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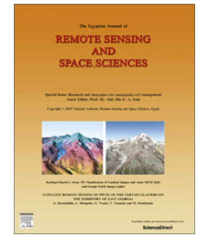

RESEARCH PAPER

Land resources assessment of El-Galaba basin, South Egypt for the potentiality of agriculture expansion using remote sensing and GIS techniques

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Abstract The socio-economic development in Egypt is based on land resources. Recently, the Egyptian government is interested in developing low desert zone areas which are located between the recent Nile flood plain and the limestone plateau, from the east and west sides, and represent an important source of aggregate materials. Therefore, this study was carried out to investigate the potentiality of El-Galaba basin soils which are located in the western part of the Aswan Governorate and are characterized by Wadi El-Kubbaniya for the horizontal agricultural expansion and their optimum agricultural use. The investigated area was remotely sensed to identify the landscape and its land resources. Terrain units were identified using draped Landsat 8 satellite image over Digital Terrain Model (DTM) to express the landscape and the associated soil mapping units. Fifteen mapping units were identified and grouped. Land capability evaluation was performed using Cervatana capability model. The results of capability modeling revealed about 3.33% of land with good use capability, 76.06% land with moderate use capability, and 0.08% marginal or non-productive land. The main capability limitations were soil and erosion risks. The Almagra model was used to produce the optimum cropping pattern and limitations of soil units. Matching the crop requirements with soil characteristics, optimum cropping pattern was obtained for wheat, corn, melon, potatoes, sunflower, sugar beet, Alfalfa, peach, citrus, and olive. The results of the study revealed the potentiality of El-Galaba basin for agricultural uses.

1. Introduction

Egypt is a net food importer, including for over half of its wheat needs. The increasing population and limited cultivated land, combined with land degradation and desertification pose significant challenges for production. Between 2010 and 2011 the total cultivated area in Egypt decreased by 1 percent, associated with encroachment on agricultural land (World Food

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Programme, 2013). Upper Egypt experienced more severe and unpredictable weather and crop failures, leading farmers to over-utilize already stressed natural resources to compensate for low productivity. Egypt has seen an increase in food insecurity as the prevalence of combined food insecurity and income poverty in Egypt raised to 17.2% (an estimated 13.7 million people) in 2011, up from 14 percent of the population in 2009. The rainfall in the Western Desert of Egypt (Sahara) is very rare and occurs mainly from cyclonic winter storms, which could occur once every 10–20 years (Goudie, 2002; Brookes, 2003). The estimates predicted economic losses as a result of climatic change as up to 14% of the African GDP if adaptation measures fail to be implemented (Clements, 2009; Nelson et al., 2009). Agriculture was the most affected sector as a result of climatic variability. The required increase in agricultural production to meet future food demand will further increase pressure on land resources.

Remote sensing techniques have been utilized in soil science for many years as a tool for soil surveyors, reducing the time and expense for sampling (Palacios-Orueta and Ustin, 1998). Geographic information system (GIS) plays a major role in spatial decision-making. The collected information for the suitability analysis for crop production should present both opportunities and constraints for the decision maker (Ghafari et al., 2000). The ultimate aim of GIS is to provide support for spatial decisions making process (Foote and Lynch, 1996). Data layers in multi-criteria evaluation are handled in order to arrive at the suitability, which can be conveniently achieved using GIS. Remote sensing and GIS were used in many studies in Egypt for land resources mapping and management (Saleh et al., 2013; Mohamed et al., 2013, 2014; Saleh and Belal, 2014) .The process of land suitability classification is the evaluation and grouping of specific areas of land in terms of their suitability for a defined land use. The suitability defines the level of crop requirements with respect to the present soil characteristics. The suitability is a measure of how well the qualities of a land unit match with the requirements of a particular form of land use (FAO, 2003). Interpreting soil qualities and site information for the agriculture use and management practices is integrated using GIS (FAO, 1991, 2007). The land quality is a complex attribute of land which acts in a manner distinct from the actions of other land qualities in its influence on the land suitability for a specific kind of use (FAO, 1985); it is the ability of land to fulfill specific requirements for the land utilization type (LUT) (Van Diepen et al., 1991). Spatial analysis can be defined as the analytical techniques associated with the study of geographic phenomena locations together with their spatial dimensions and their associated attributes (ESRI, 2001).

This study was carried out to investigate the potentiality of El-Galaba basin soils, which are a part of the Western Desert of Egypt and located in the western part of the Aswan Governorate, for the horizontal agricultural expansion and their optimum agricultural use.

2. Material and methods

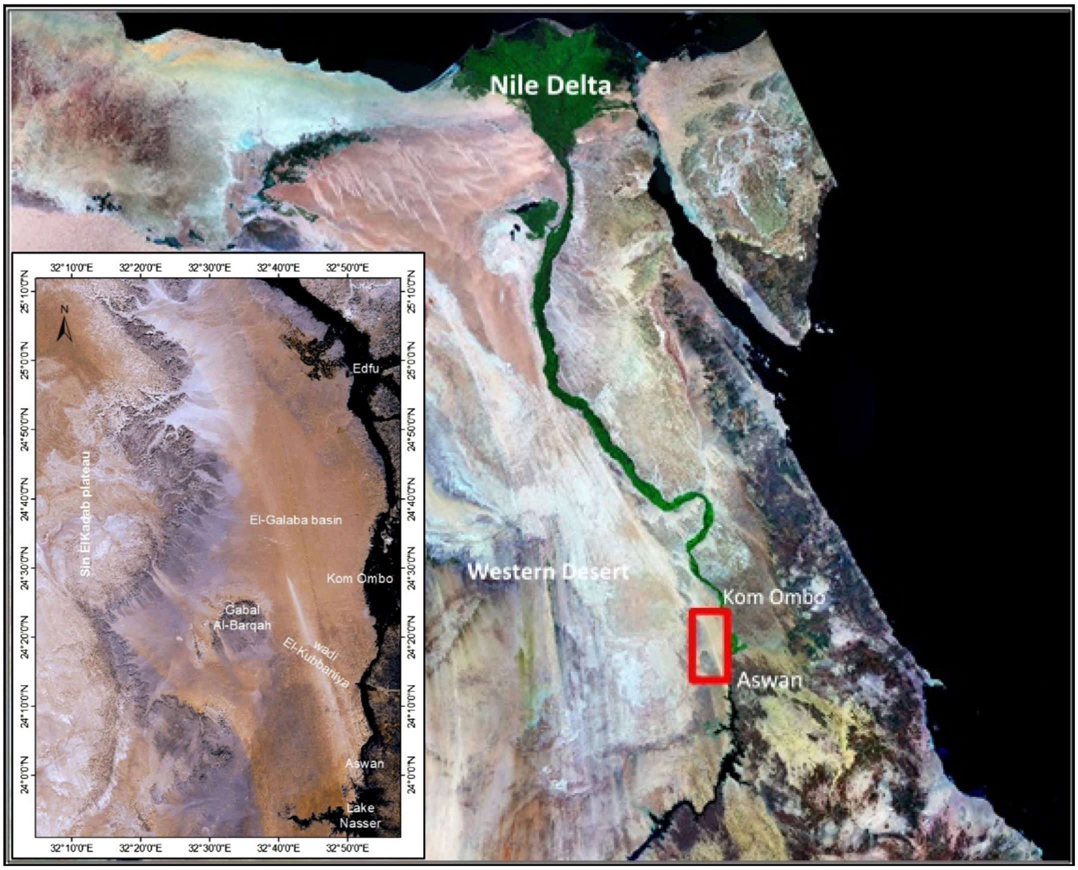
2.1. Study area

The study area is located west of Aswan, in the Western Desert and extends between latitude 24°10′ and 25°10′N and longitude 32°10′ to 33°E, and comprises the El-Galaba plain, the western part of the Kom Ombo basin, and Wadi El-Kubbaniya (Map 1). The study area of El-Galaba plain is a desert area with no landuse. The climatic conditions of El-Galaba area are typically a desert-like condition characterized by an extremely arid climate with long hot rainless summer, mild winter with – very low to no amount of rainfall. The mean temperature in winter ranges from 16.1 to 18.7 °C and 15.9 to 17.3 °C in Aswan and Kom Ombo stations, respectively. In summer, the mean temperature ranges from 32.9 °C to 33.4 °C and 32.4 to 33.0 °C in Aswan and Kom Ombo stations, respectively. The intensity of rainfall at El-Galaba area is very low to negligible as the annual intensity reaches 0.7 mm in Aswan and 1.2 mm in Kom Ombo stations, respectively, while no rain is recorded in summer. Although rainfall is not significant throughout the year, some rare and irregular storms take place over scattered localities during the winter season.

From the geologic point of view, the Galaba area is situated within the African Platform with its Pre-Cambrian folded basement, the tectonic framework is related to the Last African Orogenic belt (Said, 1962; Abd El-Razik and Razavaliaev, 1972). The Nile Valley in Egypt is controlled by wrench faults that are generally parallel either to the Gulf of Suez or the Gulf of Aqaba directions (Youssef, 1968). The western region of the Nile valley consists of a series of unconnected depressions (Attia, 1954; Said, 1962. and FAO, 1966). The study area has been affected by the same structural deformation processes that generated the Nile Valley and shaped the Kom Ombo basin located east of the Nile River (Koch et al., 2012). The Nubia sandstone sequence in the study area consists of alternating beds of sandstones, shale and clay (Issawi, 1983 and Issawi and McCauly, 1993). The faults in the study area represent two main faulting sets; NNW-SSE and NW-SE and in addition there are some major E-W trending faults. These faults are mainly of gravity types and are responsible for the development of the horst and graben structures in the studied area (Salman, 1974).

2.2. Digital image processing

The following remote sensing analyses (Fig. 1) used data from Landsat Data Continuity Mission (LDCM) sensor (Landsat 8) covering the study area acquired under clear sky conditions dated to the year 2013. Data of the blue to the short-wave infrared portion of the spectrum were used in this study. At first, the Thermal InfraRed Sensor (TIRS) bands, the coastal and the cirrus bands were excluded due to the nature of the study. The 30-m spatial resolution of Operational Land Imager (OLI) data were resampled to the higher 15-m resolution of the panchromatic band. All further digital image processing and analyses were executed using the standard approaches provided by the software ENVI 5.0 (Exelis Visual Information Solutions, 2012). The processing of data was represented by rescaling the OLI data to the Top of Atmosphere (TOA) radiance using the algorithm provided by (USGS, 2013) and the radiometric rescaling coefficients provided in the product metadata file. The OLI data were classified using the ISO-DATA classification technique (Map 2). The ISO-DATA classifier was used as it calculates the class means evenly distributed in the data space then iteratively clusters the remaining pixels using minimum distance techniques



Map 1 Location map of El-Galaba plain.

(Lillesand and Kiefer, 2000). Post classification procedures were performed on the resulted classified image to enhance the classification result. These procedures conclude Sieving, Clumping, and Majority analyses.

2.3. Digital terrain analyses

Digital Terrain Model (DTM) of El-Galaba study area was generated and prepared for the subsequent analyses (Fig. 1). Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model ASTER (GDEM) v2 1 arc-second image was used as the source data for elevation heights of the study area. Digital elevation analyses were performed on ASTER GDEM data to extract parametric information, including slope, aspect, flow direction, flow accumulation, stream networks and watersheds (Wood, 1996) using ArcMap 10.2 (ESRI, 2013). Stream networks were derived by applying an area threshold value (100 pixels) to the output from the flow accumulation function using a grid algebraic expression (Tarboton et al., 1991). The stream network links were classified and the stream's order was extracted using the method proposed by (Strahler, 1957). The raster network converted to arc coverage. El-Galaba basin was derived by first identifying the outlet cells above which the basin will be determined, and then using the identified outlets and the flow direction grids to derive the basin utilizing algorithms developed by Jenson and Domingue (1988).

2.4. Mapping units extraction

The Digital Terrain Model (DTM) was analyzed with the aid of the satellite image analysis, the previous DTM extracted parametric information (slope, aspect, and stream networks), the existing body of knowledge in geomorphology, and field observations to obtain the mapping units of El-Galaba basin. The classified satellite image was draped over the Digital Terrain Model (DTM) to get a natural 3D theme to get a better understanding of the mapping units and to facilitate extracting these units (Fig. 1).

Based on the field survey, the digital terrain analyses and the soil analyses, the obtained land classes were combined into a number of fifteen mapping units. The resulted mapping units were identified and grouped. Thirteen mapping units were identified as soil mapping units (SMU) while the other two mapping units were identified as rocky non-soil mapping units (RMU). The Sin El-Kadab plateau which represents the western borders of El-Galaba basin was excluded from the mapping units. The mapping units were verified during the field survey. Each mapping unit of El-Galaba basin was identified on the map by a symbol. Consistent nomenclature is essential for understanding the relationships and differences among mapping units and for correlating the soil units with those found elsewhere, in order to make use of the whole body of existing knowledge about soil genesis and behaviors.

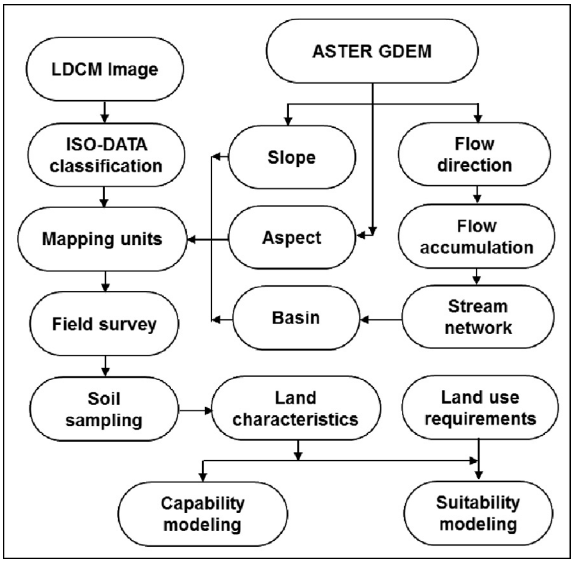


Figure 1 Framework of the methodology followed in the study.

2.5. Field survey

A rapid reconnaissance survey was made throughout the investigated area in order to gain an appreciation of the broad soil patterns and characteristic landscape of El-Galaba basin. The primary mapping units were verified based on the pre-field interpretation and the information gained during the survey. Secondly, a number of thirty-three soil profiles were dug representing the different soil mapping units of El-Galaba basin. The soil profiles were dug to a depth of 150 cm, unless obstructed or hindered by bedrock. Soil samples representing the subsequent variations within the soil horizons were collected for laboratory analyses of some physical and chemical soil properties. The soil samples were thoroughly examined and morphologically described in the selected sites according to the system outlined by (FAO, 2006). The soil profiles were geo-referenced using GPS "MAGELLAN-GPS NAV DLX-10 TM".

2.6. Soil analyses

The soil samples were air-dried, crushed softly, and passed through a 2-mm sieve to get the "fine earth." The fine earth was analyzed in the laboratory for physical and chemical analyses, that included particle size distribution, percentage fine sand, silt, clay, organic matter, pH, electrical conductivity, calcium carbonates content, etc. carried out according to (Soil Survey Staff, 2014).

2.7. Land capability modeling

A land capability modeling procedure was applied following the generally accepted MicroLEIS capability model Cervatana (De la Rosa et al., 2004). The Cervatana model forecasts the general land use capability for a broad series of possible agricultural uses following the generally accepted norms of land evaluation (FAO, 1976; Dent and Young, 1981; ONERN, 1982; Verheye, 1986). The methodological criteria refer to the system designed earlier by (De la Rosa and Magaldi, 1992) and modified for computing purposes by De la Rosa et al. (2004). The prediction of general land use capability is the result of a qualitative evaluation process or overall interpretation of the following biophysical factors: relief, soil, climate, and current use or vegetation (Fig. 2). For each diagnostic criterion or limiting factor, the land characteristics were selected, and the corresponding levels of generalization were established and related with the capability classes by means of gradation matrices (Table 1). The procedure of maximum limitation was used with matrices of degree to relate the land characteristics directly with capability classes. Matching tables were used to express inferences and define four capability classes: Class S1 (Excellent); Class S2 (Good); Class S3 (Moderate); and Class N (Marginal). Four subclasses are also defined according to site (t), soil (l), erosion risks (r), and bioclimatic deficiency (b) limitations. Matching tables were used and linked to the ARCGIS modeling environment using relational database fields which have identifier key attribute property.

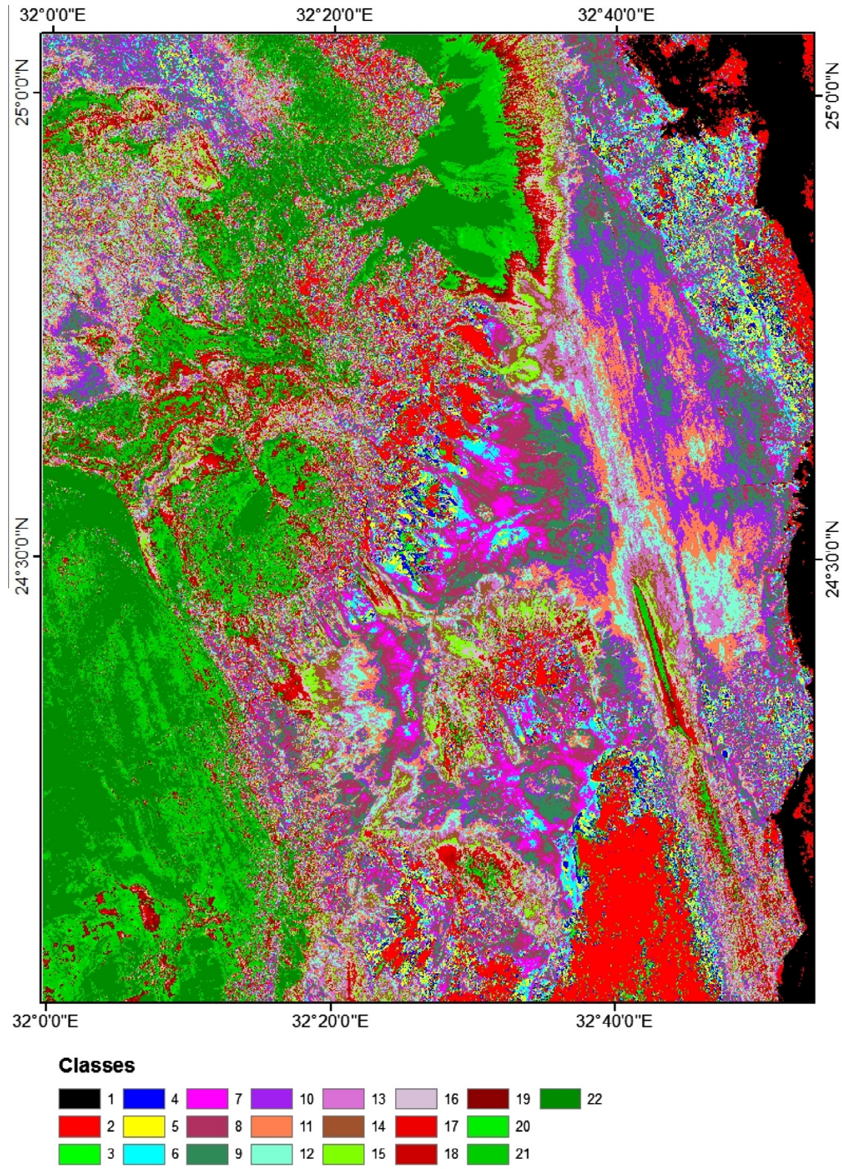
2.8. Cropping pattern modeling

A land evaluation modeling for cropping pattern was applied following the MicroLEIS model Almagra (De la Rosa et al., 1992, 2004). The Almagra model (Fig. 3) indicates the degree of suitability for a land use irrespective of economic conditions. The land use requirements were matched to the land characteristics of each mapping unit to determine its suitability depending on the gradations considered for selected criteria (gradation matrices). The suitability classes for each crop are: soils with optimum suitability (S1), soils with high suitability (S2), soils with moderate suitability (S3), soils with marginal suitability (S4), and soils with no suitability (S5). The main soil limitations are: useful depth (p), texture (t), drainage condition (d), carbonates content (c), salinity (s), sodium saturation (a) and degree of development of the profile (g). For each diagnostic criterion or limiting factor, the land characteristics were selected, and the corresponding levels of generalization were established and related with the suitability classes by means of gradation matrices. The overall soil suitability of a soil component (unit) was assessed through the maximum limitation method where suitability is taken from the most limiting factor of soil characteristics. Ten land uses were tested for their suitability in the study area, namely, wheat, corn, melon, potatoes, sunflower, sugar beet, Alfalfa, peach, citrus, olive. The requirements of each kind of land use are obtained from (Sys et al., 1993).

3. Results

3.1. Landscape characteristics

The landscape of El-Galaba basin is characterized generally by flat plain, ridges and small hills intersected by short valleys and wadis as well as the large Wadi El-Kubbaniya. This generally low relief seems to have formed in the Pleistocene (Issawi and Hinnawi, 1980). The digital elevation model analyses revealed that the ground surface elevation varies from about 600 m above sea level (asl) at Sin EL-Kadab plateau to about 77 m (asl) at the basin low areas (Map 3). The slope analyses revealed that, 37.75% of the area is flat to nearly level



Map 2 Land classes of El-Galaba plain.

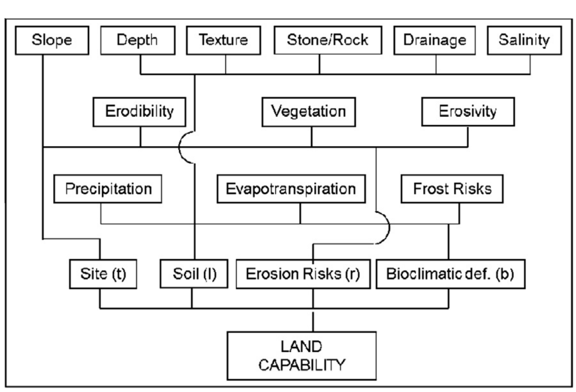


Figure 2 Flowchart of Cervatana for predicting land capability.

(0–1%), 55.16% of the area are very gently slope to sloping (1–10%), 6.60% of the area are strongly sloping to moderately steep (10–30%), and 0.49% of the area are steep (>30%). The aspect analyses resulted that, the directions of the slopes are flat (3.77%), north (5.42%), northeast (15.91%), east (17.00%), southeast (14.14%), south (11.48%), southwest (10.28%), west (10.88%), and northwest (11.12%). The highest stream order is the seventh order (Map 3). There is essentially no natural vegetation at the basin except for Wadi El-Kubbaniya which has some shrubs in the middle of the drainage, but none of the short wadis show any vegetation.

3.2. Mapping units of El-Galaba basin

Fifteen mapping units were extracted, identified and grouped in El-Galaba basin. Thirteen mapping units were identified

Table 1 Gradation matrix between the levels of generalization established for the limiting factors and classes of land use capability.

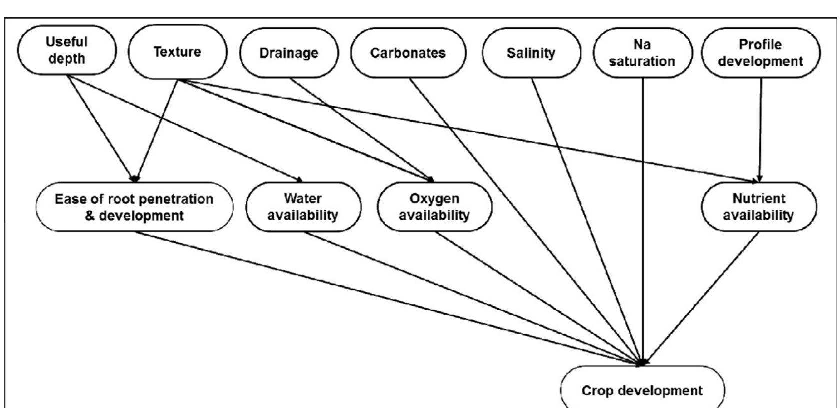
Limiting factor	Levels of generalization	Land use capability class			
		S1	S2	S3	N
Slope (t)	Nil or gentle	< 7	–	–	–
%	Slight to moderate	–	7–15	–	–
	Strong	–	–	15–30	–
	Steep	–	–	–	> 30
Soil	Useful depth	High	Moderate	Shallow	Superficial
	(cm)	(> 75)	(50–75)	(25–50)	(< 25)
	Texture	Balanced	Slight or heavy	–	–
	stoniness/rockiness	Nil or slight	Slight or moderate	High	–
	(%)	(< 15)	(15–40)	(> 40)	
	Drainage	Good	Moderate	Deficit or excessive	–
	salinity	Nil or slight	Moderate	High	Very high
	(dS/m)	(< 4)	(4–8)	(8–12)	(> 12)
Erosion risk (r)	Erodibility of soil	Slight	Moderate	High	–
				(> 30)	
	Slope	< 15	15–30	–	–
	Density of vegetation	High	Moderate	Nil	–
	Erosivity	Slight	Moderate	Strong	Very strong
		(< 150)	(150–200)	(200–300)	(> 300)
Bioclimatic deficiency (b)	Water deficiency	Low	Moderate	High	Very High
		(Class h1)	(Class h2)	(Class h3)	(Class h4)
	Frost risk	Nil to slight	Slight to moderate	High	–
		(Class f1, f2)	(Class f3)	(Class f4)	

as soil mapping units (SMU) while the other two mapping units were identified as rocky non-soil mapping units (RMU).

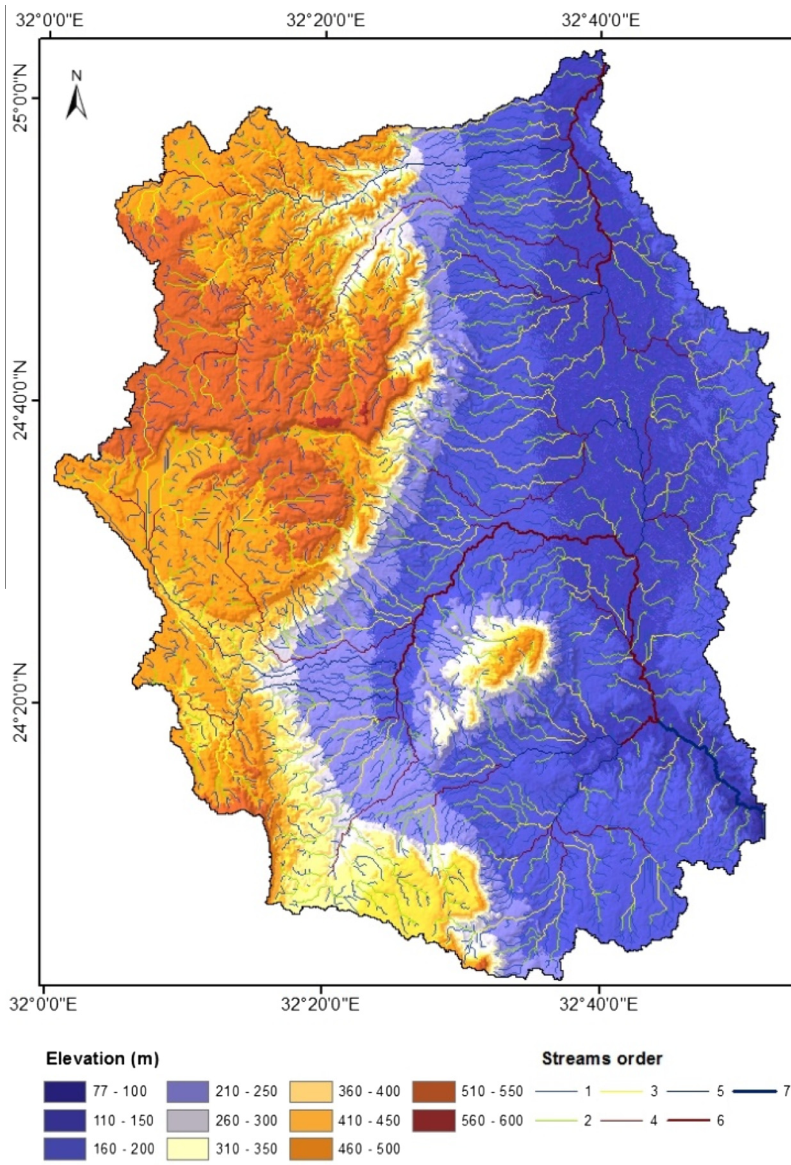
The soil mapping units (SMU) of El-Galaba basin and their associated soils were identified and delineated as shown in (Map 4). The soil mapping units (SMU) were grouped based on the soil horizons/layers similar in differentiating characteristics and arrangement in the soil profiles, except for the texture of the surface horizon, and developed from a particular type of parent material. They are equivalent to the soil series of the American soil taxonomy (Soil Survey Staff, 1999). The soils within the soil units are essentially homogeneous in all soil characteristics.

The following is a brief description of the mapping units of El-Galaba basin:

- Soil mapping unit 1 (SMU1): This mapping unit is deep, sandy, non-saline, with many gravels and some scattered boulders on the surface. It occupies an area of 223.19 km^2 (5.68%). The calcium carbonate content ranges between 1.63 and 2.71% in the different layers of the representative profiles. The organic matter content ranges between nil and 1.38%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.33 and 0.82 dS/m. The pH values ranged between 7.10 and 7.40 in the successive layers of the studied profiles. This unit comprises 5.68% of El-Galaba basin.
- Soil mapping unit 2 (SMU2): This mapping unit is deep, sandy to sandy loam, non-saline to saline, with ripples, and few rills on the surface. It occupies an area of



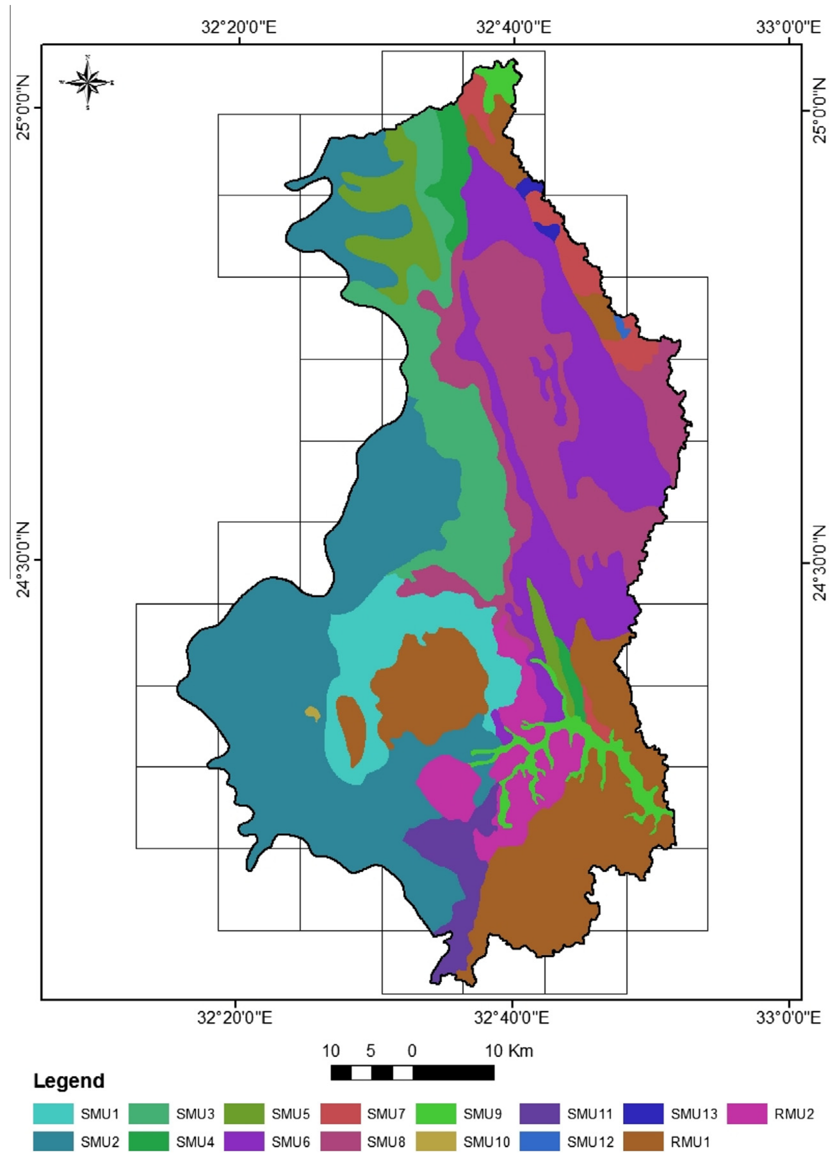
Figue 3 General scheme of the Almagra model, showing the direct and indirect effects of the selected characteristics on crop production via qualities.



Map 3 Digital Terrain Model (DTM) overlaid with stream network of El-Galaba basin.

1044.00 km^2 (26.56%). The calcium carbonate content ranges between 2.29 and 6.25% in the different layers of the representative profiles. The organic matter content ranges between 0.10 and 0.50%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.2 and 5.86 dS/m. The pH values ranged between 7.44 and 8.10 in the successive layers of the studied profiles. This unit occupies 26.56% of El-Galaba basin.

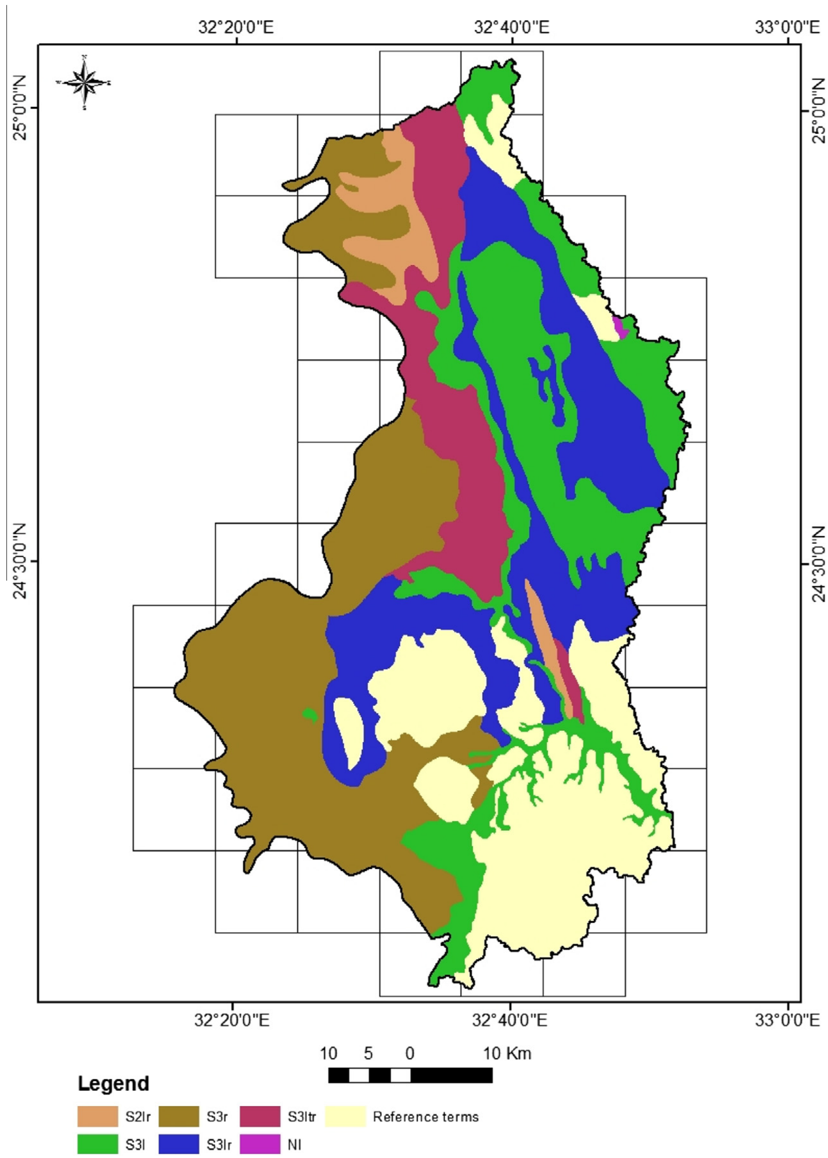
- Soil mapping unit 3 (SMU3): This mapping unit is moderately deep, gravely sandy to silty clay, non-saline, with scattered stones and boulders on the surface. It occupies an area of 318.37 km^2 (8.10%). The calcium carbonate content ranges between 3.25 and 7.29% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.07 and 0.5%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.26 and 0.45 dS/m. The pH values ranged between 7.40 and 7.79 in the successive layers of the studied profiles. This unit comprises 8.10% of the study area.
- Soil mapping unit 4 (SMU4): This mapping unit is moderately deep, sandy loam, non-saline, with some gravels on the surface. It occupies an area of 65.35 km^2 (1.66%). The calcium carbonate content ranges between 4.42 and 6.25% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.45 and 0.42%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.33 and 0.73 dS/m. The pH values ranged between 7.10 and 7.97 in the successive layers of the studied profiles. This unit comprises 1.66% of the study area.
- Soil mapping unit 5 (SMU5): This mapping unit is deep, sandy, non-saline, with gravels and few boulders on the surface. It occupies an area of 180.37 km^2 (3.33%). The calcium carbonate content ranges between 1.88 and 6.67% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.05 and 0.5%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.23 and



Map 4 Mapping units of El-Galaba basin (Sin El-Kadab plateau was excluded).

0.83 dS/m. The pH values ranged between 7.40 and 7.95 in the successive layers of the studied profiles. This unit comprises 3.33% of the study area.

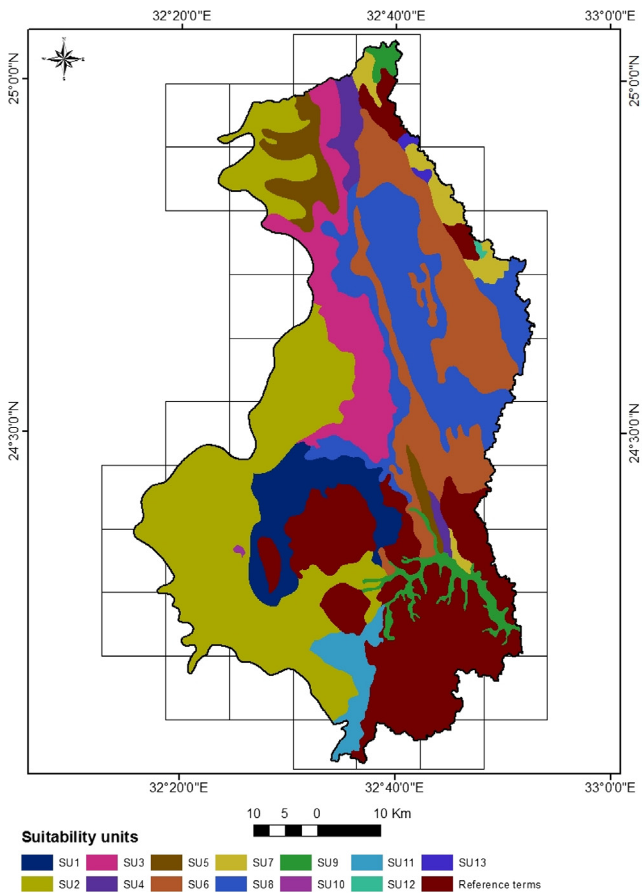
- Soil mapping unit 6 (SMU6): This mapping unit is deep, non-saline to saline, with gravels, stones, and some boulders on the surface. It occupies an area of 526.55 km^2 (13.39%). The calcium carbonate content ranges between 0.50 and 5.21% in the different layers of the representative profiles. The organic matter content is very low and ranges between nil and 0.57%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.20 and 10.40 dS/m. The pH values ranged between 7.15 and 8.18 in the successive layers of the studied profiles. This unit comprises 13.39% of the study area.
- Soil mapping unit 7 (SMU7): This mapping unit is moderately deep, very saline, with some gravels and boulders on the surface. It occupies an area of 88.95 km^2 (2.26%). The calcium carbonate content ranges between 0.10 and 0.21% in the different layers of the representative profiles. The organic matter content ranges between 0.59 and 1.09%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 24.60 and 55.00 dS/m. The pH values ranged between 6.90 and 6.97 in the successive layers of the studied profiles. This unit comprises 2.26% of the study area.
- Soil mapping unit 8 (SMU8): This mapping unit is deep, sandy to loamy sand, non-saline, with some gravels and boulders on the surface. It occupies an area of 519.91 km^2 (13.22%). The calcium carbonate content ranges between 0.50 and 5.63% in the different layers of the representative profiles. The organic matter content is very low and ranges between nil and 0.61%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.25 and 0.73 dS/m. The pH values ranged between 7.30 and 8.46 in the successive layers of the studied profiles. This unit comprises 13.22% of the study area.
- Soil mapping unit 9 (SMU9): This mapping unit is deep, sandy to loamy sand, non-saline to saline. It occupies an area of 95.30 km^2 (2.42%). The calcium carbonate content ranges between 0.50 and 3.90% in the different layers of the



Map 5 Capability classes of El-Galaba basin.

representative profiles. The organic matter content is very low and ranges between 0.02 and 0.54%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.20 and 5.56 dS/m. The pH values ranged between 7.33 and 7.95 in the successive layers of the studied profiles. This unit comprises 2.42% of the study area.

- Soil mapping unit 10 (SMU10): This mapping unit is moderately deep, sandy to loamy sand, very saline, with gravels on the surface. It occupies an area of 2.02 km^2 (0.05%). The calcium carbonate content ranges between 0.10 and 0.21% in the different layers of the representative profiles. The organic matter content ranges between 0.59 and 1.09%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 24.60 and 55.00 dS/m. The pH values ranged between 6.90 and 6.97 in the successive layers of the studied profiles. This unit comprises 0.05% of the study area.
- Soil mapping unit 11 (SMU11): This mapping unit is deep, sandy to loamy sand, saline, with some gravels on the surface. It occupies an area of 97.12 km^2 (2.47%). The calcium carbonate content ranges between 1.71 and 3.88% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.08 and 0.81%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 6.10 and 12.40 dS/m. The pH values ranged between 7.23 and 7.96 in the successive layers of the studied profiles. This unit comprises 2.47% of the study area.
- Soil mapping unit 12 (SMU12): This mapping unit is deep, non-saline, with gravels, stones and boulders on the surface. It occupies an area of 3.09 km^2 (0.08%). The calcium carbonate content ranges between 2.92 and 9.17% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.24 and 0.32%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.28 and 0.34 dS/m. The pH values ranged between 7.28 and 7.37 in the successive layers of the studied profiles. This unit comprises 0.08% of the study area.



Suitability unit	Land use									
	Wheat	Corn	Melon	Potatoes	Sunflower	Sugar beet	Alfalfa	Peach	Citrus	Olive
SU1	S2c	S1	S2t	S2t	S2c	S2ca	S2c	S2pt	S2pt	S3t
SU2	S4t	S4t	S3t	S3t	S4t	S4t	S4t	S3t	S3t	S3t
SU3	S5t	S5t	S5t	S5t	S5t	S5t	S5t	S5t	S5t	S4t
SU4	S5t	S5t	S5t	S5t	S5t	S5t	S5t	S4t	S4t	S4t
SU5	S3t	S3t	S3t	S3t	S3t	S3t	S3t	S2td	S2td	S2tdc
SU6	S3t	S3t	S3t	S3t	S3t	S3t	S3t	S5t	S5t	S5t
SU7	S4t	S4t	S4t	S4t	S4t	S4t	S4t	S3t	S3t	S3t
SU8	S3t	S3t	S2ts	S2ts	S3t	S3t	S3t	S2ts	S2ts	S2ts
SU9	S3t	S3t	S2t	S2t	S3t	S3t	S3t	S2t	S2t	S2tc
SU10	S4t	S4t	S4t	S4t	S4t	S4t	S4t	S3t	S3t	S3t
SU11	S3t	S3t	S2t	S2t	S3t	S3t	S3t	S2t	S2t	S2tc
SU12	S5s	S5s	S5s	S5s	S5s	S4s	S4s	S5s	S5s	S5s
SU13	S4t	S4t	S4t	S4t	S4t	S4t	S4t	S4s	S4s	S3ts

* Suitability classes: (S1) soils with optimum suitability – (S2) soils with high suitability – (S3) soils with moderate suitability – (S4) soils with marginal suitability – (S5) soils with no suitability.
* Soil limitations: (p) useful depth - (t) texture - (d) drainage condition - (c) carbonates content - (s) –salinity - (a) sodium saturation.

Map 6 Combined suitability unit and suitability classes for the selected land uses in El-Galaba basin.

- Soil mapping unit 13 (SMU13): This mapping unit is moderately deep, sandy to loamy sand, non-saline. It occupies an area of 9.51 km^2 (0.24%). The calcium carbonate content ranges between 1.04 and 3.02% in the different layers of the representative profiles. The organic matter content is very low and ranges between 0.10 and 0.24%. The soil salinity values reveal that, the electrical conductivity (ECe) ranges between 0.19 and 0.27 dS/m. The pH values ranged between 6.45 and 7.56 in the successive layers of the studied profiles. This unit comprises 0.24% of the study area.
- Rocky non-soil mapping unit 1 (RMU1): This mapping unit is severely to weakly dissected plateau rock land.

- Rocky non-soil mapping unit 2 (RMU2): This mapping unit is severely to weakly dissected plateau rock land, denuded, smoothened relief, and with many windblown sand accumulations.

3.3. Land use capability

The land use capability modeling resulted in three land use capability classes S2 (Good), S3 (Moderate); and N (Marginal). (Map 5) shows the land use capability resulted from the aforementioned model.

Land with good use capability: It occupies an area of 130.87 km^2 (3.33%). Sandy textured soils with relatively low salinity. Land included in this class has certain topographic and edaphic limitations, which somewhat reduce the set of possible crops and the productive capability. With an appropriate management, this type of land should be of good productivity. Moderate soil conservation practices are required to prevent this land from deterioration.

Land with moderate use capability: It occupies an area of 2990.28 km^2 (76.06%). Deep to moderately deep, gravely sandy to silty clay textured soils and non-saline to very saline land included in this class has considerable limitations linked to topographic, edaphic, or climatic factors. These substantially reduce the range of possible crops and the productive capability. This type of land needs necessarily intensive and special conservation practices to maintain continued productivity. Management techniques are difficult to apply without higher costs.

Marginal or non-productive land: It occupies an area of 3.09 km^2 (0.08%). Deep soils with gravels, stones and boulders on the surface: Land included in this class does not generally provide the ecological conditions necessary for agricultural crops, and is recommended for pasture or forestry as the only way of maintaining and recovering the productive capability. Management and conservation practices of this type of land vary depending on its topographic, edaphic, or climatic deficiencies. Totally non-productive land is included in this class.

3.4. Cropping pattern

The physical and chemical soil properties (soil suitability criteria) were further evaluated to define the land suitability for ten land uses which are: wheat, corn, melon, potatoes, sunflower, sugar beet, Alfalfa, peach, citrus, and olive. For each land use, crop requirements were matched with soil characteristics, and the optimum cropping pattern was obtained for each land utilization type. The land suitability modeling results are shown in (Map 6) for the selected land uses.

4. Conclusion

The objective of this study was to investigate the potentiality of El-Galaba basin soils, which is a part of the Western Desert of Egypt and located in the western part of the Aswan Governorate, for the horizontal agricultural expansion and their optimum agricultural use. Remote sensing and GIS are very helpful tools to store, manipulate and quantitatively evaluate soil capability and suitability. The results of the study revealed that about 79.39% of El-Galaba basin area is good to moderately good of land use capability. The main capability limitations were soil and erosion risks. Also, the suitability analyses show that the basin is suitable for ten land uses which are: wheat, corn, melon, potatoes, sunflower, sugar beet, Alfalfa, peach, citrus, and olive. El-Galaba basin is of high potentiality for horizontal agricultural expansion. This area will benefit if development is planned and executed in a manner that takes advantage of the natural resources without threatening their quality.

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