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Land Suitability Modeling of Natural Vegetation Using Integrated Remote Sensing and GIS Techniques: A Case Study

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Abstract: The objectives of this research was to facilitate the application of spatial modeling to the study of complex multi-scale vegetation-identity processes at Gulf of Suez area, Egypt. Land suitability spatial models have evolved to provide Remote Sensing (RS) and Geographic Information Systems (GIS) users with the proper tools for which to resolve complex geo-analytical problems. Given these tools, the user is able to make well informed decisions based on the problem at hand. The issue of suitable site, including analysis and selection, is a task that is well suited for such a system. The overall goal of spatial modeling may be to understand how assumptions, parameters and variation associated with the input data and how models affect the resulting output data and the conclusions made from them. Spatial and geostatistical analysis tools were used to design Land Suitability Spatial Model (LSSM). LSSM is a spatially designed model that depends mainly upon interpolation, scaling, weighting overlay, conditional and algebra statements, general filtering and site selection techniques. Using LSSM, spatially distributed sites of natural vegetation with different species were accurately defined. Plant and soils relationship was discussed showing the interaction occurs between them. Applying LSSM, different species of natural vegetation could be identified and grouped into three categories as follows:- 1-Group (A) *Alhagi maurarum, Cressa cretica and Tamarix nilotica.* 2-Group (B) *Zygphollum coccineum, Ochradenis baccatus, Acacia chrenbergiana, Halcocnemum strobiliaceum and Nitraria retusa.* 3-Group (C) *Parkinsonia aculata, Zilla spinosa, Limonium pruinosum, Haloxylon salicornicum* and *Fagonia Arabica.*

Key words: Natural vegetation, geostatistical analysis, spatial analysis, modeling

INTRODUCTION

Gulf of Suez area is singled out by the national scientific and conservation community as one of the richest communities in Egypt in terms of biodiversity, endemism and range of habitats. Its flora is diverse and unique. The economic and medicinal value of the flora of this area, both to the local peoples and in a global sense, is potentially immense. Despite its importance, this flora is under serious threat. Over 80% of the area has already been stripped of its native vegetation cover which is deteriorated by over grazing and subjection to intense erosion. Grazing by domestic livestock is the main cause of disturbances for the vegetation. Periodic flooding, as a natural disturbance, regulates growth and survival of vegetation. Quantification of species diversity and the extent of disturbance by humans and livestock is important for future management of the vegetation[1]. The immediate goals of the environmental monitoring program include the identification and quantification of the effect of site activities on the environment using state of the art techniques[2]. Nowadays, Remote Sensing and GIS techniques could be considered the most important tools for modeling and identifying natural vegetation. Researchers and scientists are applying remote sensing and geographic information systems techniques to a variety of site related tasks that are spatial in nature[3]. Among the most current and well established applications of GIS are complex forms of spatial analysis such as facility planning, site selection and land use planning[4]. While the use of GIS and automated mapping sciences have been used in previous site planning investigations[5-7], hands-on access to the technology remains mostly limited to a small group of trained and technically capable users. Land suitability models have evolved out the need to provide GIS users with the proper tools for which to resolve complex geo-analytical problems.

MATERIALS AND METHODS

Location: The investigated area lies between 29°32′ 40″ and 30°00′ 42″ Latitudes and 31°58′ 02″ and 32° 28′ 54″ longitudes, adjacent to the Gulf of Suez, Egypt.

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Climate: Mean annual rainfall is running around 10 mm/year putting into consideration the seasonal flash floods that hitting the land from the surrounding highlands. The maximum values of temperatures reach their highest value in August (36.2°C). January represents the coldest month (18.5°C). The minimum temperatures range between 7.5°C in January to 20.7°C in August. Relative humidity reaches its maximum of 64 in December; meanwhile it reaches its minimum of 22 in March. Wind velocity ranges between 6.3 and 9.4 km h^{-1} all over the year.

RS work: Digital image processing of Landsat 7.0-ETM+ satellite images dated to year 2005 was performed as follows:

- Data manipulation including image stretching, filtering and histogram matching[8].
- Rectification of satellite images using ERDAS IMAGINE 8.7.
- Enhancing the ground resolution from 30 to 15 m, fusion methodology was applied[9].
- Producing image mosaic from two Landsat 7.0 ETM+ satellite images that cover all the area using ENVI 4.1 software. Normalized difference Vegetation index NDVI was generated from ETM+ 3 and 4 bands.

Field works: Field studies included the following:

- Detailed survey of soil and natural vegetation species.
- Verification of the primary mapping units.
- Digging thirty five soil profiles for the purpose of the current work.
- Morphological description according to the FAO[10].
- Soil sampling for physical and chemical analyses.
- Plant sampling for morphological description.

Laboratory analysis: Soil samples were dried at 40°C, ground and passed through a 2 mm sieve. Material greater than 2 mm in size was discarded.

Physical analyses: Particle size data on the archived soil samples were obtained by dry sieving method. Moisture Content% (MC) and Water Holding Capacity% (WHC) were calculated according to Rowell[11]. Soil color (dry) was identified with the aid of Munsel color charts[12].

Chemical analyses: Salinity represented by T.S.S%, $CaCO_3$%, OM%, pH (1:2.5 extract), were determined according to Rowell[11].

GIS works: User interface design and incorporation of the analytical suitability model was done by customizing ARC GIS version 9.0. LSSM was designed and its procedures could be summarized as follows:

- Interpolating points to raster of Texture, OC, TSS, $CaCO_3$, pH, WHC, MC and Normalized Difference Vegetation Index (NDVI).
- Reclassifying data sets to a common scale.
- Weighting reclassified datasets that are more important to consider.
- Using conditional/algebra statements and site selection tools.
- Combining the data sets to find the most suitable location for specific vegetation species.

RESULTS AND DISCUSSION

Vegetation modeling: The GIS and vegetation classification systems in conjunction with numerous remote sensing methodologies and computer-based automated field mapping techniques have been indispensable tools in the process of vegetation modeling. Modeling of ecological and vegetational features requires recognizing Terrain/soil characteristics, plant behavior (adaptation) towards the adjacent environment in addition to the interaction between plant and soils.

Terrain/Soil characteristics

Terrain of the investigated area: Terrain of the investigated area could be divided into four main landforms:

- Red sea beach.
- Mountainous area.
- Sandy plain.
- Dry valleys.

The natural vegetation species are spread over the coastal zone area adjacent to the Red Sea beach, so the current study focused on soil and vegetation of such area.

Soil characteristics: Natural vegetation reflects soil characteristics and could be considered one of the most important indicators that measure variation through the investigated sandy plain. Soil of this plain have different pattern of sedimentation, where their texture classified into sand, loamy sand and sandy loam. Moisture content ranges between 8.3 and 12.9%. Water holding capacity fluctuates between 31.1 and 41.4%. Both of moisture content and water holding capacity are correlated with clay and organic matter contents. Soil reaction, pH values lie in the range of 7.2 and 7.8. Calcuim carbonate differ between 15.7-17.5%. Segregation and fine rounded concretions were found during the morphologic description. Organic matter content ranging between 0.17-2.0. The upper values of OM may be due to humified residuals of fish that noticed clearly during field survey. Total soluble salts are ranging between 1.5-1.8%. Values of salinity meet the requirement of Salic horizon. According to USDA[13], the investigated soils could be classified as Calcic Aquisalids, Calcic Haplosalids and Typic Haplosalids.

Soil criteria/vegetat-requirements: Soil criteria and vegetation requirements exhibit a wide range of variation through different localities. Table 1 shows soil criteria/vegetation requirements.

Adaptation to ecosystem: Gulf of Suez area is a semi-arid desert. Harsh desert conditions, such as high and low temperatures, scarcity of water and lack of soil nutrients, make it difficult for many plants to survive.

Natural vegetation species have adapted to their surroundings. They have changed in such ways that help them to conserve water and grow in the very poor desert and salty soils. Plants of the investigated area have many adaptations to cut down the water loss. The stomates are smaller and there is less number of them. Plants also have adapted to the extremes of heat and aridity by using both physical and behavioral mechanisms. The studied area perennials often survive by remaining dormant during dry periods of the year, then springing to life when water becomes available. Most of perennial plants germinate only after flashfloods occur and then complete their reproductive cycle very quickly. They bloom prodigiously for a few weeks in the spring, accounting for most of the annual wildflower explosions of the deserts. Their heat- and drought-resistant seeds remain dormant in the soil until the next year's annual rains[14]. Plants differ in their behavior if adaptations, for instance, species of *Zygophyllum* that are common in the study area have an additional adaptation: their green organs are divided into units. In times of drought a certain number of the units dry up and fall off so that the remainder of the plant is protected and does not wilt completely. In *Zygophyllum* the leaf is divided into a petiole on which sit two leaflets, each of these units can separate and fall off.

Plant and soil interaction: Plant communities are affected by the fine sediments which may retain seeds stem or root fragments and specialized organs such as tubers or turions[15]. Soils of the studied area are mainly formed of coarse sand and high salinity. The underground water is deep, except for some locations. The distribution of the community types within the surveyed area is mainly affected by soil attributes and the ability of species to adapt themselves against the prevailing conditions[16]. Gulf of Suez terrain causes concentration of available water in certain areas (water courses in sandy coastal plain), where the plants may live. That could be

Table 1: Soil criteria/vegetation requirements

Edaphic factors	Vegetation groups A	B	C
Coarse sand%	26.3±8.9	35.1±8.3	11.7±1.3
Medium sand%	51.1±2.7	47.6±5.5	55.7±3.7
Fine sand%	12.6±5.1	8.7±0.1	22.8±5.2
Clay%	16.0±5.3	7.0±3.3	13.5±3.8
Moisture Content (MC)%	8.3±1.5	10.1±5.4	11.1±6.8
Water Holding Capacity (WHC)%	36.5±4.8	31.7±10.3	41.1±2.5
Calcium Carbonate ($CaCO_3$)%	17.3±1.6	15.7±1.1	17.5±1.5
Organic Carbon (OC}%	0.9±0.1	1.1±0.2	0.4±0.1
pH (1:2.5 extract)	7.6±0.3	7.5±0.2	7.2±0.2
Total Soluble Salts (TSS)%	1.7±0.9	1.6±0.6	1.5±0.6

Source: After Abd El-Fatah and Dahmash, 2002

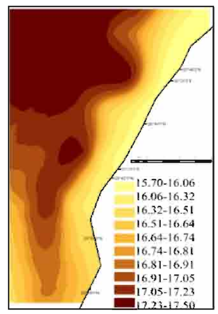

Fig. 1a: $CaCo_3$

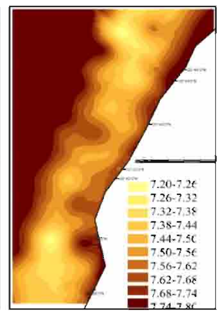

Fig. 1b: pH

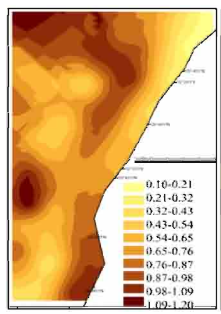

Fig. 1c: Organic Carbon

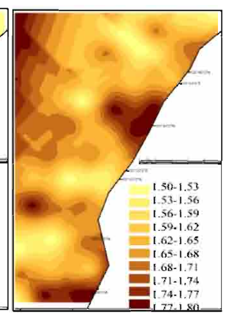

Fig. 1d: Total Soluble Salts

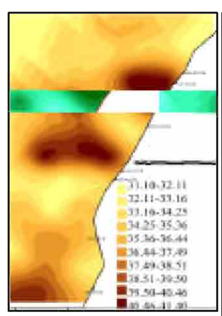

Fig. 1e: Water holding capacity

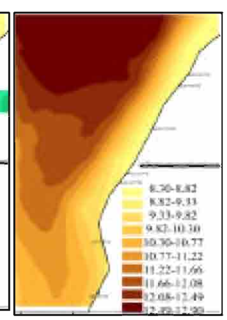

Fig. 1f: Moisture contents

considered as one aspect of microhabitat phenomena. Abd El-Fallah[17] stated that the shortage in soil moisture was the most effective environmental factor affecting the

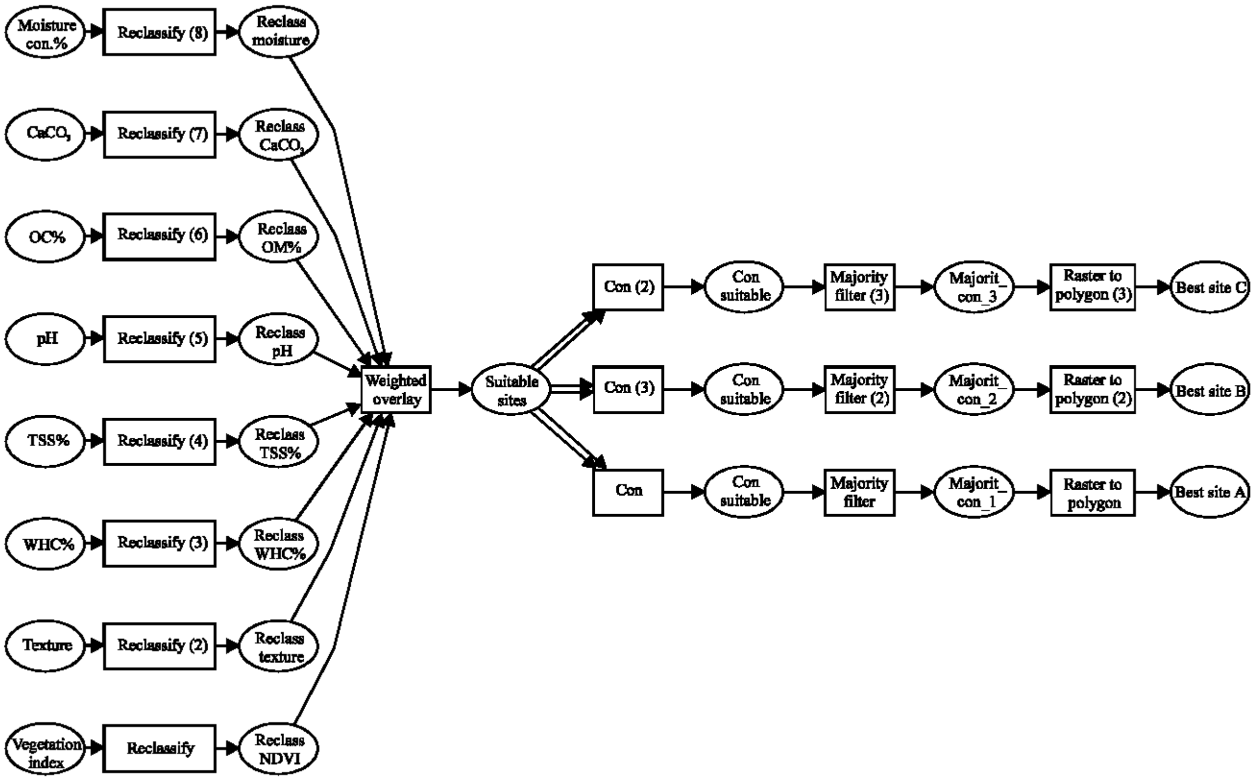

Fig. 2: Flowchart of LSSM

pattern of plant growth in desert habitat and influences the local distribution of plants and floristic composition of the community types. The study of floristic composition of plant communities in the different localities may provide an indicator of soil salinity, soil moisture content and soil reaction as well as the behavior of the dominant species in this habitat. It would appear from this study that species of different localities in the Gulf of Suez area are subjected to large variation in edaptic factors, especially $CaCO_3$, moisture content and total soluble salts. These factors exhibit a wide range of variation between the different localities than other soil characteristics. Variation in these edaphic factors demonstrates species variation in different localities in arid zones. There is an agreement with the study demonstrates the highest percentage of medium sand in soils of *Parkinsonia aculata*, total soluble salts and organic carbon in soils of *Halocnemum strobilaceum,* while the lowest percentage of medium sand in soils *Halocnemum strobilaceum*, total soluble salts in soils of *Calotropis procera*[18]. *Cressa cretica* tends to concentrate greater amounts of certain metabolic components in shoot. This may indicate that the plant is subjected to greater environmental stress. Vegetation surveys indicate that the species is confined to sandy coastal soils which are calcareous, poor in organic carbon, fairly alkaline and with very low values of water soluble salts.

Considering soil characteristics, criteria/requirements of natural vegetation, adaptation to ecosystem and plant/soil interaction, Land Suitability Spatial model (LSSM) could be designed.

LSSM: LSSM is based mainly on two techniques i.e., geostatistical and spatial analyses.

Geostatistical analysis: Map information incorporated within GIS system was frequently derived from field observations such as soil properties and vegetation types. The main purpose of using geostatistical analysis is to fill the missing values of data performing a continuous surface using interpolation technique. Geostatistical analysis includes one or more interpolation modules to facilitate such estimation. Ordinary kriging method not only used to interpolate the missing point data of texture, WHC, MC, TSS, OM, $CaCO_3$ and pH but also to calculate its reliability. Figure 1a-g shows the interpolated soil characteristics which were used with the other variables of NDVI and soil texture for LSSM inputs.

Fig. 3a: *Alhagi maurorum*

Fig. 3b: *Tamarix nilotica*

Fig. 4a: Suitable site 1

Fig. 3c: *Nitraria retusa*

Fig. 3d: *Zygphollum coccineum*

Fig. 4b: Suitable site 2

Fig. 3e: *Fagonia arabica*

Fig. 3d: *Zilla spinoza*

Fig. 4c: Suitable site 3

Spatial analysis: Spatial modeling is becoming an increasing important tool for understanding how our world works. As the systems we are embedded in become increasingly complex, the capacity for understanding the dynamics of these systems through direct experimentation diminishes and the importance of learning through interaction with virtual worlds increase. Barendregt[19] modified non-spatial logistic regression model that is implemented in a GIS as a step towards landscape ecological modeling. In the current work we designed a spatial model for predicting the suitable sites for natural vegetation growth. Poor site selection decisions in facility sitting may result from a variety of factors, the most common of which are uninformed land use planners[20]. However, recent advances in Geographic Information Systems (GIS) provide decision makers with efficient tools which organize and provide structure for the spatial decision making process[21]. The purpose of this research is to facilitate the application of spatial modeling to the study of complex multi-scale processes in Gulf of Suez area.

Figure 2 shows the flowchart of Land Suitability Spatial model (LSSM). Three vegetation groups (A, B and C) were generated after the application of LSSM (Fig. 3a-f). Vegetation types are dominated by:

- Group (A) *Alhagi maurarum, Cressa cretica and Tamarix Nilotica*.
- Group (B) *Zygphollum coccineum, Ochradenis baccatus, Acacia chrenbergiana, Halcocnemum strobiliaceum and Nitraria retusa*.
- Group (C) *Parkinsonia aculata, Zilla spinosa, Limonium pruinosum, Haloxylon salicornicum and Fagonia Arabica*.

The spatial distribution of the three groups of natural vegetation that resulted from LSSM is shown in Fig. 4a-c.

Field verification/model validation: Field survey was executed for two main purposes, for model validity and for identifying density/distribution of the different species. The predicted areas using LSSM were strongly correlated with the species distribution in the space. Confusion matrix technique was used for model verification. Under the conditions of the surveyed area, *Alhagi maurorum* is species of the wide ecological amplitude and sociological range. The species is recorded in 60% of community types. *Tamarix nilotica*, *Zygophyllum coccineum* and *Cressa cretica* are sub-dominant species recorded in 25% of the comminutes types. The other species have presence value of 15%.

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