Land Evaluation Based on GIS-Spatial Multi-Criteria Evaluation (SMCE) for Agricultural Development in Dry Wadi, Eastern Desert, Egypt

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ABSTRACT

Wadi Al Assiuti is one of the almost promising developed areas in Egypt that is located at the East of Nile River-South Part of Asyut Governorates. It is bounded by longitudes 31°13'42"-31°40'12" E and latitudes 27°01'35"-27°26'45" N. The application of a GIS-Spatial Multi-Criteria Evaluation (SMCE) approach was used to identify the almost suitable areas for the production of maize, cotton, alfalfa, wheat, potato, tomato, guava and mango crops. Climate, relief, soil databases as well as specific criteria of the selected crops were integrated using GIS raster coverage’s. This information was used to obtain the criteria maps, that in turn were used as input into the MCE algorithm. Several decision support procedures in the GIS software were applied to obtain the suitability maps for each crop. Advanced tools such as Remote Sensing (R.S.), Geographic Information Systems (GIS) and Digital Elevation Model (DEM) were used to produces geomorphology, soil and capability maps. Fourteen geomorphological units were recognized i.e., decantation basin, overflow basin, high recent river terraces, low recent river terraces, alluvial fans, levee, out wash plain, rubble terraces, wade bottom, wade plain, wades, hills, plateau and island. Using US Soil Taxonomy in 2010, two soil orders were identified-Entisols and Aridisols were represented by five great groups; Typic torriorthents, Vertic haplargids, Vertic haplocalcids Typic haplocalcids and Lithic haplocalcidos. Five soil capability classes were recognized in the studied area C2, C3, C4, C5 and C6. The results showed a total of 1889.2, 5742, 2134 and 118 ha is optimal (S1) for the following crops; alfalfa, cotton, wheat and maize, respectively. On the other hand, mango, guava, tomato and potato were not realized as optimum crops in this area. Five capability classes i.e., C2, C3, C4, C5 and C6 were recognized in the studied area.

Key words: Spatial multi-criteria evaluation, GIS, land evaluation, Wadi El assyouty, Egypt

INTRODUCTION

The main policy of the Egyptian government is to establish new agricultural communities in the new reclaimed area. The investigated area occupied a considerable portion of the eastern desert in Egypt. Egyptian government is putting into its consideration ambition schemes reclamation of new lands to reduce the gap among population increment and food demands. Agricultural use must be under government control and includes but is not limited to cultivating the soil, producing crops for human food animal feed, planting seed or for the production of fibers (El-Nahrawy, 2011). Site
selection is a key element in any aquaculture operation, affecting both success and sustainability as well as solving land or water use conflicts (Hossain et al., 2009; Hossain and Das, 2010). The linking of environmental assessment tools, Remote Sensing (RS) and Geographic Information System (GIS) with their capability in handling available geo-spatial data sources to prepare terrain and soil maps for applications at various spatial and temporal scales. Decision Support Systems (DSS) that are simple, spatial, flexible, non-deterministic and have a long track record of practical application in a policy environment have until recently been uncommon. There has been a rapid expansion in the development and description of both quantitative and soft system methods that can be applied to decision-making processes and many of these have application in the spatial domain (Hill et al., 2005). The same author said the new methods in spatial systems for Multi-Criteria Decision Analysis (MCDA) in the context of the history and application of ASSESS (A System for Selecting Suitable Sites). As a spatial implementation of the Analytic Hierarchy Process (AHP), ASSESS has been used extensively for MCDA in a policy environment. According to Jafari and Zaredar (2010), Land Suitability Analysis (LSA) is a GIS-based process applied to determine the suitability of a specific area for considered use, i.e., it reveals the suitability of an area regarding its intrinsic characteristics (suitable or unsuitable). Also, this analysis involved with considering wide rages of criteria including environmental, social and economic factors. The Multi-Criteria Analysis (MCA) supports the analysis of multiple decision alternatives and land-use options and aids the identification of the most suitable management solution for a given purpose and the effects of alternative options may be presented in a variety of forms, such as monetary units, physical units, qualitative judgments (Beinat and Nijkamp, 1998). Geographical Information Systems (GIS) provide the decision-maker with a powerful set of tools for the manipulation and analysis of spatial information. The functionality of GIS is, however, limited to certain deterministic analyses in key application areas such as spatial search. The integration of Multi-Criteria Evaluation (MCE) techniques with GIS is forwarded as providing the user with the means to evaluate various alternatives by multiple and collecting criteria and objectives (Carver, 1991). The Analytic Hierarchy Process (AHP) method commonly used in multi-criteria decision making exercises was found to be a useful method to determine the weights. It may deal with inconsistent judgments and provides a measure of the inconsistency of the judgment of the respondents. The GIS is found to be a technique that provides greater flexibility and accuracy for handling digital spatial data. The combination of AHP method with GIS in our study area proves it is a powerful combination to apply for land-use suitability analysis (Mustafa et al., 2011).

The main objective of the current work was to identify and evaluate land resources of Wadi Al Assiuti as well as produce suitability maps for crops based on physical and climatic factors using a Multi-Criteria Evaluation (MCE) and GIS approach in dry wadis, Eastern Desert, Egypt.

MATERIALS AND METHODS
Location: The studied area occupies the Eastern part of Nile River. It extends towards the South East edge of Asyut town. It is bounded by longitudes 31°13' 42" to 31°40' 12" E and latitudes 27°01' 35" to 27°26' 45" as shown in Fig. 1. Wadi Al Assiuti is one's of the arable areas that located Along the Nile valley in the desert fringes. Wadi Al Assiuti, has many groundwater wells were drilled for irrigation, domestic and industrial uses. Topographically, the low land ranges among contour lines 50 and 180 m and it is surrounded by the high land that represents the carbonate plateau. It ranges in elevation between 200 and 450 m above main sea level. Wadi Al Assiuti is one's of the largest dry wadis in Middle Egypt, with a remarkable dry drainage basin, whose main
channel reaches about 186 km in length. It includes potential soils where classifications indicated the suitability of the Wadi for agricultural development if irrigation water is available. In general rainfall in the Eastern Desert of Egypt is very rare and occurs mainly from cyclonic winter storms, that may occur once every 10-20 years.

Digital image processing: Digital image processing was done using ENVI 5 software image processing included image calibration to reflectance enhancement, rectification and sup-setting. Band composition Landsat 7 ETM+ image was displayed using band composition of RGB (7 4 2) (Lillesand and Kiefer, 2000). Main geomorphic units were interpreted, delineated and digitized using Arc GIS 10.1.

Multi-Criteria Evaluation (MCE): The first step in delineating suitable areas for the crop was to identify the relevant environmental component variables such as climate, soil and topography. The identified the following variables as relevant soil parameters to suitable crop growing in the study area were soil pH, soil depth, texture, electrical conductivity, calcium carbonate percent, cation exchange capacity, organic matter, saturation percent and slope, elevation, precipitation, minimum and maximum temperature (Sys et al., 1993; De la Rosa et al., 2004). These variables and their corresponding interpolated maps were used as a basis to build standardized factor maps. Using these variables as criteria, a Pair-Wise Comparison Matrix (PWCM) (Saaty, 1980) was constructed. In the context of a Sys et al. (1993) and FAO (1985), established the criterion weights for determining suitable areas for crop cultivation. The following procedure was used: (1) Explanation of the general objective of this evaluation, (2) Identification of the relevant set of criterion and (3) Explanation of a PWCM and its main purpose and completion procedure. Subsequently, the pair-wise comparison of criterion was carried out, according to the scale used in this evaluation. The PWCM construction method uses an underlying scale with values from 1/9 to
9 to rate the relative preferences of the two criteria. This method has been tested theoretically and empirically for a variety of decision-making situations, including spatial decision-making and has been incorporated into a GIS-based decision-making procedure (Malczewski, 1999). The matrix consistency ratio obtained was verified to be less than the maximum value suggested 0.1 (Saaty, 1980). Using the PWCM data, weight per factor was obtained using the ArcGIS WEIGHT function. In order to obtain the map of suitable areas for crop production, the criteria (factor) maps were constructed using ArcGIS procedures. One map for each variable was created, taking into account only the crop growing cycle in the study area. The MCE method used (weighted linear combination) requires that all factors must be standardized or transformed into units that can subsequently be compared (Jafari and Zaredar, 2010).

The Fuzzy Membership (FM) approach was used to generate the factor maps. A fuzzy set is characterized by a FM grade that ranges from 0.0 to 1.0, ranging from non-membership to complete membership, respectively. In this case study, it was defined that the non-optimum level of biophysical requirement per factor as 0.0 and 1.0 FM grades as the optimum level of biophysical requirement per factor. The FM standardizing approach produced several factor maps with the interval ranging from 0 (very low suitability) to 255 (very high suitability). In the categorical factor maps (e.g. soil depth, soil pH and textural classes soil), the user-defined function options were used, establishing FM through fuzzy numbers; both the cases (numerical and categorical factor maps) were applied using the FUZZY procedure in ArcGIS software. In addition, a Boolean constraint map was constructed; Pixels with a 0 value were considered representative of unsuitable areas such as bodies of water, rock land and cities. Pixels with a value of 1 were classified as suitable areas for the evaluation. As well as, to confirm the non-redundancy requirement between all factor maps, a correlation matrix (except for the soil depth and the textural class’s soil maps) was constructed and analyzed. Once the factor maps, their weights and the Boolean constraint map were obtained, the MCE procedure within ArcGIS was applied to produce the map of suitable areas.

**Produce physiographic and soil mapping:** The remotely sensed data and soil maps were geometrically rectified to the projection of Universal Transverse Mercator (UTM) coordinate system optimally enhanced and histogram matched to be comparable during the visual interpretation through AgrcGIS software. The Root Mean Square Error (RMSE) for the rectified image was less than 0.4 pixels. The DEM of the investigated data and the slope class map of the study area are shown in Fig. 2, respectively. After eliminating the speckle effects by smooth filtering, a vector map of the slope classes was produced by screen digitizing. The produced vector format slope class map was overlaid to color composite landsat image of the studied area to delineate soil boundaries and other land features by visual interpretation. A 3D perspective view map and a hill shade relief map were generated using the DEM where the 3D presentation of the landscape is required to detect soil and land form relationships (Fig. 3). Thus, a color hill shade relief map with slope classes was produced by overlaying the final maps. Soil properties for mapping units were determined based on the physical and chemical analyses according to Abdel-Samei (1991).

**Field studies:** Field studies and ground truth were carried out to identify the geomorphologic units and examine the reality of the interpretation. Twenty two soil profiles representing the different mapping units were dug to depth of 150 cm unless obstructed or hindered by bedrock. soil profiles were thoroughly examined and morphologically described in the field according to the system outlined by FAO (1990). Soil samples that representing the subsequent variations within
the soil horizons were collected, air-dried, crushed softly and passed through a 2 mm sieve to get the “fine earth”. However, values for gravel percent by volume and weight were also recorded. The fine earth of soil samples was subjected to physical and chemical analyses, where particle size distribution was determined according to Rengasamy and Churchman (1999). Soil color (wet and dry) was identified by Munssel color charts (Soil Survey Staff, 1951).

Electric conductivity, soluble cations and anions, EC dS m\(^{-1}\), CaCO\(_3\) %, OM %, pH, exchangeable Na and CEC cmol kg\(^{-1}\) were determined according to Richards (1954) and Rengasamy and Churchman (1999).
RESULTS AND DISCUSSION

Geomorphology: Geomorphic units were identified throughout interpreting satellite image that was considered one of the most common, versatile and economical forms of advanced techniques. The basic advantages of satellite image afford the reality to the ground observation. The geomorphic units were recognized and delineated by analyzing the main landscape that extracted from the satellite image with the aid of the different maps and field survey. The obtained data reveal that, fourteen geomorphic units were recognized as follow: Decantation basin that cover an areas about 601.0 ha, it was representing about 0.6% of the total area, overflow basin cover areas of about 1699 ha and form about 1.7% of the total area. High recent river terraces, low recent river terraces which covering areas about 1624 ha and form about 1.6% of the total area, alluvial fans cover an area 118966 about 12% of the total area of out wash plain cover areas of about 5796 ha and form about 5.9% of the total area, rubble terraces cover areas of 9385.2 ha that form 9.6% of the total area, wade bottom cover areas of 7691 ha and about 7.8% of the total area, wade plain cover area of 6200 ha that form 6.3% of the investigated area, wades cover areas of 6440 ha and form about 6.6% of the total area. In addition to levee unite, hills water bodies and Island that
Fig. 4: Geomorphology of the investigated area

cover an area about 1.9% of the total investigated area. Plateau sheets cover an area about 37% of the investigated area. Geomorphologic units are represented by Fig. 4.

**Soil properties and classification**: Based on the Soil Survey Staff (1999), two soil orders were identified *Entisols* and *Aridisols*, that were represented by ten great groups Fig. 5. The soil sets of the mapping units were outlined as follows:

**Soil of flood plain**: The flood plain topographic unit is included; overflow basin, decantation basin and river terraces. The obtained data indicated that soil depths were ranged between 70-150 cm.
Fig. 5: Soil map of the studied area

Soil texture class is clay, sandy loam, loamy sand. pH value ranging between 7.25 and 8.4. EC value ranging between 0.4-1.8 dS m\(^{-1}\). The CaCO\(_3\) content ranging between 4.5 and 33.9%. The soil classified as **Typic haplocalcids** and **Vertic natrargids**.

**Soil of recent river terraces:** The recent river terraces are included high and low recent river terraces. These units are originated from Nile sediments before high dam contraction. It is developed from sediments of Ethiopian plateau that transported by Nile river and subsequently deposited in both the valley and delta. Depth of these soils lays around 150 cm. Soil texture class is clay, silt clay and sand clay loam. pH value ranging between 7.4 and 7.8. EC value ranging between 0.6 and 1.5 dS m\(^{-1}\). The CaCO\(_3\) content ranging between 5.5 and 25.7%, the soil classified as **Vertic haplocalcids**.

**Soil of wadis:** These units included wad, wadi bottom and wadi plain. The soil depths are ranging between 100-150 cm. Soil texture class is sand, loamy sand and sandy loam. pH value
neutral to slightly alkaline 7.45 and 8.7. The EC value ranging between 0.35 and 3.5 dS m$^{-1}$. The CaCO$_3$ content ranging between 7.1 and 41%, the soil classified as *Typic haplocalcids* and *Typic toriorthents*.

**Soil of out wash plain:** This unit has a flat surface covered with fine sand and formed by wind action. The soil depth is ranging between 50-55 cm. Soil texture class is sand, sand clay loam and loamy sand. pH value ranging between 7.4 and 8.9. The EC value ranging between 0.7 and 2.7 dS m$^{-1}$. The CaCO$_3$ content ranging between 30.67 and 60%, the soil classified as *Lithic haplocalcids*.

**Soil of rubble terraces:** These areas were slightly saline. Depth of these soils are shallow its around 40-50 cm. Soil texture class is sand clay loam, loamy sand. pH value neutral to slightly alkaline 7.8 and 8.6. The EC value ranging between 0.6 and 6.20 dS m$^{-1}$. The CaCO$_3$ content ranging between 11.4 and 87.7%, the soil classified as *Lithic haplocalcid*.

**Soil of levee:** Levee is formed as a result of deposition in relatively low laying area. Depth of these soils lies around 150 cm. Soil texture class is sand clay loam. pH value ranging between

Fig. 6: Land capability of the studied area
7 and 8.2. The EC value are low ranging between 0.6 and 0.8 dS m$^{-1}$. The CaCO$_3$ content ranging between 7.2 and 14.6%, the soil classified as *Typic torriorthents*.

**Land evaluation**

**Land capability:** The outputs of the model were linked to the GIS modeling environment using relational database fields that have identifier key attribute property through matching tables to obtain the final maps for land capability for the studied areas. Figure 6 and Table 1 show the areas of land capability classes. The results of the capability model revealed the following:

- **Lands of capability order (C1):** Capability order (C1) doesn’t realize in any soils of the study area.
- **Lands of capability order (C2):** The soils characterized by capability order (C2) are located adjacent to Assiut governorate and included the soils that have developed and can be managed with little. The main limitations of C2 capability class are soils, erosion risks and bioclimatic deficiency. These lands are required a good and proper management, in this case the soil productivity is ranged between moderately high to high for fair range of crops.
- **Lands of capability order (C3):** This class includes the soils which have moderately development as well as moderate capability and moderate severe limitations that restrict the range of crops and require special conservation practices. The main limitations of these lands differed from soil, erosion risks and bioclimatic deficiency. Such lands have low to fair productivity fair range of crops and improvement practices can be feasible.
- **Lands of capability orders (C4, C5 and C6):** These lands have of marginal capability. As well as very severe limitations that restricts their use for arable culture. The main limitations of these lands with C4 and C5 capability classes are soil depth, texture and ECe and bioclimatic deficiency. These lands have low to marginal productivity and recommended for producing forage crops, forestry and agroforestry systems.

**Land suitability:** According to specific criteria obtained from soil characteristics for crop development as a function of productivity. A set of suitability classes were obtained using spatial multi-criteria evaluation model in ARCGIS software. In this study, ve suitability classes were established. Lands designated as S1-S5 indicated soils with optimum, high, moderate, marginal and no suitability, respectively. The several of hectares available to each suitability class are showing in Table 2. The results showed that the following crops; alfalfa, cotton, wheat and maize are categorized as highly suitable (S1) and represented about 1889.2, 5742, 2134 and 118 ha, respectively. On the other hand mango, guava, tomato and potato didn’t realize in this degree (S1) of land suitability. The results showed that highly suitable areas (S1) were found mostly in areas under current Nile deposits (alluvial deposits) and characterized by: slope level of 0-2%, soil pH level between 7.6-7.3, soil drainage imperfectly drained, texture class clay, humidity levels > 80 and temperatures between 20-35°C. In total, 6459.4, 8109, 4709, 8231, 73, 1733, 73 and 31.13 ha for alfalfa, cotton, wheat, maize, mango, guava, tomato and potato, respectively were considered as (S1). On the other hand, in total 48383, 42911, 49945, 48383, 56455, 54191, 56041 and 56483 ha for alfalfa, cotton, wheat, maize, mango, guava, tomato and potato, respectively were categorized as (S3) were from the studied area. Where the soil limitation factors such as were soil depth soil texture and erosion risk. Generally not suitable areas (N) were it’s located adjacent to the plateau and upper plateau, were slope level >50% and soil profile depth is shallow. Figure 7-14 were shown suitability of select crops in the studied area.
Fig. 7: Suitability classes for alfalfa

Fig. 8: Suitability classes for cotton
Fig. 9: Suitability classes for wheat

Fig. 10: Suitability classes for maize
Fig. 11: Suitability classes for mango

Fig. 12: Suitability classes for guava
Fig. 13: Suitability classes for tomato

Fig. 14: Suitability classes for potato
Table 1: Area of the capability classes and references terms

| Capability classes | Area   |
|--------------------|--------|
| C2                 | 9600.038 |
| C3                 | 16426.893 |
| C4                 | 23448.581 |
| C5                 | 4280.288 |
| C6                 | 3015.164 |
| References terms   | 3271.303 |

Table 2: Suitability area for selected crops

| Suitability degree | Alfalfa | Cotton | Wheat | Maize | Mango | Guava | Tomato | Potato |
|--------------------|---------|--------|-------|-------|-------|-------|--------|--------|
| Very highly suitable | 1889.2  | 5742   | 2134  | 118   | -     | -     | -      | -      |
| Highly suitable     | 6459.4  | 8109   | 4709  | 8231  | 73    | 1733  | 73     | 31.13  |
| Suitable            | 48383   | 42911  | 49945 | 610.8 | 755.5 | 54191 | 56041  | 56483  |
| Moderately suitable | 420.63  | 369.9  | 361.5 | 420.6 | 608.3 | 1028  | 608.3  | 608.3  |
| Non suitable        | 40720   | 40719  | 40720 | 40720 | 41122 | 40721 | 40721  | 40723  |

Other studied area used GIS-based Multicriteria Evaluation (MCE) methods to analyze the land evaluation. Land evaluation is carried out to estimate the land capability and land suitability for a specific use such as arable farming or irrigated agriculture. Land suitability evaluation is a prerequisite for land-use planning and development (Pereira and Duckstein, 1993; Parakash, 2003; Mokarram and Aminzadeh, 2010). Different soil chemical parameters and physical parameters are evaluated for different crops. Subsequently all of them are integrated using a multi criteria decision making and GIS to generate the land suitability maps for various crops (Mustafa et al., 2011).

CONCLUSION

Advanced tools such as Remote Sensing (R.S.), Geographic Information System (GIS) have been used for evaluating the natural resources and to produces geomorphology and soil maps of the investigated area. Fourteen geomorphic units were recognized i.e., Decantation basin, overflow basin high recent river terraces, low recent river terraces, alluvial fans, levee, out wash plain, rubble terraces, wade bottom, wade plain, wades, hills, plateau and island. Two soil orders were identified Entisols and Aridisols which represented by five great groups; Typic toriorhents, Vertic haplargids, Vertic haplocalcids, Typic haplocalcids and Lithic haplocalcids.

The agro ecological factors and limitation production factors of crops were integrated using computerized models for evaluation of agricultural soils. Several decision support procedures in the GIS software were applied to obtain the suitability maps for each selected crop. The application of SMCE approach was used to identify suitable areas for the production of maize, cotton, alfalfa, wheat, potato, tomato, guava and mango crops in wadi El Assyout -Egypt. Five soil capability classes were recognized in the studied area C2, C3, C4, C5 and C6. The results showed a total of 1889.2 ha, 5742 ha, 2134 ha, 118 ha is optimal (S1) for the following crops; alfalfa, cotton, wheat and maize, respectively. On the other hand, mango, guava, tomato and potato didn’t realize as optimum crops in this area. Five capability classes i.e., C2, C3, C4, C5 and C6 were according recognized in the studied area.

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