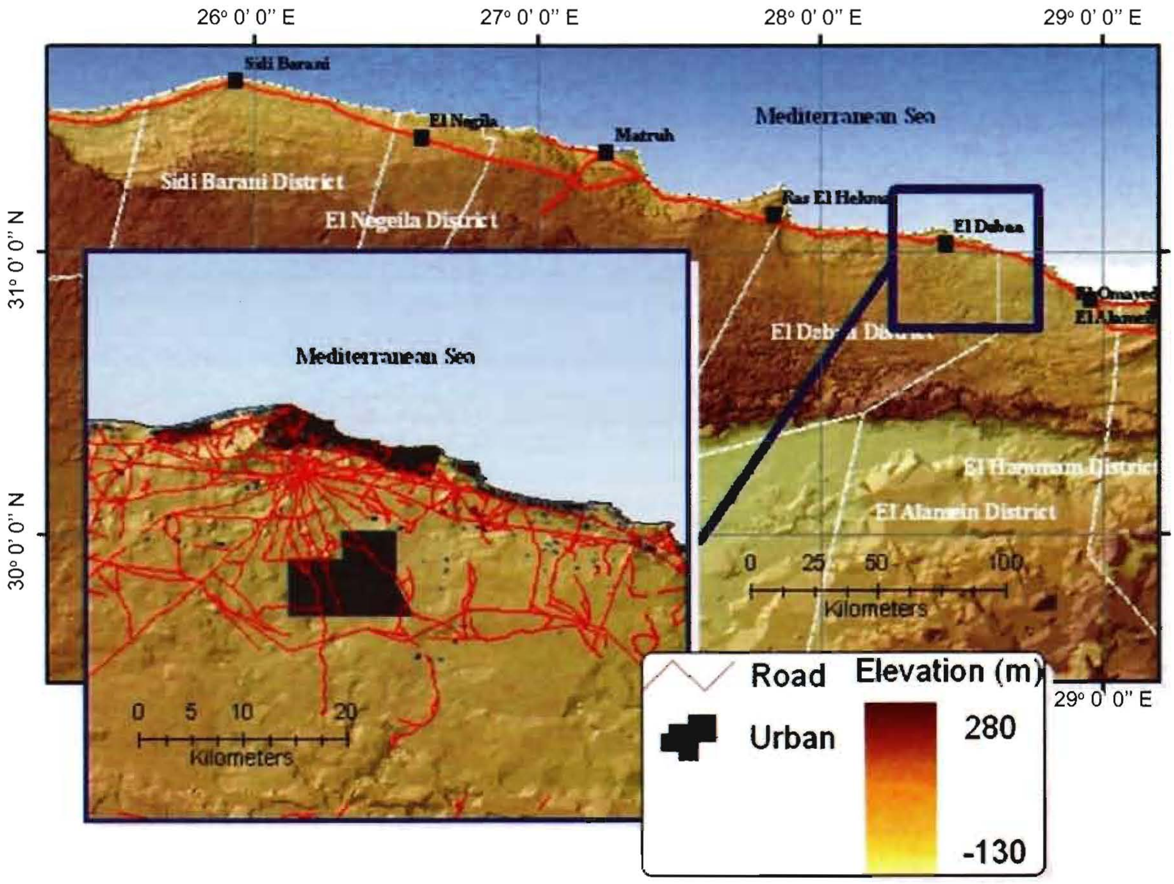

Fig. 1. Location map of the study area.

south of the Highway, is the main settlement in the study area. Different tiny villages are scattered in the area between the International Coastal Highway and the railway. These scattered settlements belong to "El-Daba'a Town Municipality". The population of El-Daba'a Municipality was approximately 12,000 inhabitants in 2006 (IDSC, 2007). Most of the population is resident in El-Daba'a Town, while the little scattered villages are inhabited by the local people, called Bedouin.

The climate of El-Daba'a is hot-dry in summer and rainy-warm in winter. It is affected with the contrary wind from the Mediterranean Sea in winter, and the northern wind from Europe in summer. Dust storms arise periodically in spring and autumn from the southwest. The annual average temperature of the region is about 21°C, and receives average precipitation rate of about 138 mm, with average humidity levels of 67% (NRC, 1987).

In the study area, there are four ecological habitats that have been recognized. These are wadies, gravel plains, sand dunes and wetland (Kassas, 1993). The habitats are dominated by *Thymelaea hirsute* (Zahran and Willis, 1992). These habitats support a wide range of animal life. Distinctive birds include the Barbary Partridge *Alectoris barbara*, Dupont's Lark *Eremophila bilopha*, and Red-rumped Wheatear *Oenanth moesta* (Goodman *et. al.* 1989). Characteristic mammals include the Long-eard Hedgehog *Hemiechinus auritus*, Cape Hare *Lepus capensis*, Anderson's Gerbil *Gerbillus andersoni*, Shaw's Jird *Meriones shawi*, Fat Sand Rat *Psammomys absus*, Lesser Molerat *Spalax leucdon*, Middle Eastern Dormouse *Eliomys melanurus*, Greater Egyptian Jerboa *Jaculus orientalis*, and Four-toed Jerboa *Allactaga tetradactyla* (Hoath, 2003). Reptiles include Moorish Gecko *Tarentola mauritanica*, Northern Elegant Gecko *Stenodactylus mauritanica*, Changeable Agama *Trapelus mutabilis*, and Small-spotted Lizard *Mesalina guttulata* (Baha El Din, 2006).

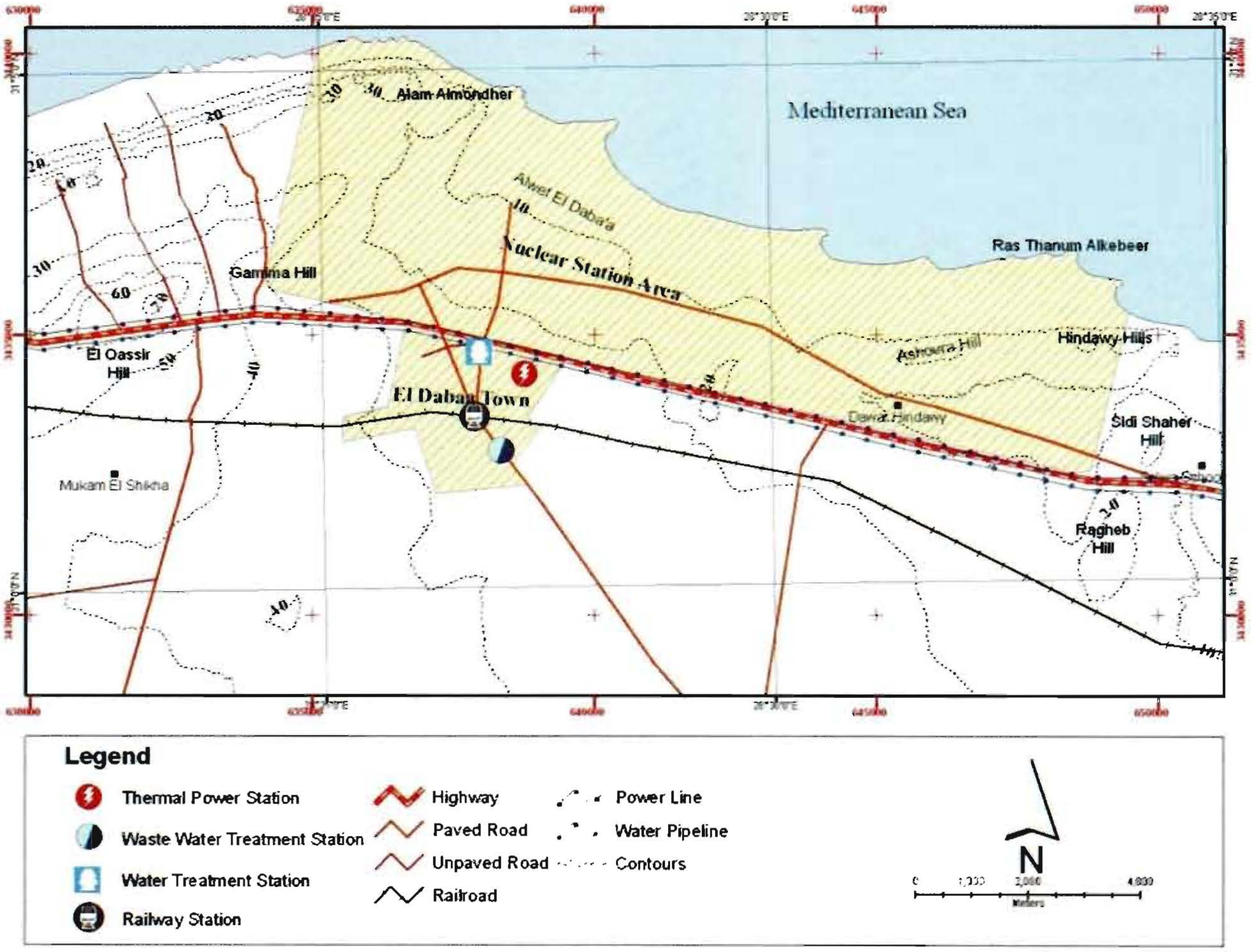

Fig. 2. Study area map.

MATERIALS

Data Availability

Species Data

The data of species sighting sites are collected by Matrouh Resource Facility administrated by Environmental Affairs Authority. These data describes 28 sites for 10 species sighting. These species are five mammals (*Gerbillus andersoni, Lepus capensis, Psammomys absus, Jaculus orientalis,* and *Hemiechinus auritus*), two birds (*Alectoris Barbar* and *Eremophila bilopha*), and three reptiles (*Tarentola mauritanica, Stenodactylus mauritanica,* and *Mesalina guttulata*). Each site is identified by its geographic location where this location is accompanied by the species classification, English common name, scientific name, and local Arabic name.

Spatial Data

Spatial data included the maps and satellite images that are used to develop the geodatabase. Two topographic maps are used to create most of the base map features such as power line, railroads, and roads. These two maps are titled El-Daba'a and Ras Abu Kharouf, produced by the Military Survey Unit in 1996. Both maps are scaled to 1:50000 and projected to Universal Transverse Mercator *UTM* – Zone No. 35N with 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* is used in this study. The image is dated 4 September 2002. The image is rectified to UTM 35N / WGS 84 by the provider, and included six bands of 28.5 m spatial resolution and single panchromatic band of 14.25 m spatial resolution. Two bands – which are thermal bands 61 and 62 - are removed from the image, due to their irrelevance for the analysis scheme used in this study.

Field Surveys

Three expeditions through the period of December 2004 to July 2006 were made to the study area. The objectives of these three expeditions are to collect the ground truth data for satellite image processing and to collect data to develop map for natural habitats.

METHODOLOGY

The methodology used in this paper attempts to combine the pervious data into one geodatabase. In this context, the work of this study is presented in two phases: I) geodatabase development; and II) GIS analysis.

Phase I included producing of a base map showing the principal features of the study area, such as roads, by digitizing the topographic maps. These features are updated using the panchromatic Landsat 7 ETM band data. The contour lines and highs spots in the topographic maps are used to produce Digital Elevation Model (DEM), which is utilized to create another terrain features maps like slope and aspect. The species data are drawn with their attributes. Moreover, image processing was used to produce land cover map from Landsat 7 ETM multispectral bands. These products are stored in a ArcGIS/ArcInfo personal geodatabase format, where spatial relationships are established to understand the relation between species and habitats.

Phase II included an analysis of the spatial data using proximity analysis to conclude the counter-area for the different species and zonal statistics to identify the spatial properties for habitats and counter-areas.

Geodatabase Schema

ArcGIS/ArcInfo 9.x Personal Geodatabase Schema is used to store the data produced in phase I. The schema of this geodatabase is shown in Table 1. As indicated in the table, the geodatabase includes six feature datasets. The first feature dataset is BASE feature dataset, which includes the principal feature classes that defined the study area. These feature classes are: BASEMAP feature class which is polygon geometry defining the terrestrial and marine areas; LANDMARK feature class which is point geometry identifying the location of main land marks; LANDOWNERSHIP feature class which is polygon feature to map the authority of El-Daba'a Town and El-Daba'a Nuclear Power Station; and MASK feature class which is a polygon geometry identifying the area of interest for raster analysis processes.

The second feature dataset is ECOLOGY. This feature dataset includes two feature classes, FAUNA and NATURAL_HABITAT. FAUNA is point geometry to describe the sighting sites of species. NATURAL_HABITAT is polygon geometry feature class identifies the natural habitats area. There is also a spatial relationship which named FAUNA_HABITAT, which defines relationships between FAUNA feature class and NATURAL_HABITAT feature class to show what is the habitat of an identified species sighting site and *vice versa*.

The third feature dataset is FACILITIES dataset, which includes four feature classes: FACILITIES feature class is point geometry showing some main facilities such as water stations and waste water treatment stations; POWERLINE and WATERPIPELINE are line geometry showing the main power line and water pipe line in the study area respectively; and WATERWELL which is point geometry for artesian and non-artesian water wells in the study area.

The fourth feature dataset is Topography dataset, which include a line geometry feature class called CONTOURS to represent the contour lines from the topographic maps and point geometry feature class called ELEVATIONPOINTS to store the height spots in the study area.

The fifth feature dataset is Transportation feature dataset, which includes two feature classes: point geometry feature class called RAILSTATION to show the rail stations in the study area and ROADS feature class which is a line feature that stores the roads and railroad data in the study area.

In addition to these feature datasets, there are four raster datasets to represent the hypsographical features, which are the digital elevation model DEM, aspects ASPECTS, slope in percentage SLOPE_P, the hill shades HLSHAD, and the final enhancement Landsat 7 image. Furthermore, an annotation feature class is stored in the geodatabase to present the map label.

Table 1. Geodatabase Schema.

Dataset	Data Class	Geometry	Attributes
Base	Basemap	Polygon	Type – Area – Length
	Land Ownership	Polygon	Title– Area - Length
	Mask	Polygon	MaskID– Area - Length
	Landmark	Point	Title
Ecology	Fauna	Point	Species – SightingDate
	Natural_ Habitats	Polygon	Title – Area - Length
Facilities	Facilities	Point	Title
	Waterwell	Point	Title – Type
	Powerline	Line	Title – Length
	Waterpipeline	Line	Title – Length
Topography	ElevationPoints	Point	Elevation
	Contours	Line	Elevation
Transportation	RailStation	Point	Title
	Roads	Line	Title – Type – Length
Hypsography	DEM	Raster	Elevation
	ASPECT	Raster	Aspect in Degree
	SLOPE	Raster	Slope in percentage
	HLSHD	Raster	Hill shade
	EnhancETM	Raster	Enhanced satellite image.

GEO DATABASE DEVELOPMENT

Geodatabase development for the ecological assessment of the study area included a number of activities. These activities are described below.

Data Vectorization

The topographic maps described before were used to extract different features. To conduct this activity, these maps are scanned and vectorized using ArcScan extension for ArcGIS/ArcInfo 9.x software. The products of vectorization are edited to remove scanning and vectorization error then stored in the geodatabase. The stored data are updated by comparing it to the satellite data in the field. Data vectorization included also converting the descriptive data for species sighting sites to point geometry feature class and producing habitat map from field survey.

Terrain Feature Mapping

The contour lines, vectorized before, are converted to point geometry and merged to height spots to produce one feature class. This feature class is fed to the Inverse Distance Weight (*IDW)* interpolation algorithm to produce digital elevation model DEM for the study area. The DEM is used to conclude the other terrain features like aspect, slope and hill shades. The digital elevation model is shown in Fig. 3.

Land Cover Mapping

Image processing of Landsat 7 ETM data produced the land cover map in two sub-activities, data enrichment and data classification. Image processing was achieved using Erdas Imagine 9.0 software. These two processes are described below.

Data Enrichment: Data enrichment is a technique used to enhance the spatial resolution of satellite imagery by merging it to high resolution imagery. Landsat 7 ETM+ dataset include 28.5 m spatial resolution multispectral data and 14.25 m spatial resolution panchromatic band. Merging multispectral data to panchromatic data produces new multispectral dataset with 14.25 m spatial resolution. The result of this task is shown in Fig. 4.

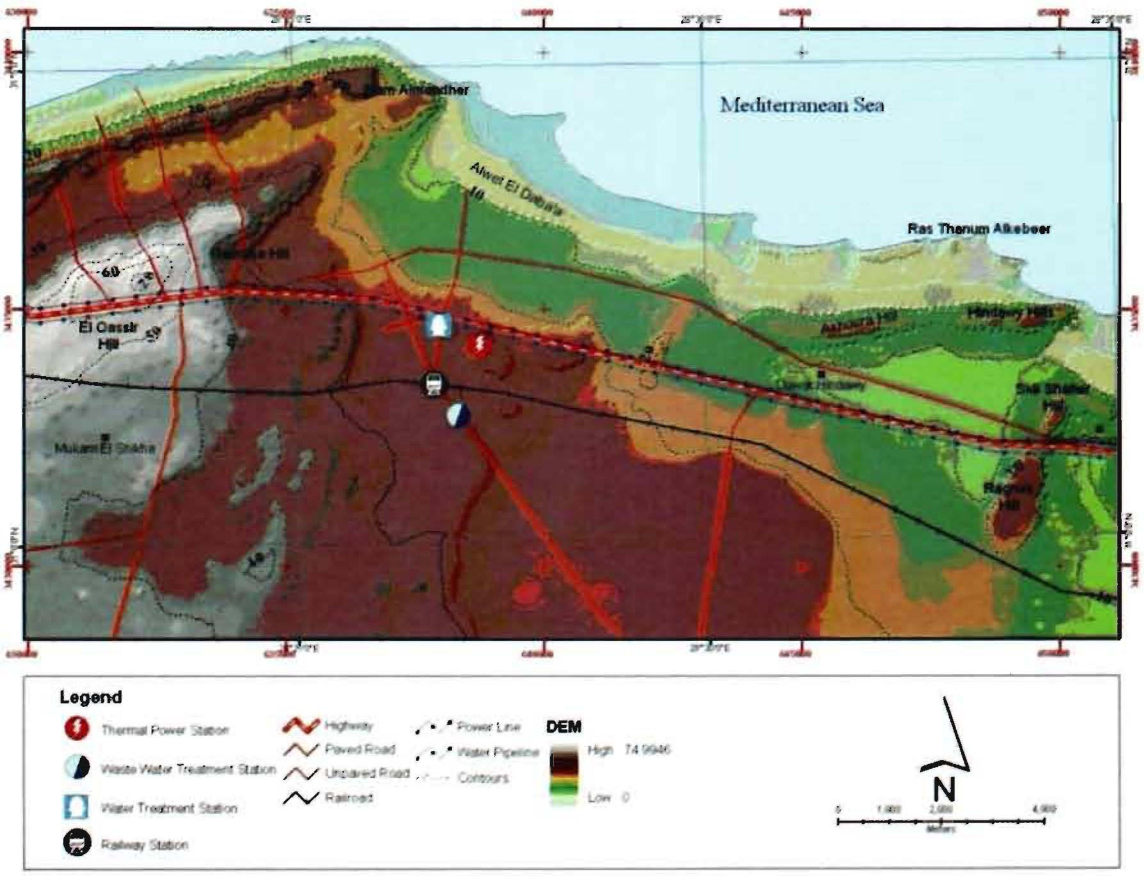

Fig. 3. Digital Elevation Model for the Study Area.

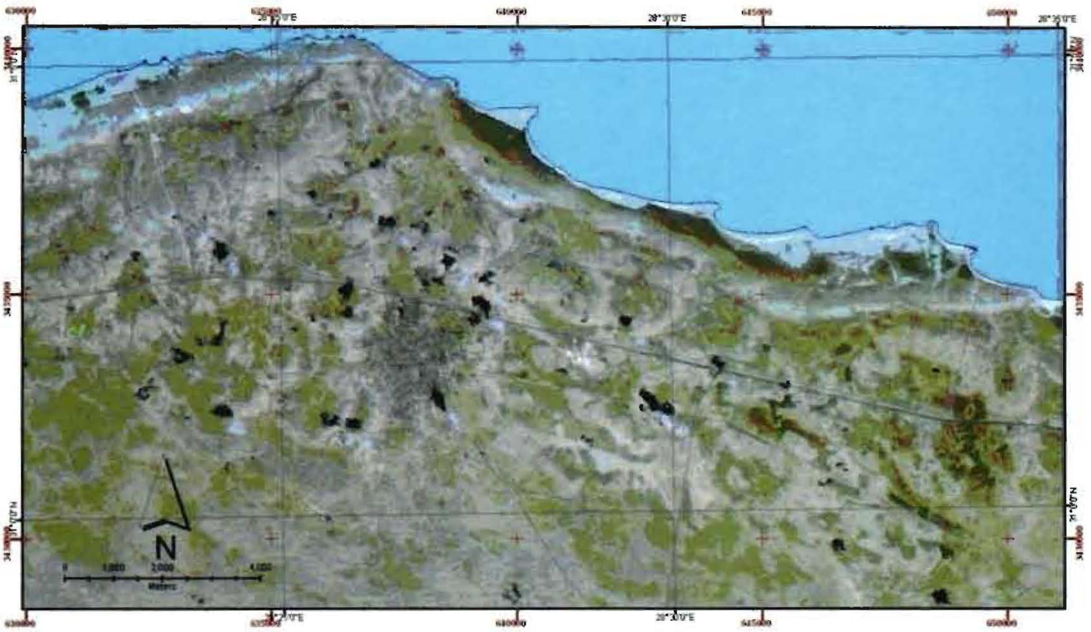

Fig. 4. False Color Composite (RGB:742) for Spatial Enriched Landsat 7 ETM Multispectral Dataset.

Image Classification: The data used for this task included Landsat ETM+ image and field observation in the same period of image acquisition. Through field visits, six land cover classes are identified in the study area. These classes are defined based on the Classification scheme for Northwestern Coastal Area (Mohammed *et al.*, 2000). These classes are urban, shrubs, sandstone, sand, orchards and dense vegetation.

Both of the enriched image and field observation are used to generate a group of signatures. These signatures are designed to be completely representative for the land cover classes in the study area. The processes of signature development included assigning locations of training samples of the required signatures, creating statistical parameters of the signatures, and testing both separability and contingency of these signatures to be accepted and activated.

The accepted signatures were fed to "maximum likelihood classifier" to classify the subset image. The product is a primary land cover thematic map. To create the final land cover thematic map, the primary land cover map accuracy is calculated, which is equal to 92.6%. Therefore, the primary land cover map is considered to be final map and is presented in Fig. 5.

SPATIAL ECOLOGICAL PROPERTIES ANALYSIS

Ecological properties in the context of this paper are defined by two factors; the natural habitat map and the counter area map. Natural habitat map was drawn by field survey. To draw counter-area map, simple procedure was used. This procedure is based on proximity analysis. Using species sighting sites – FAUNA feature class - as a source input data for Euclidean distance analysis procedure, new polygon feature class is produced. Each class in this feature class is identified as a counter area for a specific species. The counter area is defined spatially as the area close to the specific species more than other species, and in the ecological context is the area dominant by the individuals of the considered species.

Spatial ecological properties assessment means identification of the dominant spatial properties in each natural habitat area and in each counter-area. To identify this feature a set of zonal statistics were achieved where natural habitat polygon feature class and counter-area polygon feature class are used as a zonal map and the variables are LANDCOVER, DEM, SLOPE_P, ASPECT raster datasets. Merging species sighting sites, counter-area and natural habitats produces the ecological map for the study area, which is shown in Fig. 6, while the spatial properties of species counter-area and natural habitats are presented in Table 2 and Table 3, respectively.

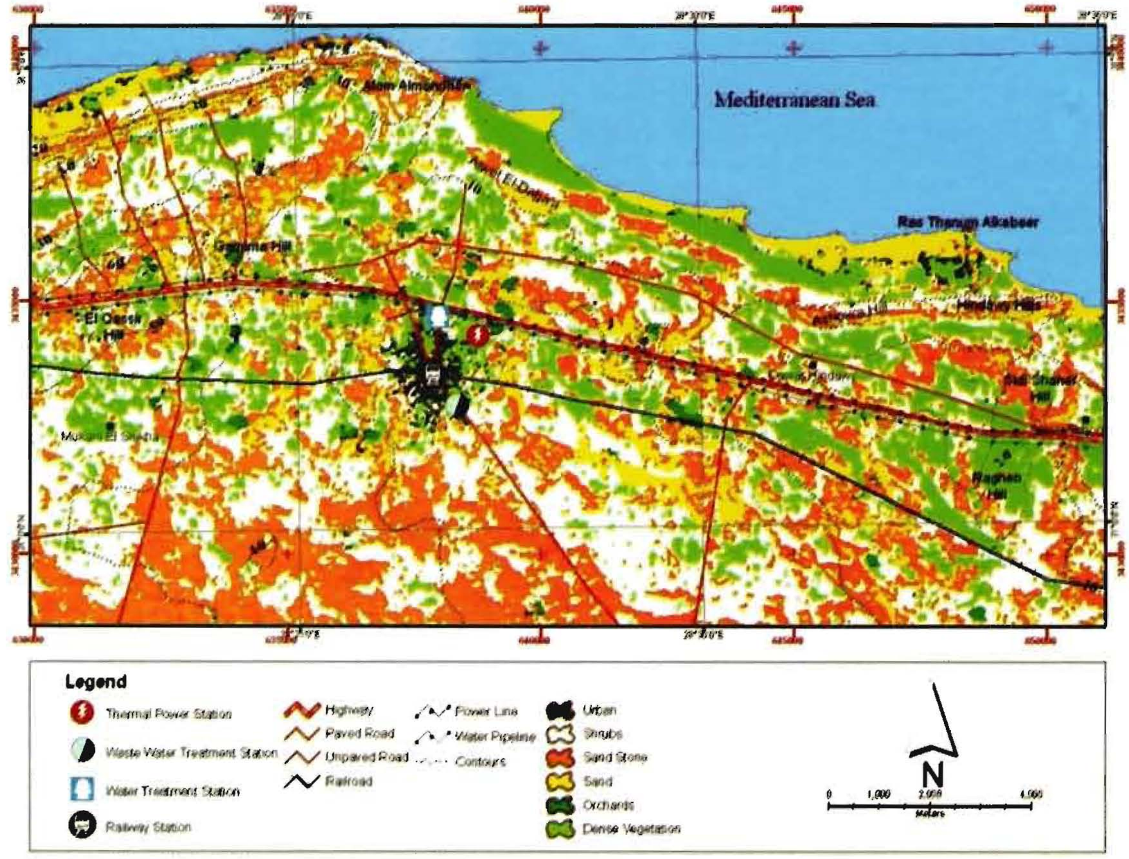

Fig. 5. Land Cover Map of the Study Area.

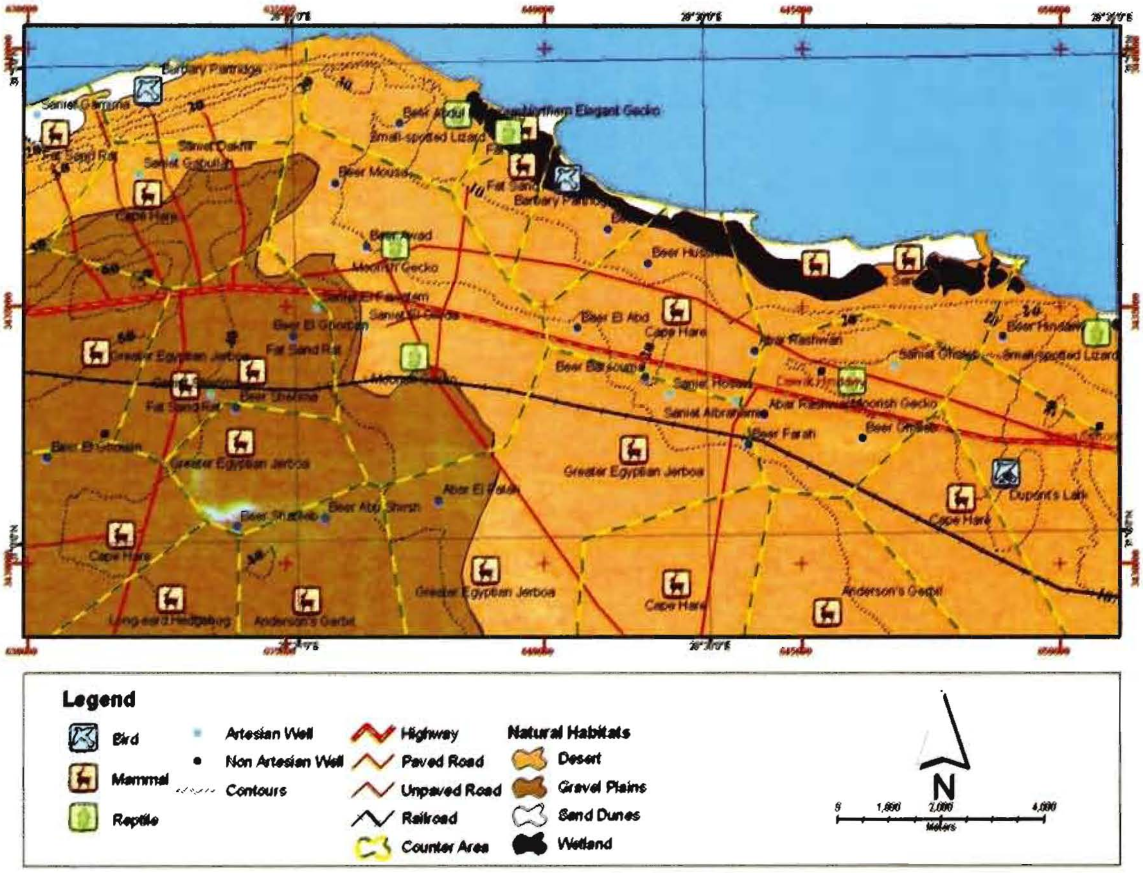

Fig. 6. Ecological Map for the Study Area.

Table 2. Spatial Properties for Species Counter-Area.

Species	Dominant Land Cover	Mean Elevation	Mean Slope	Mean Aspect
Alectoris barbara	Shrubs	12.60	1.52	149.16
Eremophila bilopha	Shrubs	12.58	0.55	107.90
Gerbillus andersoni	Sand Stone	28.86	0.21	77.57
Hemiechinus auritus	Sand Stone	38.87	0.34	164.62
Jaculus orientalis	Shrubs	33.14	0.47	110.75
Lepus capensis	Shrubs	25.66	0.63	126.66
Mesalina guttulata	Shrubs	12.75	1.53	152.99
Psammomys obesus	Shrubs	21.47	0.98	153.53
Stenodactylus mauritanica	Dense Vegetation	1.57	0.36	45.98
Tarentola mauritanica	Shrubs	21.24	0.52	105.74

Table 3. Spatial Properties for Natural Habitats in the Study Area

Habitat	Dominant Land Cover	Mean Elevation	Mean Slope	Mean Aspect
Gravel Plains	Shrubs	38.24	0.66	145.01
Sand Dunes	Sand	3.80	1.10	146.75
Desert	Shrubs	18.17	0.70	110.30
Wetlands	Dense Vegetation	3.20	0.43	103.69

RESULTS

It can be seen from Table 2 and 3 that the most important land cover for the biodiversity in the study area, in their order of importance, are sand, dense vegetation, sand stone and shrubs. This order is based on the area covered by these classes. Therefore, these land cover classes are the dominant in the natural habitats and counter-areas for species. Then, the importance of land cover class is defined by scarcity of the simple ecosystem composed of this land cover and the species that occupy it.

Using these tables and the ecological map for the study area shows that the coastal area which has an elevation of less than 25 m above sea level and average slope of less than or equal to 1% are rich with five species from the ten considered species. Based on this information, a simple spatial ecological sensitivity index *SESI* is designed to illustrate the ecological sensitivity of the area and to aid in its management planning. The SESI illustrates the sensitivity based on two consecutive rules. These are:

- All areas that have an elevation of less than or equal to 25 m above sea level and have a slope of less than or equal to 1% are considered as ecologically sensitive area; and
- Each land cover class within the main sensitive area is considered as a sensitive sub-area according to the fragility of this land cover. *Fragility* of the land cover class is inversely proportional to the area occupied by this land cover class. It points to the high potential of this land cover class to be lost in the future under the current circumstances.

Based on the second rule, four sub-areas had identified, and are ranked from 1 to 4, where 1 means the most sensitive area, and 4 means the least sensitive area. The areas occupied by sand are considered as the most sensitive area because the sand is the smallest area among the dominant land cover classes. The second sensitive area is the area occupied by dense vegetation. The third is the area occupied by sandstone. The less sensitive area is the area occupied by shrubs. Fig. 7 shows the spatial ecological sensitivity index for the study area as produced by the implemented rules.

To map the SESI inside both of El-Daba'a town and the nuclear power station area, the land ownership map and SESI map are superimposed and the attribute data of these layers are merged into the attribute of the result map to describe the area of each sensitive area in the nuclear power station area and in El-Daba'a Town. Table 4 shows a comparison for the area of each sensitive sub-area in the power station area and in El-Daba'a town.

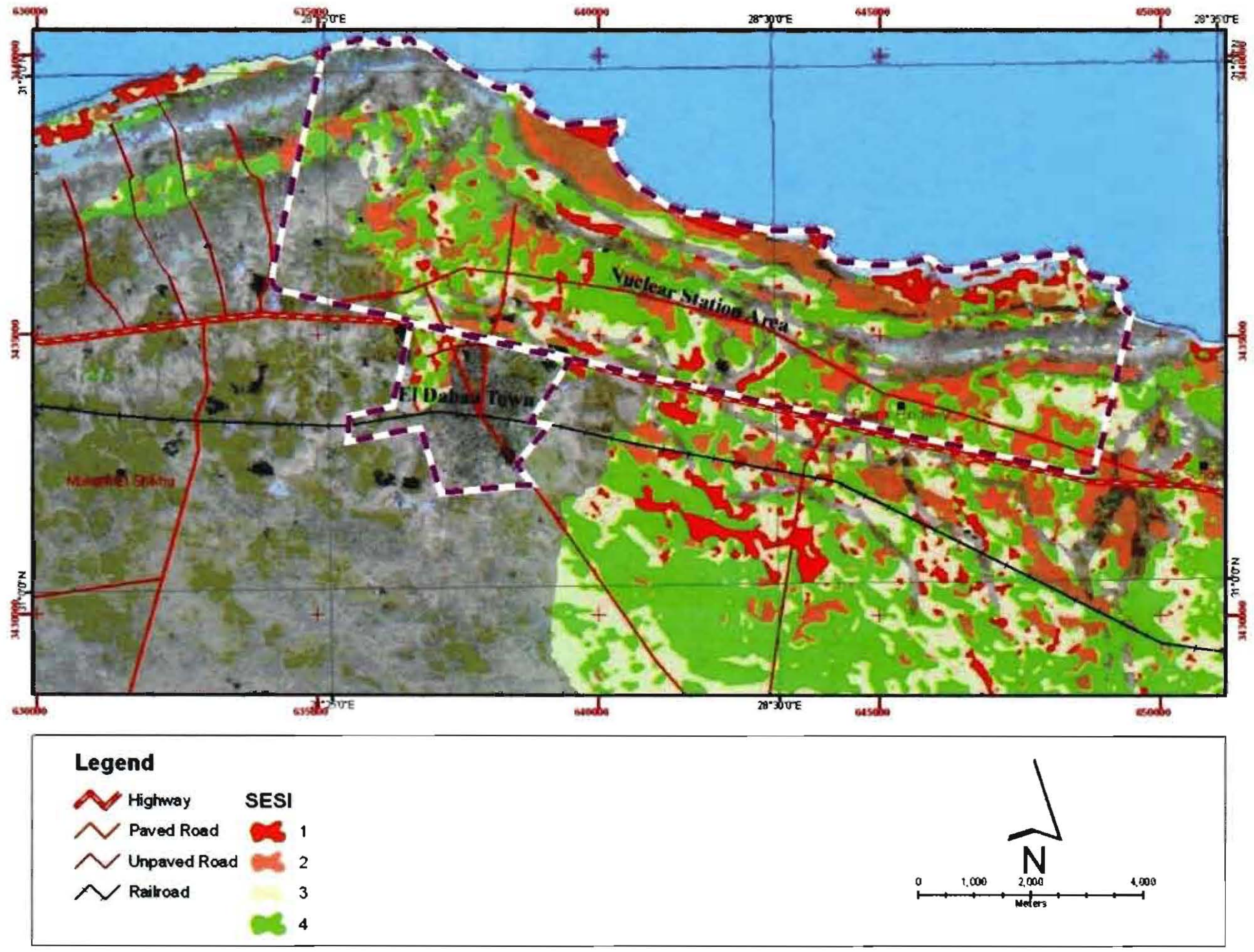

Fig. 7. Spatial Ecologic Sensitivity Index SESI map.

Table 4. Area of Each Sensitive Area in the Power Station Area and El-Daba'a Town.

SESI	Power Station Area (m^2)	El-Daba'a Town (m^2)
1	3763172.47	165628.08
2	11655132.60	145565.92
3	7105038.79	371665.41
4	11975257.75	278709.25

CONCLUSION

The sensitive areas in the area allocated for the nuclear power station are larger than those in El-Daba'a Town. Therefore, it is important to take into consideration the preparation for an environmental management plan to conserve the ecological characteristics of El-Daba'a region, especially, if a decision is made that the project of the nuclear power station is to start.

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