Integrated Land Use Planning in Wadi El-Amal, Aswan Governorate, Egypt

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Abstract: The study shows how to use cutting-edge geospatial technology to better assess desert resources and provides a systematic approach that can be used elsewhere under the same conditions. A total studied area of 19320 Faddan in Wadi El-Amal located in Aswan governorate, Egypt. This study area is a desert; however, haphazard planning, management practices, and inadequate investments result in land and water resource degradation. The pedo-morphologial, physical, chemical, fertility characteristics of the selected soils were studied based on in-situ, remotely sensed and other data sources. Data on water geochemistry of water samples, collected from three dug wells were also utilized for this study. Five soil mapping units (SMUs) were prepared based on soil depth, rock fragments intensity and size, soil texture, and land topography. The SMUs are: (i) deep moderately fine textured soils with almost flat topography (4760 Faddan; 24.64%), (ii) deep gravelly medium textured soils with gently undulating topography (4740 Faddan; 24.53%), (iii) moderately deep gravelly coarse textured soils with gently undulating topography (3350 Faddan; 17.34%), (iv) shallow cobbly coarse textured soils with undulating topography (2900 Faddan; 15.01%), and (v) very shallow stony coarse textured soils with undulating topography (3570 Faddan; 18.48%). Different evaluation methods were utilized to characterize, evaluate, and plan the studied lands based on the collected data related to soil, water, environmental, political, and socioeconomic criteria. Three different evaluation methods namely qualitative desert land potentiality evaluation (Q_LDLPE), the American land capability classification (USDA LCC), and qualitative desert land aptness for crops (Q_LDLAC) were used to implement assess the potentiality and capability of the studied lands to produce various suitable crops. Q_LDLPE model has grouped the study area into four potentiality classes (high, moderate, slight, and low) while the USDA LCC system classified the study area into three capability classes (class-III, class-IV, and class-V). The characteristics of each soil unit were compared with the requirements of major crops of the study area and suitable crops for each unit were identified. Six land utilization types (field crops, vegetables, citrus-fruits, oil crops, forages, aromatic plants) were suggested as value-added crops for cultivation following the precision farming technique. The results of the evaluation analyses were integrated to propose a sustainable plan through integrated desert land use planning (IDLUP) methodology. Accordingly, about of 66.51% of the total study area (12850 Faddan) was determined for agricultural development, while the rest area (33.49%) was excluded from the agrarian expansion and may be used for the housing and constructions. Value-added crops were prioritized as follows: Field crops and vegetables (4760 Faddan) > citrus-fruits and oil crops (4740 Faddan) > medicinal, aromatic plants, and forages (3350 Faddan). The findings suggest strategies for coping with sustainable agricultural practices for the present study area and provide an integrated methodology for future assessments elsewhere, especially in the desert areas.

Keywords: Geospatial technologies; Land evaluation; Land use planning, Wadi El-Amal, Aswan

INTRODUCTION

Land and water are the basic natural resources on which the existence of humankind depends (Corato and Brady, 2019; Moonjun *et al.,* 2020). In all aspects of land use planning, it is necessary to study the potentials, problems, utilization levels and suitability of land and water resources for various uses (Elwan and Sivasamy, 2013a; Ellili-Bargaoui *et al.,* 2020). Agricultural development on newly reclaimed lands in Egypt has led to many national debates about food security and budget deficits, and the living conditions of the new settlers at the local level (Elwan, 2019). In this context, policy-makers in Egypt are always seeking the best land allocation system for these new lands (Alary *et al.,* 2018; Elwan, 2019). The Egyptian government has set a goal to end hunger, achieve food security, and improve nutrition through sustainable agriculture by the year 2030 (Alary *et al.,* 2018). In order to realize this goal, profound changes in land use, especially in agriculture, to ensure sustainable food production and enhance incomes of small-scale food producers are necessary (Corato and Brady, 2019).

One of the most pressing scientific challenges in the coming decades is to increase agricultural production (Moonjun *et al.,* 2020). Any land use recommendation without giving due consideration to soil resources and their constraints may not help to achieve the goal of sustainable agricultural production (Elwan and Sivasamy, 2013a). Many attempts were made by researchers to study the suitability of land and water for various uses. Initially, these kinds of suitability studies were qualitative in nature while quantitative aspects gained importance afterward (Elwan and Sivasamy, 2013b). In this context, integrated desert land use planning (IDLUP) methodology play an important role in increasing agricultural production of a desert region for applying the precision system through sustainable natural resources planning and management (Elwan and Sivasamy, 2013b; Elwan, 2019). Precision agriculture is an integrated crop management system that combines information technologies with rational agricultural industries and attempts to provide amounts and type of inputs based on actual needs of cultivation in small farms that are located inside a large farm (Tohidyan and Rezaei-Moghaddam, 2018; Ellili-Bargaoui *et al.,* 2020).

Many pedo-morphological properties, such as color value, root abundance, and structure, are dynamic and influenced by land use type and management

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(Suther and Leigh, 2020). Studies have emphasized to use the pedo-morphological properties for land and soil quality evaluation (Juhos and Madarāsz, 2016; Suther and Leigh, 2020). However, most of the soil quality studies have only used the soil physical, chemical, and biological properties, ignoring the pedological context for the soil quality evaluation (Suther and Leigh, 2020). Suitability analysis of groundwater for irrigation purposes is also necessary for suggesting optimal planning measures because the groundwater is being increasingly used for agricultural production in semi-arid regions (Elwan, 2013).

Geospatial technologies are now widely used in resources monitoring and estimation of hydrologic variables such as land evaluation and land use planning (Elwan, 2013). Many resource assessment approaches based on remote sensing can be easily extended to different models. Soil maps consist a collection of soil mapping units that are used to delineate areas with similar soil properties (Itichaa and Takeleb, 2019; Voltz et al., 2020). Many researchers have put a great effort into enhancing and increasing standardization of soil mapping units (Itichaa and Takeleb, 2019; Ellili-Bargaoui et al., 2020; Voltz et al., 2020).

Despite the merits of resource assessments as stated in many published research works, integrated assessments are seldom used (Elwan and Sivasamy, 2013b; Emmet-Booth et al., 2019; Ellili-Bargaoui et al., 2020). Detailed information on diverse properties is not available for El-Amal soils. Furthermore, information about environmental, socioeconomic, and political criteria is vital for planning sustainable management practices (Elwan, 2013; Emmet-Booth et al., 2019). Since most of the agricultural lands in developing countries are similar to these conditions, the present study is attempted as a case to develop a framework to assess the land and water resources potential, utilization level and land suitability for agriculture; and to evolve better management strategies (Elwan and Sivasamy, 2013a; Ellili-Bargaoui et al., 2020). Keeping these factors in mind, the current study aims at developing an extensive framework for assessing the land and water resources of an arid El-Amal watershed in order to achieve the goals of land use planning and agricultural sustainability. Specifically, the study was done to (i) characterize the soils based on their morphology, physical, chemical, and fertility properties (ii) identify the land potential limitations through applying land evaluation methods for determining reasonable agricultural development priorities, and (iii) guide the decision makers towards scientific management of existing land resources through suggesting an optimum land use plan.

MATERIALS AND METHODS

Choice of the Study Area

The study area, Wadi El-Amal area, comprises a part of Wadi Kurkur which is situated in the southern part of the Western Desert, southern Egypt. It lies ~25 km to the southwest of Aswan, Egypt. As shown in Fig. (1), it sprawls between the latitudes of 23° 50' to 23° 58' North and longitudes of 32° 32' to 32° 39' East, and covers an area of about 19320 Faddan. The elevation ranges from 279 to 310 m above sea level (Fig. 1). The various rock types outcropping in the area produced different soil on several landscape positions. It starts from the tertiary rocks of southern mountainous and rocky terrains at summit, shoulder, and backslopes, then goes through the mixed sedimentary areas in the footslope, and finally ends with the Quaternary sediments at the toeslope in the north (El-Shazly et al., 1977; Said, 1962).

Wadi El-Amal study area is located at the Nubian plain within the middle reach of Wadi Kurkur. Wadi Kurkur is presently a dry riverbed and defunct tributary of the Nile Basin (Said, 1962). It traverses the main geomorphic provinces of the region: the Sinn El-Kaddab Plateau, Nubian Plain, Red Sea Hills, and Nubian Swell (Gaber et al., 2018). With an average elevation of 350 m, the Sinn El-Kaddab plateau is comprised of a ~1 km thick sequence of Late Cretaceous-Early Eocene clastic and carbonate sediments (Issawi, 1978). This prominent carbonate tableland is extensive, stretching ~300 km from north-to-south and ~100 km westward from Kurkur to the Darb El-Arbain escarpment, which borders the Kharga Oasis depression (Issawi, 1978). Such setting had facilitated ground water sapping during previous wet periods along the contacts of permeable fractured limestone and the impermeable shale (Gaber et al., 2018). The Nubia sandstone sequence in the study area consists of alternating beds of sandstone, shale, and clay (Issawi, 1978).

Climatological data from 1995 to 2019 were obtained from Aswan meteorological station by the Egyptian Meteorological Authority (2020). The study area is located in the desert climate belt (hyper-arid conditions), where it is characterized by hot dry summer and warm rainless winter. The average daily temperature of the site ranges from 13.5°C in January to 35°C in July, and the mean annual precipitation is 1.5 mm. Such meteorological data were used for matching the climatic requirements of crops and identifying land utilization types through land aptness evaluation for crops. Socioeconomic measures and national policies are the dominant drivers of agricultural, urban, and industrial land development (Kuang et al., 2016). Based on field surveys and statistics data (Central agency for public mobilization and Statistics of Egypt, 2020), socioeconomic indicators (e.g., infrastructure, labor, agricultural technologies, human management, and markets) and political entities (e.g., decision making, agricultural policies, and land tenure) were collected for promoting land evaluation procedures.

Remotely Sensed Data Acquisition

ETM+ images of 2020, covering the study area in Aswan Governorate, Egypt, were used in the present study. The space images were collected and processed to be included in the GIS land resource database. Pre-processing commonly comprises a series of sequential operations, including radiometric correction or normalization, image registration, geometric correction, masking and image enhancement. The digital maps were corrected for different errors and edge-matched

after the geo-referencing processes. Soil and land capability maps of Wadi El-Amal study area were developed in GIS format at different scales.

The chemical and physical characteristics of soil samples obtained from different soil units in the studied area were analyzed in the laboratory. The results of these analyses were recorded in database tables and then integrated into the attribute tables of digital GIS. Land capability classes were defined according to the rating of soil properties adapted from Gad (2015). According to the methodologies of applied land evaluation systems, each land quality was evaluated qualitatively based on its resiliency to the applicable constraints (Elwan, 2019). Land capability and potentiality maps were produced using GIS technology, depending on the potentiality/capability classes calculated in the established database.

Sampling and Analyses

The study comprises a series of tasks that were performed during pre-fieldwork, fieldwork, and post-fieldwork stages. During the pre-fieldwork stage, preparation of base maps was undertaken for planning of soil and land survey activities. Base maps of the study area were created using ARC-GIS 10.1 software by overlaying a 30 m resolution LANDSAT ETM+ and Google Earth imagery. The derived attributes of slope, landform, and land use/land cover were used to delineate the study area boundary. The location and number of soil pedons that helped field survey activities were estimated and distributed on the base map at a specific resolution (Fig. 2).

During the fieldwork stage, all field investigations were done following a preliminary survey of the study site. Using the regular grid survey system, about 71 soil pedon were distributed across the toposequence of Wadi El-Amal area and physically located in the field using predetermined GPS coordinates (Fig. 2). The landscape variables such as elevation, landform, slope steepness, land use type, vegetation type, and parent materials were characterized according to FAO (2006) guideline and Schoeneberger *et al.* (2012). Soil pedons were excavated at each location to 1.5 m depth unless restricted by rock or water table. The Cr horizon was named in the field because of its "soft" rock nature (Soil Survey Staff, 2014a). At each locality, a cleaned profile was described and sampled following standard United States Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) methods (Schoeneberger *et al.,* 2012; Soil Survey Division Staff, 2017). Field morphological descriptions included horizon nomenclature, horizon thickness and boundary, color, texture, structure, consistence, redoximorphic features, roots, and other pedo-morphological characteristics. Hereafter, soil samples were collected from each layer/horizon to evaluate pedo-morphological, physical, chemical, and fertility characteristics of the studied soils. The entire study site was divided into five major soil mapping units (SMUs)

using soil and landscape data. The SMUs were delineated based on criterions such as soil depth, soil texture, rock fragments intensity/size, and land topography to develop soil units that have similar characteristics.

Post-fieldwork activities were focused on soil analyses in the laboratory, geospatial mapping and evaluation recommendations. Horizontally oriented soil samples were taken from soil pedons for laboratory analyses. Collected soil samples were air dried and separated through 2 mm sieve size based on the standard procedures given by Van Reeuwijk (1993). The coarse rock fragments content (> 2 mm in diameter) was considered as gravel (2-76 mm), cobbles (>76-250 mm), stones (>250-600 mm), and boulders (>600 mm) (Soil Survey Division Staff, 2017). This coarse fraction was determined for each soil sample using the equation: rock fragments content % = (weight of coarse materials/weight of coarse and fine materials) × 100 (Soil Survey Staff, 2014b).

After sieving, the finer samples (< 2 mm) were packed in the polythene bags for determination of physical, chemical, and nutrient characteristics. Particle-size analyses were determined using dry sieving and the pipette method (Soil Survey Staff, 2014b). Available water content (A.W), EC, soluble cations and soluble anions, sodium adsorption ratio (SAR), pH, CEC, $CaCO_3$, gypsum, and organic matter (O.M) were estimated as per the standard procedures (Jackson, 1973; Page *et al.,* 1982; Van Reeuwijk, 1993; Soil Survey Staff, 2014b). The available concentration of nitrogen was estimated using Kjeldahl distillation method (FAO, 1970). Standard methods given by Soltanpour and Schwab (1977) were used for estimating available concentrations of phosphorus and potassium. Available concentrations of micronutrients (Zn, Cu, Mn, and Fe) were determined according to Lindsay and Norvell (1978). Groundwater samples were geochemically analyzed as per the standard procedures and methods (Mani *et al.,* 2007). Then, quality of groundwater was assessed according to Ayres and Westcott (1976).

Land Evaluation and Land Use Planning Methods

Method used in the current research is the integration among field observation, soil laboratory analyses, and land evaluation results. Three systems of land evaluation namely qualitative desert land potentiality evaluation (Q_LDLPE), the American land capability classification (USDA LCC), and qualitative desert land aptness for crops (Q_LDLAC) were used to determine the potentiality and capability of the studied lands to produce various crops. They were integrated and linked to the integrated desert land use planning (IDLUP) procedure to plan of the study area. The basic principles of Q_LDLPE, Q_LDLAC and IDLUP methods are not described in details here, but the details can be found in Elwan (2013; 2019). They briefly discuss henceforth.
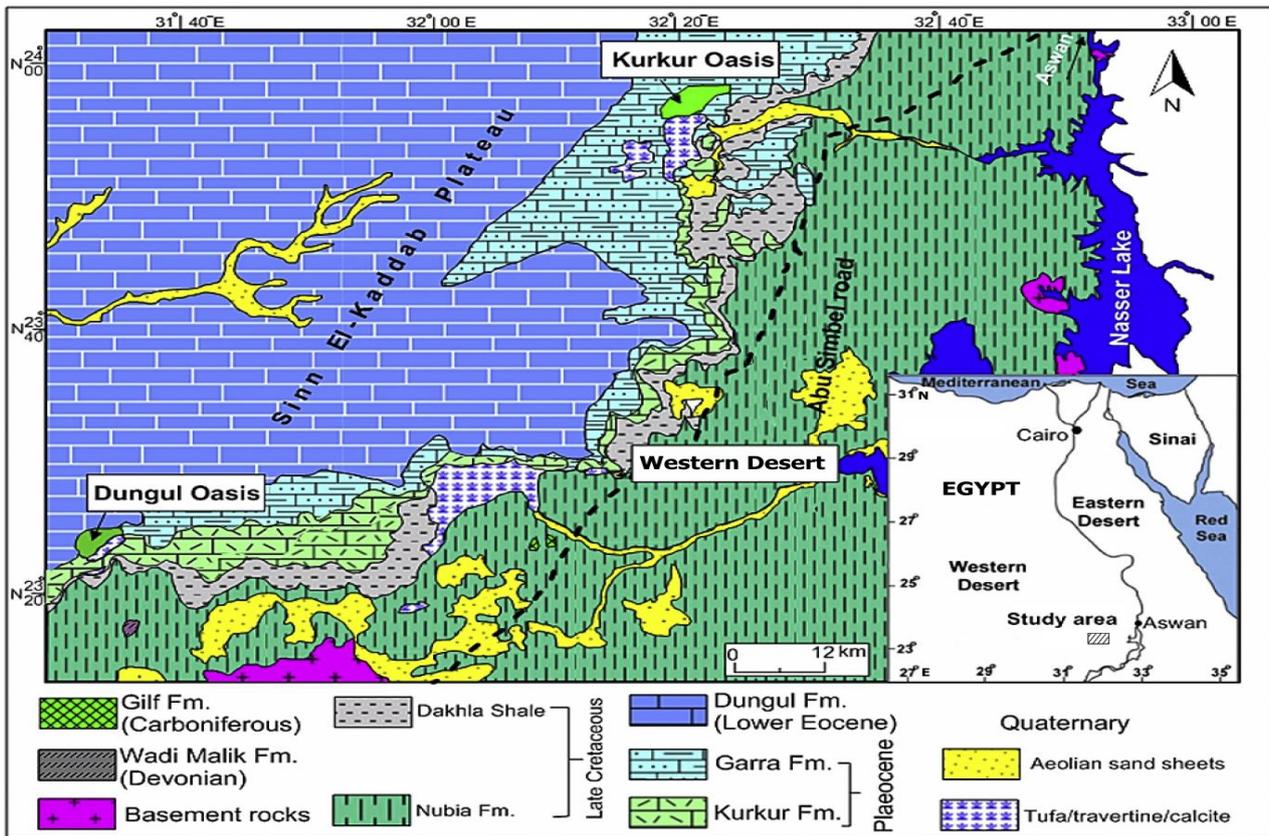
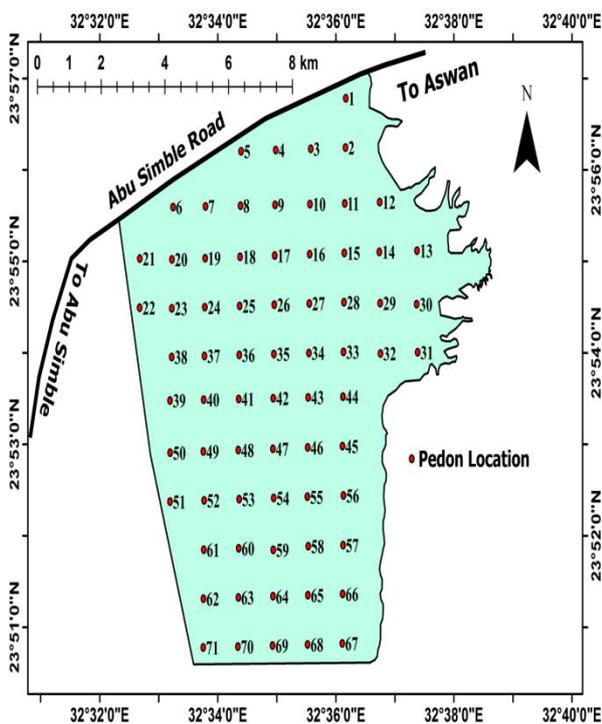**Fig. (1):** Location of study area showing the geology formation.

Fig. (2): Regular grid survey system of pedon locations across the study area

Q$_L$DLPE model

Q$_L$DLPE model is originally devised for the agricultural rating of desert land, in particular, for hyper-arid, arid, and semi-arid zones (Elwan, 2013; 2019). Ratings are generated from a wide range of pedon and landscape characteristics as well as the socioeconomic and political factors. It involves the calculation of a potentiality index on the basis of twenty-two factors, each of which is given a numeric weight and rating value. The significance of each of the criteria regarding sustainability is not equal. In other words, different aspects have different impacts/weights on sustainability. Accordingly, the weight of each factor considered in this model is determined separately. Criteria weight is assumed between zero and one (decimal numbers) based on their contribution in the crop productivity. The numerical rating values of criteria are set between 0 and 100 based on the degree and kind of the limitations (Elwan, 2013; 2019). The criteria involved referring to the environment, soil, socioeconomic status, and political entity. Environmental criteria comprise water availability, topography, and natural hazards. Soil criteria include effective soil depth, coarse fragments, texture, soil water retention, drainage, pH, CaCO$_3$, salinity, gypsum, fertility status, and matrix color. Furthermore, socioeconomic status discusses the availability of infrastructure, labors (manpower), technologies, human management, and markets. Nevertheless, the political entity is related to the right of making decisions, agricultural policies, and land tenure. Then, the totality of all the criteria percentages is calculated by Eq. (1) for Q$_L$DLPE as follows:

$$LPI = \{(R_1 \times W_1) + (R_2 \times W_2) + (R_3 \times W_3) + (R_4 \times W_4) + (R_5 \times W_5) + (R_6 \times W_6) + (R_n \times W_n).\} \quad \ldots\ldots \quad (1)$$

Where LPI is the land potentiality index percentage, *R* is the rating score, *W* is the weighting score, and the subscript numbers ($_{1, 2, 3, 4, 5, 6}$, and $_n$ …) stand for twenty-

two land criteria related to environment, soil pedon, socioeconomic measures, and political entity. The resultant index obtained is positioned to a potentiality category of the land. The potential categories are as: (i) high potential land (81-100%); (ii) moderate potential land (66-80%); (iii) slight potential land (46-65%); (vi) low potential land (26-45%); and (v) non-potential land (<25%) (Elwan, 2013; 2019).

USDA LCC model

Land capability classification used in this study is according to USDA classification (Klingebiel and Montgomery, 1973; Helms, 1992; Gad, 2015). Land are classified into eight classes depend on the intensity and type of limitation factor. The classification system consists of capability class, capability subclass, and capability unit. Land was grouped in a class based on landscape, slope, soil depth, texture, and soil reaction. Subclasses were recognized for specific limitations such as erosion, excess wetness, rooting zone constriction, and climatic limitation. Capability units are grouped based on similar criteria related to landscape, soil, and water characters for plant growth. Class-I to class-IV are suited land for cultivation, while class-V to class-VIII are generally not suited land for cultivation. The main properties of class-I (very highly capable land) have very few limitations. Class-II (highly capable land) has some limitations that reduce plant growth and needs moderate conservation measures. Class-III (moderately capable land) has medium risk and need special conservation practice. Class-IV (low capable land) has high grade of liability/high risk and severe limitations that reduce the choice of plant can be cultivated and need very careful conservation practice. Class-V (very low capable land) has very high grade of liability/very high risk (Gad, 2015). Class-VI to Class-VIII has extremely severe limitation so generally not suited to cultivate plant (Klingebiel and Montgomery, 1973).

Land aptness evaluation for crops approach

Qualitative desert land aptness for crops (Q_LDLAC) has been used to assess the desert land aptness for predicting a variety of added-valued crops based on six criteria including climate, environment, soil, agricultural policies, agricultural research technology, and market responses as per the guidelines given by Elwan (2013; 2019). Q_LDLAC model is a powerful tool to predict one or more outputs according to one or more input in a learning procedure. Adaptation to the guidelines was made as necessary based on climate, environment, field and laboratory findings. The process of this evaluation is the matching of crop growth requirements against land characteristics (criteria). The climate sub-criteria are air temperature, evapotranspiration, relative humidity, wind velocity, and precipitation. The environmental sub-criteria are irrigation water availability, topography of the landscape, and environmental hazards. While the soil sub-criteria are effective soil depth, soil texture, coarse fragments, soil salinity (EC), soil reaction (pH), lime content ($CaCO_3$), gypsum content, soil moisture, drainage, and fertility status. Agricultural policies are crop insurance, land tenure, and decision making, to

select the varieties of crops which achieving food security according government plan. In this approach, four aptness classes (high, moderate, slight, and non-aptness) are differentiated based on the matching process and the degree of limitations. During aptness analyses, the selection of final aptness class is based on the weights of the criteria/sub-criteria. Climate, irrigation water availability, and solum depth factors have high weights (Elwan, 2013, 2019).

IDLUP methodology

IDLUP is a logical decision-making process in which desert resources are assessed using various evaluation methods in the context of objectives, and thus potential options that can be implemented by the land user are identified (Elwan, 2013, 2019). It is an extremely complex subject, combining socioeconomic of land use, institutional aspects, and technological interventions with an assessment of potential future requirements (Elwan, 2013, 2019). Ultimately, IDLUP is a set of systematic technical procedures to evaluate the offered options given by the used evaluation methods. The main criteria of IDLUP model are integrated into GIS to obtain appropriate scores indicating the sustainability status of the value-added crop production and their priorities. Every landuse planning project is different. Objectives and local circumstances are extremely varied, so each plan will require a different treatment. However, a sequence of five steps has been found useful as a guide for landuse planning of desert areas (Elwan, 2013). The main steps of IDLUP procedure are: (i) identifying and analyzing the current land use situation in the field through characterizing soil, water, socioeconomic measures; (ii) determining what alternative solutions exist through applying the specialized desert land evaluation methods; (iii) choosing the best option based on the above evaluation discussions, and deciding which crops to grow and which technologies to apply; (iv) allocating land to different kinds of uses in respect to institutional arrangements; and (v) specifying management standards and inputs (Elwan, 2019).

RESULTS AND DISCUSSION

Soil Mapping Units

The site was divided into five soil mapping units (SMUs), as shown in Fig. (3). Topography, soil depth, and soil texture were used to classify soil mapping units. The identified USDA soil textural groups were based on Schoeneberger *et al.* (2012). The SMUs are: (i) deep moderately fine textured soils with almost flat topography, (ii) deep gravelly medium textured soils with gently undulating topography, (iii) moderately deep gravelly coarse textured soils with gently undulating topography, (iv) shallow cobbly coarse textured soils with undulating topography, (v) very shallow stony coarse textured soils with undulating topography. The first soil mapping unit (SMU1) covered an area of 4760 Faddan (24.64%) and developed on toeslope position. It occurred on nearly level slopes dominated by deep (> 100 cm) moderately fine textured soils (clay loam, sandy clay loam, silty

clay loam). Natural drainage within pedon layers varied from moderately well drained to somewhat poorly drained. This map unit consists deep (<150 cm) to very deep (>150 cm) soils containing less than15% of gravel throughout soil pedon layers. These two soils often occur so closely associated that it is impractical to separate them during mapping. Hence, they are mapped as a complex of two similar soils.
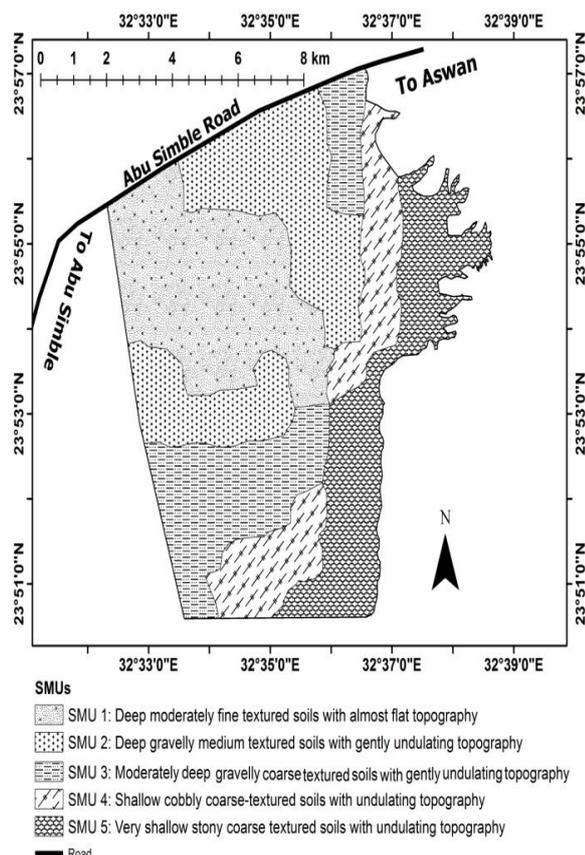

Fig. (3): Delineated soil mapping units of the study area using Arc-GIS technique

The SMU2 occupy an area of 4740 Faddan (24.53%). Soils of this unit consist of deep, moderately well drained soils formed in very fine sandy loam alluvial material underlain by water-sorted sand and gravel. These soils were developed on gentle slopes (1–2%) at footslope positions of plain landforms comprising soils enriched with loam and silt loam. Because of seasonal deposition of finer soil materials, they showed medium textured soils deeper than 100 cm.

The SMU3 covered an area of 3350 Faddan (17.34%) and formed at backslope geomorphic position (Fig. 3). It was prevalent along the plain landforms having uniform slopes of 5-7% dominated by moderately deep (100->50cm) cobbly coarse textured soils. These soils showed high concentration of cobbles (>15 to <35%) with undulating topography. SMU4 occupied an area of 2900 Faddan (15.01%) and formed on shoulder position. The soils were formed at foot to mid-slope position in version land comprising a wide range of slope gradient (5-15%). Soils of the SMU5 covered an area of 3570 Faddan on shoulder position geomorphic unit. These soils were very shallow (<25 cm) and dominated by stones (>35) and coarse textured soils. Both SMU4 and SMU5 were widespread at shoulder position and dominated by sand and loamy sand soils shallower than 50 cm. Soils of these land units showed wide gravelly and stony surfaces with sandy loam texture.

Groundwater Quality

The main water resource for agricultural purposes in the study area is the groundwater which is available in limited amounts. Groundwater is available from different water-bearing formations of different lithology including sandstone, limestone, and fractured basement. This water source occurs under different hydrogeological conditions which may be free water, semi-confined, and confined or flowing springs conditions. Groundwater potentialities of Wadi El-Amal are promising for agriculture as it is available from different aquifers related to Wadi fill, Duwi (limestone and phosphate beds intercalations), and Nubia sandstone formations. They have a good thickness and away from seawater intrusion. Furthermore, Nubia formation existed at shallow depths.

Quality of irrigation water plays a major role in deciding crop yields. Water samples were collected from three different wells located in different soil mapping units (1st sample from SMU1, 2nd sample from SMU2, and 3rd sample from SMU3). The results of geochemical analysis of groundwater samples (Table 1) showed that the average concentration of pH varied from 7.35 to 8.01 indicates that groundwater of the study area is very hard in nature, and hardness is mainly due to the bicarbonate salts of calcium and magnesium. Regarding the groundwater quality of third soil mapping unit (SMU3), the concentration of boron was in moderate and chloride was in severe limits, where their values were 0.94 mg/l and 19.2 meq/l, respectively.

Table (1): Chemical composition of groundwater samples collected from three wells across soil mapping units

Well No.	SMU[a]	pH	EC$_w$[b] (dS/m)	Soluble cations (meq/l)			SAR[c]	Soluble anions (meq/l)				B (mg/l)
				Ca^{+2}	Mg^{+2}	Na$^+$		Cl$^-$	SO$_4^{-2}$	HCO$_3^-$	CO$_3^{-2}$	
1	SMU1	7.35	0.70	1.05	0.86	5.15	3.49	4.77	0.88	1.35	0.07	0.29
2	SMU2	7.78	1.47	4.42	2.01	8.25	5.75	10.20	2.01	2.09	0.20	0.38
3	SMU3	8.01	2.81	6.31	3.88	16.98	7.52	17.95	1.65	3.39	0.15	0.94

[a] **SMU** (Soil Mapping Unit)
[b] **EC$_w$** (Electrical Conductivity of groundwater)
[c] **SAR** (Sodium Adsorption Ratio)

EC$_w$ and SAR values were found within severe limits. Among the cations, sodium is a dominant constituent, which possesses more than 50% of ions in the overall concentration of all cationic elements. While analyzing the major constituents of the anions, it is found that the chloride ion has a higher concentration than bicarbonate followed by sulphate and carbonate in the groundwater samples. Accordingly, the quality of groundwater was placed under permissible conditions. On the contrast, results of groundwater samples of first soil mapping unit (SMU1) well showed that its quality was rated as good water for irrigation without salinity or alkalinity hazards for crops.

Soil Morphology

Soil morphology is affected by climate, land use, farming systems, and seasonal variations (Suther and Leigh, 2020). Generally, soils are studied for their morphology at an appropriate moisture level between field capacity and permanent wilting point for better visualization and understanding of the pedogenic processes. Major morphological properties of sites and pedons of Wadi El-Amal are presented in Table (2), and visualized in Fig. (4). The morphology of the soil mapping units (SMUs) on toeslope differed from that of the soils on upland shoulder in their effective depth, soil color, concentrations, redoximorphic features, and the absence or presence of diagnostic horizons. The soils of first mapping unit showed 3-4 layers described as follows (Table 2 and Fig. 4): a 35 cm reddish yellow (7.5YR 6/6) silt loam Ap anthropic horizon on top of a 20 cm brownish yellow (10YR 6/8) sandy clay loam calcic horizon. By contrast, the solum was absent in the studied lands on higher slope positions whereas the subsolum layers; e.g., regolithic layer (C), saprolithic (Cr), and paralithic layers (R), defined by Moragues-Quiroga et al., 2017, were noticed at different depths (Fig. 4). Furthermore, saprolithic (Cr), and paralithic layers (R) were only noticed in the shoulder pedons (SMU4 &SMU5) as in Fig. (6). They were represented by a very pale brown (10YR 8/2) sand C layer, and light gray (10YR 7/2) sandy Cr layer.

The soil color of all pedons was widely varied from 7.5YR to 10YR in hue, 5 to 8 in value, and 2 to 8 in chroma (Table 2). The soil color ranged from reddish yellow (7.5YR 6/6) at the surface horizons to light gray (10YR 7/2) at the subsurface layers (Fig. 4). In the third soil mapping unit (SMU3) on backslope position, an abrupt change from the top to the bottom in their dominant color, from brownish yellow (7.5 4/2) to very pale brown (10YR 8/2), was observed.

There was a considerable variation in grade, size, and the shape of soil structure characteristics within each pedon and among soil mapping units. The pedons at toeslope position exhibited a moderate fine subangular blocky and weak medium granular structure in the Ap soil horizon and from moderate medium angular blocky to the weak medium subangular blocky structure in the calcic soil horizons, and consistence from slightly hard to extremely hard when dry. The studied pedons occurred on upland shoulder exhibited structureless units (e.g., single grain or massive) throughout the pedon layers and consistence from nonsticky to moderately sticky and nonplastic to moderately plastic when wet (Table 2 and Fig. 4).

Common redoximorphic features, as an indication of the presence of periodic saturation of upper parts of pedon, were observed as ferriargillans or manganese films in the soils studied of SMU1. Iron was oxidized mostly on the surfaces layers that were dominantly reddish brown. Therefore, the calcic horizon (Ckkm) was formed which is an altered horizon and strongly developed due to accumulation of secondary CaCO$_3$. Masses of Fe or Mn and redox features were common in the studied soils in Wadi El-Amal study area. Petrocalcic and cemented horizons restrict root penetration. Furthermore, poorly aerated, and poorly drained soils can limit root system development.

Soil Physical Properties

Gravel, fine-earth fractions, and soil available water (A.W.) are presented in Table (3). The gravel content increased significantly in the shoulder and backslope positions and ranged from 19.44% to 34.25% for the respective C and Cr layers (Table 3 and Fig. 4). The abrupt increase and the change in the size of rock fragments between C and Cr layers evidenced a lithologic discontinuity. The lower slope positions (toeslope and footslope) had a gravel content ranging from 2.07% to 21.04% in the Ckkm layers in the SMU1 and SMU2. In contrast, the studied soils at toeslope and footslope position (e.g., SMU1 and SMU2) had rock fragments in gravel size compared with those soils on at backslope and shoulder (e.g., SMU4 and SMU5) which had rock fragments more than 15% in cobbles and stones size.

Soils across all landscapes showed differences in particle size distribution (Table 3). With decreasing slope and elevation above sea level, the clay fraction in all upper soil horizons in the studied soils increases significantly. Whereas clay concentration in the surface horizons of downslope soils were 37.15% in clay loam texture to 20.5% forming sandy clay loam texture in the surface layer of pedon 23 (Table 3). By contrast, clay fraction within pedons backslope and shoulder was similarly low at 9.45% and 1.25%, respectively, compared with those of the toeslope and footslope soils. Meanwhile, sand-sized particles dominated the fine-earth fractions across upper slope position, with a general decrease in sand content with decreasing elevation.

Soil available water values increased with decreasing elevation across the toposequence and showed values between 23.55-30.14% in SMU1, 15.95-19.25% in SMU2, 5.36-9.15% in SMU3, 5.15-7.36% in SMU4, and 4.25-6.45% in SMU5 (Table 4). The highest values of A.W. were in the lowland soils, which may be attributed to the high concentrations of clay and organic carbon.

Table (2): Soil morphology and pedogenic features of representative pedons over soil mapping units across study area

SMU	Pedon No.	Horizon /layer	Depth interval (cm)	Matrix color (Moist)[a]	Structure (Grade, size, type)[b]	Consistence (Dry, wet)[c]	Redoximorphic features (Kind)[d]	Concentrations (Quantity, size, kind, location, hardness)[e]	Surface cover (kind, Size)[k]	Root restriction (Kind)[h]	Natural drainage	Slope position & gradient
I	21	C	0-35	7.5YR	0, MA	SH, SS-SP	RMX & F3M	f,CAM,TOH	SG, GR	Petrocalcic	Moderately well drained	Toeslope & nearly level
		CK	35-105	7.5YR	1, F, ABK	HA,SS-SP	FEF & F3M	c,2,CAN,MAT				
		Ckm	105-130	7.5YR	2, M, SBK	VH, MS-SP	FEF & F3M	f,1,CAN,TOH				
		Ckkm	130-155	7.5YR	2, F, SBK	MH, MS-MP	CLD & RMX	m,1,CAN,MAT				
	35	Ap	0-25	10YR	0, MA	HA,MS-MP	FEF & F3M	m,2,CAC,MAT	SG, GR	Cemented horizon (CH)	Somewhat poorly drained	Toeslope & nearly level
		Ck	25-90	10YR	2, M, ABK	EH,MS-MP	FED & F3M	c,2,CAN,MAT				
		Ckkm	90-140	10YR	1, CO, SBK	VH, SS-SP	RMX & F2M	c,1,CAN,MAT				
II	49	C	0-30	10YR	0, MA	SH,SS-SP	RMX & F2M	f,1,CAN,MAT	SG, GR & CB	Strongly contrasting textural stratification (SR)	Moderately well drained	Footslope & very gently sloping
		Ck	30-70	10YR	0, MA	MH,MS-MP	FEF & F3M	c,2,CAC,TOH				
		Ckkm	70-110	10YR	2, F, SBK	MH,SO-PO	FED & FMN	m,1,CAN,ARF				
		Ckm	110-145	10YR 7/8	0, SGR	MH,SO-PO	FMC & FMN	m,2,CAN,ARF				
III	52	C	0-20	10YR	0, MA	SH,SS-SP	FMC & FMN	f,1,CAM,SPO	SED, GR & CB	Petrocalcic (PE)	Somewhat poorly drained	Backslope & gently sloping
		Ck	20-40	10YR	0, MA	EH,SS-SP	FMN & F3M	c,1,CAC,MAT				
		Ckm	40-65	10YR	2, F, SBK	VH, SS-SP	FMC & FMN	m,2,CAN,ARF				
		2C	65-95	10YR	2, F, SBK	VH,MS-MP	FMC & FMN	m,1,CAN,ARF				
IV	63	C	0-30	10YR	2, M, PL	SH,SO-PO	None	f,1,CAM,SPO	RK, ST	Densic bedrock	Poorly drained	Shoulder & gently sloping
		2Cr	30-45	10YR 7/6	0, MA	SH,SO-PO	None	m,2,CAN,ARF				
V	66	Cr	0-15	10YR	3, F, PL	VH,SO-PO	None	f,1,CAN,ARF	BR, BY	Paralithic bedrock (BPL)	Very poorly drained	Shoulder & sloping
		R	15-20	10YR 7/2	0, SGR	SH,SO-PO	None	f,2,CAN,MAT				

All symbols are used based on Schoeneberger et al. (2012).

[a] **Matrix color:** 7.5YR 6/6, 6/8 (reddish yellow), 10YR 5/1 (gray), 10YR 5/2 (grayish brown), 10YR 5/4 (yellowish brown), 10YR 6/6, 6/8 (brownish yellow), 10YR 7/2 (light gray) 10YR 7/6, 7/8, 8/6, 8/8 (yellow), 10YR 8/2, 8/3, 8/4 (very pale brown).

[b] **Structure:** Type: ABK (angular blocky), SBK (subangular blocky), PL (platy), SGR (single grain), MA (massive); grade, 0 (structureless), 1 (weak), 2 (moderate), 3 (strong); Size: VF (very fine), F(fine), M (medium) CO (coarse), VC (very coarse), EC (extremely coarse).

[c] **Consistence: Dry:** MH (moderately hard), HA(hard), VH (very hard), EH (extremely hard), **Wet:** Stickiness: SO (nonsticky), SS (slightly sticky), MS (moderately sticky), VS (very sticky), PLASTICITY: PO (nonplastic), SP (slightly plastic), MP (moderately plastic).

[d] **Redoximorphic features:** RMX (reduced matrix), Fe^{+2}, masses), F3M (oxidized iron,Fe^{+3}, masses), FEF (Ferriargillans, Fe^{+3}stained clay films) FMC (iron-manganese concretions; cemented distinct layer), FMN (iron-manganese nodules, cemented), CLD (clay depletions), FED (iron depletions).

[e] **Concentrations:** Quantity: f(few), c(common), m(many); size: 1(fine), 2(medium), CAM (carbonate masses), CAN (CaCO₃ nodules), CAC (carbonate concretions among joints and in matrix), Location: MAT(in the matrix), TOT(throughout), SPO(on surface along pores), RPO (on surface along root channels), CRK (in cracks), TOH (at top of horizon), ARF (around rock fragments).

[f] **Surface cover: Kind**: SG (barren land- sand and gravels); SED (sedimentary rock fragments); RK (barren land- rock;) BR (bedrock); Size: GR (Gravel); CB (Cobbles); ST (Stones); BY (Boulders);
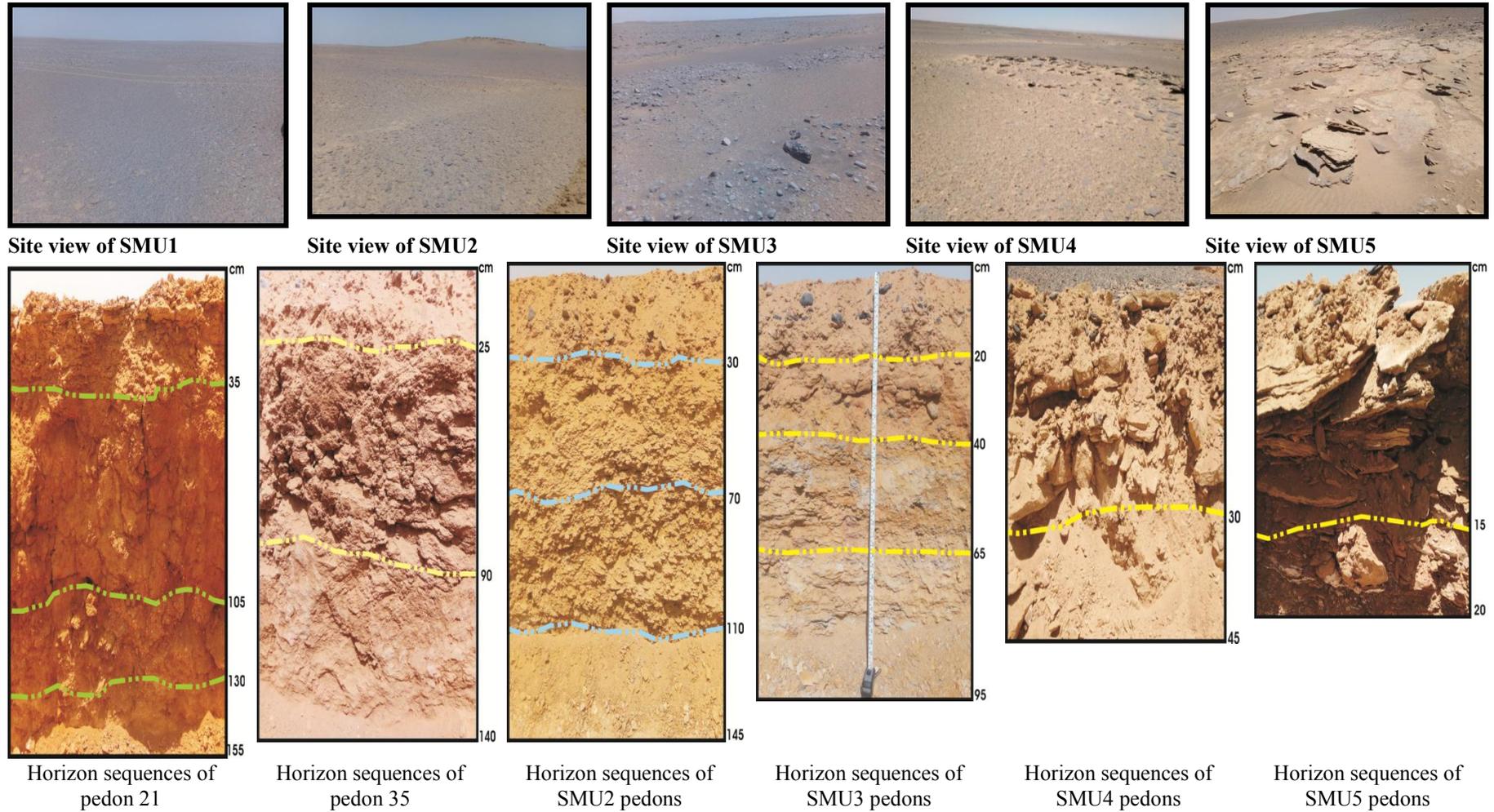
Site view of SMU1   Site view of SMU2   Site view of SMU3   Site view of SMU4   Site view of SMU5

Horizon sequences of pedon 21   Horizon sequences of pedon 35   Horizon sequences of SMU2 pedons   Horizon sequences of SMU3 pedons   Horizon sequences of SMU4 pedons   Horizon sequences of SMU5 pedons

Fig. (4): Selected pedons with different layer sequences of SMU4 and SMU5 formed at shoulder slope position.

Table (3): Physical properties of representative pedons in a toposequence in Wadi El-Amal study area, Aswan

| SMU | Pedon No. | Depth interval (cm) | Coarse-earth fraction (%) | Fine-earth fractions (%) | | | | | | A.W. (%) |
| | | | | Sand | | | Silt | Clay | Textural class | |
				Coarse sand	Medium sand	Fine sand				
SMU1 (Toeslope)	**21**	0-35	4.15	20.75	10.25	24.25	24.25	20.5	Sandy clay loam	23.55
		35-105	3.65	5.52	3.45	7.35	50.18	33.5	Silty clay loam	27.13
		105-130	6.41	4.76	16.24	9.15	32.7	37.15	Clay loam	30.14
		130-155	5.64	16.68	15.87	33.25	5.1	29.1	Sandy clay loam	25.35
	35	0-25	4.08	6.65	9.15	3.45	49.83	30.92	Silty clay loam	28.65
		25-90	3.95	19.45	24.55	19.25	5.51	31.24	Sandy clay loam	24.15
		90-140	2.07	13.66	10.25	15.24	25.17	35.68	Clay loam	29.15
SMU2 (Footslope)	**49**	0-30	15.98	8.27	2.65	49.2	28.63	11.25	Sandy loam	15.95
		30-70	19.57	10.85	9.25	21.15	35.1	23.65	Loam	19.25
		70-110	21.04	7.83	5.87	11.25	54.8	20.25	Silt loam	17.25
		110-145	16.18	12.44	20.66	6.45	48.8	11.65	Loam	18.65
SMU3 (Backslope)	**52**	0-20	20.24	34.3	13.05	35.15	12.25	5.25	Loamy sand	7.05
		20-40	17.37	41.34	21.25	27.56	2.7	7.15	Coarse sand	5.36
		40-65	16.09	45.03	18.24	25.47	1.81	9.45	Loamy sand	8.45
		65-95	15.71	20	10.25	50.25	16.05	3.45	Loamy fine sand	9.15
SMU4 (Shoulder)	**63**	0-30	29.18	20.19	30.05	45.21	3.3	1.25	Sand	5.15
		30-45	19.44	29.24	10.77	57.35	0.49	2.15	Fine sand	7.36
SMU5 (Shoulder)	**66**	0-15	34.25	28.62	40.29	24.54	1.99	4.56	Coarse sand	4.25
		15-20	29.38	17.51	15.14	60.24	0.64	6.47	Fine sand	6.45

Soil Chemical Properties

The results of chemical analyses conducted on soils of Wadi El-Amal are listed in Table (4). The pattern of salinity within the pedon across the study area is related to landscape distribution and slope position. According to Soil Science Division Staff (2017), ECe values were highest for the toeslope soils, ranging from 1.61 to 3.63 dS m^{-1} (slightly saline) in SMU1. In contrast, lower salinity values (0.38-0.87 dS m^{-1}) were recorded in upper slope positions (SMU4 & SMU5). Consistent with Soil Science Division Staff (2017), pH is alkaline across all studied pedons which varied from 7.93 (moderately alkaline) to 8.98 (strongly alkaline). The vertical distribution of the pH within each pedon may vary among landscape positions and may either decrease or increase with an increase in depth. SAR values varied from 1.99 to 9.17% and are not consistent with pH values in the studied soils.

According to FAO (2006), the results of field and laboratory analysis showed an extremely calcareous character in all native pedons of studied soils with values of CaCO$_3$ ranging from 13.65% (strongly calcareous) to 39.1% extremely calcareous (Table 5; Figs. 4, 5 & 6). CaCO$_3$ values were consistent with the pH values in all studied soils. The maximum value was recorded in the Cr layers across pedons of SMU4 and SMU5. Lime content was relatively higher in studied soils due to their calcareous nature of the bedrock, as well as leaching of bicarbonate from upper soils during flash flooding and their subsequent precipitation as carbonates in the lower soils. Gypsum concentration across all studied pedons was low (0.07-0.52%). The irregular trend of CaCO$_3$ and gypsum with depth could be due to the variable nature of the geological materials.

Fertility Status

Organic matter (O.M) content was found at very low levels which varied from 0.07-0.47% across the study area (Table 5). The low content was due to poor vegetation and the high rate of organic matter decomposition under hyper-thermic temperature regime which leads to extremely high oxidizing conditions. O.M concentration varies horizontally across the slope position, and vertically within the pedon. It increased strongly downslope and with pedon depth. According to Horneck et al. (2011), the entire soils of the study area had low levels of available nitrogen and phosphorus which varied from 11.1 to 45.83 ppm, and 1.64 to 6.89 ppm, respectively. This could be attributed to the low content of organic carbon in these soils and the fixation of released phosphorus by lime and hydroxides of Ca and Mg. By contrast, available potassium was high (125.8-275.0 ppm) in SMU1 and SMU2 soils and medium (96.3-104.6 ppm) in SMU3. While available potassium concentration in SMU4 and SMU5 was observed in low levels which ranged between 44.21 and 59.12 ppm (Table 5). The distribution of organic matter in these soils was primarily related to physiography and slope location.

Table (4): Soil chemical characteristics in a catena of Wadi El-Amal study area

SMU	Pedon ID	Horizon /layer	pH	EC_e dS/m	Soluble Cations (mg/l)				Soluble Anions (mg/l)				SAR (%)	$CaCO_3$ (%)	Gypsum (%)
					Na^+	K^+	Ca^{+2}	Mg^{+2}	Cl^-	SO_4^{-2}	CO_3^{-2}	HCO_3^-			
SMU1 (Toeslope)	21	C	7.98	2.19	14.07	0.95	4.37	2.43	15.04	4.35	0.0	2.43	7.63	25.1	0.15
		CK	8.72	2.57	16.70	1.02	4.49	3.49	17.70	5.00	0.0	2.99	8.36	37.2	0.22
		Ckm	8.79	1.91	12.35	0.85	2.48	1.77	12.95	3.54	0.0	0.88	8.47	31.1	0.41
		Ckkm	7.93	1.61	10.07	0.58	3.22	2.30	10.35	3.98	0.0	1.84	6.06	27.7	0.14
	35	Ap	8.17	2.59	16.78	0.82	6.20	3.45	17.51	6.17	0.0	3.45	7.55	23.2	0.23
		Ck	8.34	3.63	22.79	1.01	7.84	4.51	24.30	8.41	0.0	3.43	9.17	25.0	0.09
		Ckkm	8.90	2.78	16.98	0.85	6.05	3.49	17.25	6.72	0.0	3.39	7.77	31.1	0.18
SMU2 (Footslope)	49	C	8.40	1.63	10.04	0.37	3.40	2.43	10.19	3.62	0.0	2.43	5.88	27.2	0.37
		Ck	8.39	0.87	5.69	0.76	1.39	0.84	6.18	1.66	0.0	0.84	5.39	15.2	0.34
		Ckkm	8.27	0.82	5.53	0.38	1.49	0.75	5.74	1.43	0.0	0.98	5.23	17.2	0.52
		Ckm	8.24	1.91	12.45	0.85	2.45	1.79	13.99	2.53	0.0	0.85	8.41	25.25	0.24
SMU3 (Backslope)	52	C	8.02	0.79	5.30	0.28	1.39	0.96	5.64	1.33	0.0	0.96	4.89	19.1	0.00
		Ck	8.98	1.35	9.16	0.44	2.45	1.47	10.29	1.27	0.0	1.96	6.54	32.41	0.21
		Ckm	7.98	1.45	9.26	0.44	2.45	1.47	10.29	1.37	0.0	1.96	6.61	22.15	0.08
		2C	8.85	2.27	14.87	0.95	4.37	2.42	15.54	4.65	0.0	2.42	8.06	33.1	0.26
SMU4 (Shoulder)	63	C	8.05	1.73	12.25	0.85	2.45	1.72	12.94	3.50	0.0	0.83	8.48	25.7	0.17
		2Cr	8.78	0.74	4.54	0.80	1.24	0.84	4.69	1.74	0.0	0.99	4.45	22.1	0.11
		Cr	8.94	0.86	5.54	0.38	1.69	0.99	6.04	1.57	0.0	0.99	4.79	33.9	0.27
SMU5 (Shoulder	66	R	8.09	0.38	1.81	0.23	0.95	0.81	1.90	1.18	0.0	0.71	1.99	39.1	0.07
		C	8.17	0.87	5.69	0.76	1.39	0.84	6.18	1.66	0.0	0.84	5.39	13.65	0.31

The studied micronutrients consist of four essential elements: iron (Fe), manganese (Mn), zinc (Zn), and copper (Cu. These elements occur in very small amounts in both soils and plants, but their role is equally as important as the primary or secondary nutrients. On the basis of critical limits of available micronutrients given by Jacobsen *et al.* (2005) and Horneck et al. (2011), the studied soils of SMU1, SMU2, and SMU3 were marginal to adequate in available iron, manganese, zinc, and copper. Micronutrient cations of Fe, Mn, Zn, and Cu in these soils ranged from 3.83 to 7.49 ppm, 1.48-3.44 ppm, 0.74-2.44 ppm, and 0.54-1.76 ppm, respectively (Table 5). By contrast, other soils of SMU 3 and SMU 4 were very low to low in these nutrients, where they ranged from 0.91 to 2.45 ppm for Fe, 0.12-0.39 ppm for Mn, 0.19-0.38 ppm for Zn, 0.06-0.13 ppm for Cu (Table 5). Low available micronutrients in the soils may be attributed to high soil pH and the calcareous content observed and could react with Ca^{++} and Mg^{++} cations or $CaCO_3$ to produce insoluble compounds that are not readily available for plant uptake (Hodges, 2007). A deficiency of one or more of the micronutrients can lead to severe depression in growth, yield, and crop quality. Soils of SMU3 and SMU4 do not contain sufficient amounts of these nutrients to meet the plant's requirements for rapid growth and good production. Therefore, supplemental micronutrient applications in the form of commercial fertilizers or foliar sprays must be made. Chemical fertilizer application should be in small, regular rates that are applied close to plant roots as sandy soils have the very little capacity to hold large concentrations of nutrients. Addition of organic matter levels can help to reduce any micronutrient 'fixation' reactions that may be present, by binding Ca^{++} and Mg^{++}, and forming soluble complexes which may be available to plants (Hodges, 2007). CEC varied from 3.17 cmol (+) kg^{-1} in studied pedons at upper slope positions in SMU5 to 27.45 cmol (+) kg^{-1} at lower slope position in SMU1 (Table 5). This showed that the soils of SMU4 and SMU5 have low nutrient retention capacity. CEC values were highly concomitant with O.M and clay content horizontally across toposequence and vertically within pedons. The CEC values indicate the fertility potential in soil of SMU1 at toeslope compared with that of upland at back slope and shoulder slope positions. Low CEC levels in the studied soils at shoulder position may also be due to heavy base leaching down the pedons, as well as the soil's very low clay content.

Table (5): Nutrient and fertility status of the investigated soils across the studied soil mapping units

SMU	Pedon No.	Horizon /layer	O.M (%)	Available macro and micronutrients, ppm							CEC Cmol (P^+) kg $^{-1}$
				N	P	K	Fe	Mn	Zn	Cu	
SMU1 (Toeslope)	21	C	0.20	44.02	6.89	193.6	4.59	2.14	1.52	1.76	25.95
		CK	0.28	39.83	5.42	215.0	5.69	3.44	1.33	1.11	19.18
		Ckm	0.47	43.02	5.93	228.4	4.16	1.91	1.16	0.72	27.45
		Ckkm	0.14	45.83	6.14	275.0	4.56	2.04	1.51	1.20	21.45
	35	Ap	0.40	41.70	5.66	244.4	6.17	1.95	1.71	1.07	26.48
		Ck	0.27	45.90	6.88	229.4	5.56	2.74	1.09	0.82	24.25
		Ckkm	0.31	39.17	5.45	235.5	7.49	2.12	1.41	1.09	25.86
SMU2 (Footslope)	49	C	0.44	31.3	6.33	134.2	3.72	1.50	1.91	0.94	14.08
		Ck	0.20	35.20	4.60	125.8	4.20	1.89	1.63	0.85	16.05
		Ckkm	0.29	25.80	2.65	136.5	3.98	1.48	1.41	0.58	15.09
		Ckm	0.14	34.91	2.51	173.1	4.34	1.56	2.44	1.53	13.89
SMU3 (Backslope)	52	C	0.27	22.70	4.84	98.2	4.78	1.80	0.91	1.02	7.68
		Ck	0.23	31.00	2.92	96.3	3.90	1.58	1.42	0.74	6.09
		Ckm	0.11	37.10	1.64	104.6	3.83	1.64	0.74	0.74	6.24
		2C	0.20	20.40	3.39	101.9	4.35	1.70	1.32	0.59	5.36
SMU4 (Shoulder)	63	C	0.10	19.74	1.65	55.23	2.45	0.39	0.22	0.13	4.25
		2Cr	0.02	17.21	2.35	59.12	2.08	0.51	0.19	0.06	3.08
SMU5 (Shoulder)	66	Cr	0.07	11.10	3.20	44.21	2.15	0.32	0.38	0.07	5.32
		R	0.07	13.50	1.87	45.35	0.91	0.12	0.20	0.09	3.17

Land Evaluation of Wadi El-Amal Area

Based on the characteristics of water, soil, environment, and socioeconomic and political collections, the interpretative groupings of land evaluation methods (Q_LDLPE, USDA LCC, and Q_LDLAC) were carried out as presented in Table (6) and Figs. (5 and 6). The agricultural limitations were identified for each soil mapping unit. Irrigation water is available with good quality, low aggregated soil limitations, and good status of socioeconomic measures; besides the political factors which support the development of SMU1 and SMU2. Despite the high content of gravel in footslope soils, it couldn't be considered a severe limitation for crop production. Slightly salinity and highly lime content at specific locations at toeslope were the slight limitations of the area which can be improved by specific management. As a result, the Q_LDLPE index has placed the SMU1 and SMU2 in high potential classes to produce a wide range of crops (Table 6 and Fig. 5). Meanwhile, irrigation water is available but with permissible conditions at the area of SMU3 that is why the Q_LDLPE index placed these resources in slight potential class.
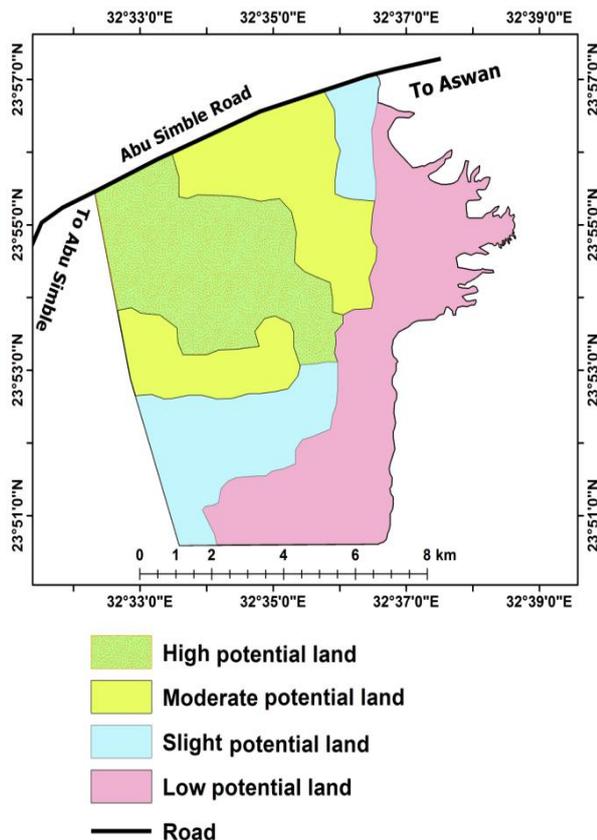

Fig. (5): Land potentiality classes of Wadi El-Amal study area using Q_LDLPE model

Among salient soil limitations, shallower depth, somewhat poorly drainage, coarse fragments either on the surface of the land or within pedon layers, high content of lime, and low in fertility status as well as the undulating topography were found to be the most important constraints for agricultural development in the area of SMU4 and SMU5. Consequently, lands occupied on the shoulder were placed under low

potentiality class based on Q_LDLPE method. Soils of SMU5 with very severe limitations owing to undulating topography, soil erosion hazard, the very shallowness of soil depth, poor drainage, coarse fragments severe limitations of soil erosion, poor infrastructure, lack of technical knowledge, and weak institutional support made up the Q_LDLPE index low which placed under low potentiality classes (Table 6 and Fig. 5). The low potential land is not sufficient to grow crops in a profitable way. Thus, the non-agricultural activities are recommended for the midland area; *e.g.,* road construction to link the lower portions (toeslope) of the Wadi to its upper portion (shoulder).
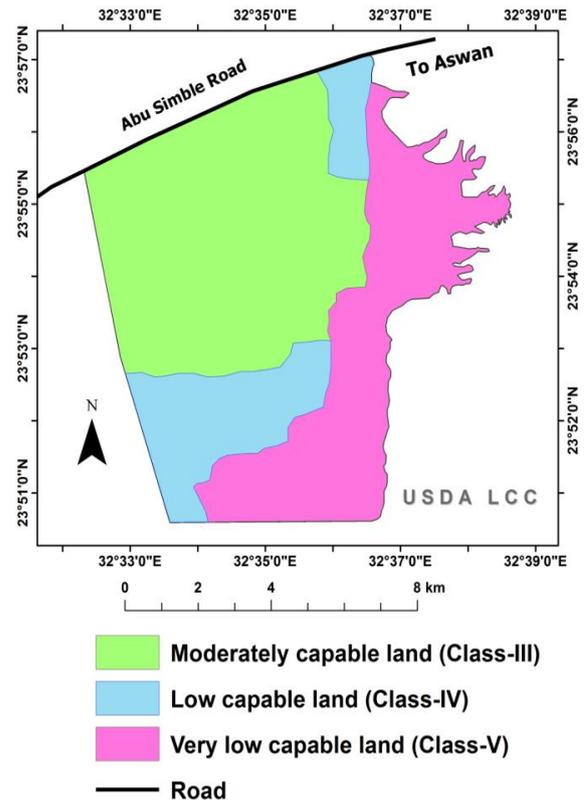

Fig. (6): Land capability classes of Wadi El-Amal study area using the American land capability classification method

Accordingly, the land under study could be categorized as per Q_LDLPE model into four potentiality classes (Fig. 5). Around 4760 Faddan (24.64%) was found to have high potential land. This area is entirely covered by the soils of SMU1. Moderate potential class was for SMU2 which occupy an area of 4740 Faddan. In contrast, slight potential lands were for SMU3 (3350 Faddan) and low potential class covered an area of 6470 Faddan (33.49%) and distributed on SMU4 (2900 Faddan) and SMU5 (3570 Faddan) (Table 6 and Fig. 5). On the other hand, USDA LCC system has grouped the studied lands into three capability classes (Table 6 and Fig. 8). The moderately capable lands (Class III) represent 49.17% of the total area; it is associated with the soils of SMU1 and SMU2. Low capable lands cover 17.34% of the study area (3350 Faddan) which represented by SMU3. Lands of SMU4 and SMU5 had very low capable classes; these units represent 33.49% of the total area (6470 Faddan).

Based on the climate, soil physical (Table 3), chemical characteristics (Table 4), and fertility data (Table 5), interpretative groupings of Q_LDLAC were worked out for agricultural priority as presented in Table (6). The criteria of climate, environment, soil, and agricultural policies were determined and matched with the optimum crop requirements for different strategic crops. The affecting limitations were regarding climate, limited irrigation water, land topography, shallow soils, sandy texture, high contents of gravel and coarse fragments, soil salinity, pH, $CaCO_3$, soil available water, soil drainage, and poor fertility. Additionally, agricultural policies criteria for priority crops were considered as suggested by the Egyptian government in respect to marketing responses achieving self-sufficiency in this area. Precision farming technology interventions in soil and water management, as well as crop enhancement, are expected to result in high agricultural output for adapting to the local conditions of the studied region (Tohidyan and Rezaei-Moghaddam, 2018).

Accordingly, six land utilization types (LUTs) were tested for their aptness in the studied soils. Four different classes of land aptness (high, moderate, slight, and non-aptness) were separately given for each crop based on the intensity of significant limitations. Only the high aptness crops were suggested to be cultivated in the mapped soils (Table 6). These crops were prioritized over the study area as optimum land utilization types (LUTs) for profitable cultivation based on the high market value. They are: (i) field crops (sugar beet, cassava, quinoa, wheat, barley, and maize); (ii) vegetables (tomatoes, cucumber, peppers, potatoes, pea, soybean, squash, and onion); (iii) citrus-fruits such as mango, datepalm, olive, lemon, and grape; (iv) oil crops (sesame, canola, jojoba, and jatropha) were suggested for achieving self-sufficiency in edible oil and biofuel; (v) forages (sorghum, panicum, and alfalfa) were selected as alternatives for livestock fodders to be cultivated in SMU3; and (vi) medicinal and aromatic plants (coriander, mint , senna, and rose) (Table 6).

Land Use Planning of Study Area

On the basis of the previous results of land evaluation procedures, the IDLUP methodology has decided and outlined in Table (6) and presented in Fig. (7). Based on the value-added for crops, the priority order for agrarian expansion was determined and suggested for all crops. As per IDLUP model, the studied lands were planned into two main groups which are: (a) planning for agricultural development, and (b) planning for non-agricultural development. The agrarian expansion should be divided into equal pieces to achieve the precision farming in a sustainable basis. The priority order for agricultural development was based on the addition value of crops. The value-added crops were selected as land utilization types and prioritized as follows: field crops and vegetables (4760 Faddan) > citrus-fruits and oil crops (4740 Faddan) > medicinal and aromatic plants and forages (3350 Faddan). For optimum land use planning of the study area, lands of SMU4 and SMU4 which occupy 6470 Faddan (33.49%) were excluded from the agricultural development.

Henceforth, the priorities of land utilization planning were categorized into four priorities as follows:
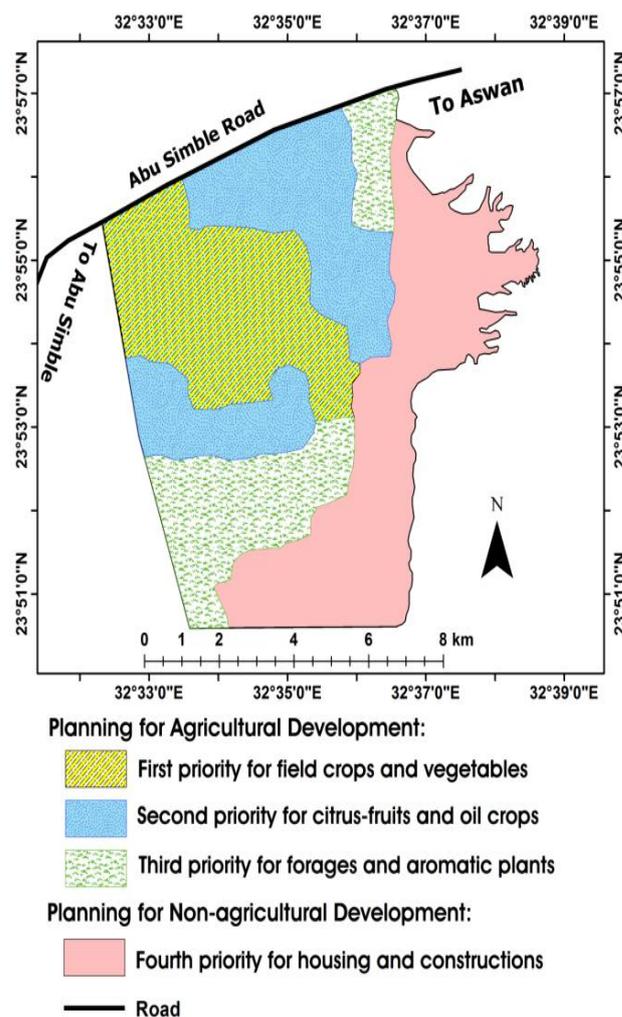

Fig. (7): Integrated planning of Wadi El-Amal area for sustainable development

First priority for field crops and vegetables:

High potentiality lands (4760 Faddan) (Fig. 4) must always come as the first priority for sustainable protected agriculture (Fig. 7). Soils belonging to this group have got the potential function to produce rich and cash vegetables through greenhouse technologies overcoming the environmental risks (Fig. 7). Egypt is a net food importer, including for over half of its wheat needs. To achieve the food security, the self-sufficiency of strategic and food crops in the studied region must be done by increasing their production per unit by following the priority pattern (wheat > sugar beet > cassava > quinoa > maize > barley).

Second priority for citrus-fruits and oil crops:

The high value-added crops such as Oil crops and citrus-fruits were selected to be the second priority for cultivation in SMU2 (4740 Faddan). Soils belonging to this group have got moderate potential function to produce these crops in profitable basis. The agrarian expansion in this area is based on the following priority pattern: jojoba > canola > sesame > olive > datepalm > mango > lemon > peach > grape.

Third priority for aromatic plants and forages:

Slight potential land which occupies 3350 Faddan on SMU3 was proposed for the third priority for precision farming using aromatic plants and forages in profitable way. Based on the value-added for these crops, the priority order for agrarian expansion was determined as follows: rose > coriander > senna > mint > panicum > alfalfa > sorghum > clover.

Fourth priority for housing and constructions:

The area of SMU4 and SMU5 was excluded from the agricultural activities. This area (6470 Faddan) is suitable for non-agricultural activities such as housing, new towns, urban settlements, and industries. New smart Abu-Simble city is suggested to be constructed in the area of SMU4 which extends on 2900 Faddan. The new city should include all the services such as hospital, schools, university, club, and other governmental institutions. The roads should be constructed first to link the soil mapping units with the Abu-Simble road. The industries, museum, and other related tourism activates should be established in the area of SMU5 which extends on 3570 Faddan.

Table (6): Land evaluation classes and suggested planning priorities across soil mapping units

SMU[a]	Q_LDLPE class[b]	USDA LCC[c]	Q_LDLAC[d]	IDLUP[e]	
			High aptness LUTs	Planning and priority pattern	Areal coverage
SMU1	H	Class-III	LUT1 (Field crops): wheat, cassava, quinoa, barley, maize, sugar beet. LUT2 (Vegetables): tomatoes, cucumber, potatoes, peppers, soybean, onion, and squash.	Precision farming: 1st priority for wheat > sugar beet > cassava > quinoa > maize > barley > tomatoes > potatoes > peppers > soybean > cucumber > squash > onion.	4760 Faddan (24.64%)
SMU2	M		LUT3 (Citrus-fruits): grape, olive, datepalm, mango, peach, lemon LUT4 (Oil crops): jatropha, jojoba, canola, sesame.	Precision farming: 2st priority for jatropha > jojoba > canola > sesame > olive > datepalm > mango > lemon > peach > grape.	4740 Faddan (24.53%)
SMU3	S	Class-IV	LUT5 (Forages): panicum, alfalfa, sorghum. LUT6 (Medicinal and aromatic plants): rose, coriander, senna, mint.	Precision farming: 3st priority for rose > coriander > senna > mint > panicum > alfalfa > sorghum.	3350 Faddan (17.34%)
SMU4 SMU5	L	Class-V	Non-productive lands.	Non-agricultural land: 4st priority for housing and constructions.	6470 Faddan (33.49%)

[a] SMU (soil mapping unit)

[b] Q_LDLPE (Qualitative desert land potentiality evaluation), H (high potential land), M (moderate potential land), S (slight potential land), L (low potential land)

[c] USDA-LCC (USDA Land capability classification), Class-III (moderately capable land, Class-IV (low capable land), Class-V (very low capable land)

[d] LUT (land utilization type)

[e] IDLUP: Integrated desert land use planning

CONCLUSION

This work incorporates evaluation of all aspects related to soil, water, climate, socioeconomic measures in the desert ecosystem of Wadi El-Amal area, Aswan, Egypt. Specialized desert land use planning approaches attempted in the present study can be better tools for optimizing desert land use on a sustained basis. Q_LDLPE model has grouped the study area into four potentiality classes while the USDA LCC system classified the study area into three capability classes. Q_LDLAC has suggested six land utilization types as value-added crops for cultivation in the study area. IDLUP has planned an area of about of 66.51% of the total study area (12850 Faddan) for agricultural development and excluded the rest area (33.49%) from the agrarian expansion which may be used for the housing and constructions. The value-added crops in the agrarian expansion area were prioritized as follows: field crops and vegetables (4760 Faddan) > citrus-fruits and oil crops (4740 Faddan) > medicinal and aromatic plants and forages (3350 Faddan).If these suggested measures are adopted correctly, it would help to reduce desertification process in the study area. These measures could also reduce the severity of drought and increase the agricultural productivity. The methodology presented in this paper could be very helpful to meet the target of zero hunger. This methodology including Q_LDLPE, USDA LCC, Q_LDLAC, and IDLUP can be easily incorporated in GIS domain and could be applied to local, regional and national scales in desert regions. This integrated methodology can also be applied elsewhere to ensure sustainable food production systems and to progressively improve land and soil quality.

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التخطيط المُتكامل لاستخدام الأراضي بوادي الأمل، محافظة أسوان، مصر

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قسم البيدولوجي، شعبة مصادر المياه والأراضي الصحراوية، مركز بحوث الصحراء، القاهرة، رقم بريدي ١١٧٥٣

يعتبر وادي الأمل من أهم الموارد الأرضية الصحراوية التي أدرجت ضمن خطة الدولة لتعويض النوبيين متضرري بناء السد العالي. تمتد منطقة وادي الأمل على مساحة ١٩٣٢٠ فدان، وتعتبر جزء من وادي كركر ، أسوان، وهو من أهم أحواض المجاري المائية الذي يزخر بإمكانياته المائية والأرضية. ومن هذا المنطلق، إستهدفت هذه الدراسة تقييم كلاً من الموارد المائية والأرضية عبر منطقة وادي الأمل من أجل التخطيط الأمثل لإستخدام تلك الموارد زراعياً أو عمرانياً. ولتحقيق هدف هذه الدراسة تم تجميع بعض العينات من مياه بعض الآبار المتواجدة بمنحدر الوادي Downslope من أجل تحليلها معملياً للوقوف على درجة صلاحيتها للري. ولدراسة الموارد الأرضية لهذا الوادي فقد تم تمثيل الأراضي تحت الدراسة بعدد ٧١ قطاعاً أرضياً من خلال إجراء شبكة متساوية الأبعاد لتشمل كافة الإختلافات في مورفولوجية الأشكال الأرضية بمنطقة الدراسة. شملت الدراسة الحقلية وصف المنطقة Landscape وصفاً مورفولوجياً كاملاً، بالإضافة إلى حفر القطاعات الأرضية لعمق ١٥٠ سم مالم يعترض الحفر وجود طبقة صخرية، تم وصف قطاعات التربة الممثلة وصفاً بيدومورفولوجياً من حيث تقدير لون التربة Soil color، و تحديد الحدود الفاصلة بين الطبقات، سمك كل طبقة، القوام، نوع وشكل وحجم البناء، درجة التماسك، درجة الالتصاق واللدونة للتربة، وكذلك وصف أي مظاهر بيدومورفولوجية أخرى كتكوينات ثانوية طرأت على طبقات قطاعات التربة، مع تحديد نسبة الزلط والفتات الصخري من حيث درجة إنتشاره وأحجامه طبقاً للنظام الأمريكي وهي كالتالي: حصى (2-76mm) Gravel، جلاميد صغيرة (76-250mm) Cobbles، جلاميد متوسطة الحجم (250-600mm) Stones، جلاميد كبيرة (mm 600<) Boulders، حيث تم تجميع عينات التربة مُمثلة للإختلافات البيدومورفولوجية للتتابع الطبقي للقطاعات. أشارت النتائج المعملية إلى أن معظم مياه الري تعتبر صالحة لمعظم المحاصيل المُزمع زراعتها مع الحكمة والترشيد في الإستخدام مع تطبيق أنظمة الري الحديثة وخاصة تحت السطحية Sub-surface irrigation بإتباع نظم الزراعة الدقيقة Precision farming. كما أوضحت نتائج الفحص الحقلي والتحليل المعملي لعينات التربة تواجد إختلاف في قوام التربة والذي تباين ما بين القوام متوسط النعومة Moderately fine textured soils إلى القوام الرملي الخشن Coarse textured soils مع تواجد الحصى والزلط بأحجام مختلفة (Gravel, cobbles, stones). كما افتقرت أراضي الوادي للمادة العضوية وبعض المغذيات النباتية الصغرى والكبرى. وبناءً على معايير هامة مثل: العمق الفعال للتربة، قوام التربة، نسبة الحصى أو الزلط ونوعه، وطبوغرافية سطح الأرض، فقد تم تقسيم تربة منطقة وادي الأمل إلى أربع وحدات خرائطية Soil mapping units (SMUs) وهي كالتالي: (i) أراضي عميقة، متوسطة نعومة القوام، ذات طبوغرافية مستوية تقريباً (٤٧٦٠ فدان ؛ ٢٤٬٦٤%)، (ii) أراضي عميقة، متوسطة قوام التربة حصوية، ذات طبوغرافية خفيفة التموج (٤٧٤٠ فدان ؛ ٢٤٬٥٣%)، (iii) أراضي متوسطة العمق، خشنة القوام حصوية، ذات طبوغرافية خفيفة التموجّ(٣٣٥٠ فدان ؛ ١٧٬٣٤%)، (iv) أراضي ضحلة العمق، خشنة القوام زلطية، ذات طبوغرافية مموجة (٢٩٠٠ فدان ؛ ١٥٬٠١%)، (v) أراضي ضحلة جداً، خشنة القوام زلطية، ذات طبوغرافية مموجة (٣٥٧٠ فدان ؛ ١٨٬٤٨%). من أجل وضع إستراتيجية لكيفية الإستفادة من الموارد الأرضية والمائية المتاحة بمنطقة الدراسة؛ وطبقاً لخواص مياه الري الكيميائية، وصفات التربة البيدومورفولوجية والفيزيائية، والكيميائية، والخصوبية، بالتكامل مع المعايير البيئية والعوامل الإقتصادية والإجتماعية والسياسية والتي قد تؤثر على عمليات إتخاذ لقرار بمدى تنمية هذه المنطقة من عدمه، فقد تم تقسيم أراضي منطقة وادي الأمل بواسطة نظام Q$_L$DLPE لتقييم قدرة الأرض الكامنة في البيئة الصحراوية إلى أربع مجموعات وهي كالتالي: (١) أراضي ذات قدرة إنتاجية عالية High potential lands ممتدة على أراضي وحدة التربة الخرائطية الأولى SMU1، (٢) أراضي ذات قدرة إنتاجية متوسطة Moderate potential lands ممتدة على أراضي وحدة التربة الخرائطية الثانية SMU2، (٣) أراضي ذات قدرة إنتاجية هامشية (Slight potential lands) والتي تمثل أراضي وحدة التربة الخرائطية الثالثة SMU3، و (٤) أراضي ذات قدرة إنتاجية منخفضة (Low potential lands) ممتدة على البقعة الصخرية الضحلة وهي تمثل ٦٤٧٠ فدان تشمل وحدات التربة الخرائطية SMU4 و SMU5. كما أمكن تقسيم أراضي منطقة الدراسة عند تطبيق النظام الأمريكي USDA Land capability classification (USDA LCC) إلى ثلاث مجموعات وهي كالتالي: (١) أراضي الدرجة الثالثة Class-III وهي أراضي متوسطة الإنتاجية Moderately capable lands والتي تغطي مساحة ٩٥٠٠ فدان لتمثل ٤٩٬١٧% من إجمالي منطقة الدراسة وتشمل أراضي وحدات التربة الخرائطية الاولى والثانية SMU1 & SMU2 ، (٢) أراضي الدرجة الرابعة Class-IV وهي أراضي منخفضة الإنتاجية Low capable lands والتي تغطي مساحة ٣٣٥٠ فدان لتمثل ١٧٬٣٤% من إجمالي منطقة الدراسة وتشمل أراضي وحدة التربة الخرائطية الثالثة SMU3 ، (٣) أراضي الدرجة الخامسة Class-IV وهي أراضي ذات إنتاجية منخفضة جداً Very low capable lands والتي لا يمكن زراعتها، وتغطي ٣٣٬٤٩% من إجمالي منطقة الدراسة وتشمل أراضي وحدات التربة الخرائطية الرابعة والخامسة SMU4 & SMU5. فضلاً عن ذلك، فقد تم تطبيق نظام تقييم صلاحية المحاصيل بالأراضي الصحراوية للإستخدام الزراعي (Q$_L$DLAC) على الأراضي المدروسة لمعرفة أنواع التراكيب المحصولية الملائمة لخصائص التربة والصفات الكيميائية لمياه الري وكذلك المعايير المناخية لمنطقة الدراسة، حيث تم إقتراح بعض التراكيب المحصولية Land utilization types (LUTs) للتنمية الزراعية والتي تناسب كل نوع من أنواع الأراضي المدروسة بصورة كبيرة؛ وهي كالتالي: المحاصيل الحقلية (الكينوا، الكسافا، القمح)، محاصيل الخضر Vegetables (الطماطم، البطاطس، الخيار، فول الصويا، البازلاء، البصل، الكوسة)، الفاكهة والموالح (العنب، الزيتون، نخيل البلح، التين، الجوافة، المانجو، الليمون)، محاصيل الزيت Oil crops (الجاتروفا، الجوجوبا، الكانولا، السمسم)، ومحاصيل العلف Forages (البونيكام، البرسيم الحجازي، السورجم)، يليه النباتات الطبية والعطرية Medicinal and Aromatic Plants (الورد البلدي، الكزبرة، السنا، النعناع). وبناءً على كافة نتائج تقييم قدرة الأرض الإنتاجية والتراكيب المُقترحة للزراعة بأراضي منطقة الدراسة من خلال نظم التقييم التي تم إستخدامها بمنطقة الدراسة (Q$_L$DLPE, USDA LCC, Q$_L$DLAC)، فقد تم تخطيط أراضي منطقة وادي الأمل بإستخدام نموذج IDLUP لتخطيط الأراضي الصحراوية بالمناطق الجافة وشبه الجافة، فقد تم تقسيم منطقة الدراسة إلى قسمين رئيسيين هما: (أ) الأراضي القابلة للزراعة وهي تمثل ٦٦٬٥١% والتي تمتد على مساحة ١٢٨٥٠ فدان وتشمل ثلاث وحدات خرائطية SMU1, SMU2, SMU3 (ب) الأراضي غير القابلة للزراعة والتي تبلغ مساحة ٦٤٧٠ فدان (٣٣٬٤٩%) ، وتمتد على أراضي SMU4 , SMU5 ، حيث تم وضع إستراتيجية التنمية الشاملة لأراضي منطقة الدراسة من خلال تحديد أربع أولويات للتنمية تشمل كيفية الإستفادة من الأراضي الصالحة للزراعة والأخرى غير القابلة للزراعة. فقد تم وضع ثلاث أولويات للتنمية الزراعية من خلال إختيار المحاصيل ذات القيمة المضافة الأعلى تسويقاً بالمنطقة بنظام الزراعة الدقيقة Precision farming والتي تساهم بشكل كبير في التنمية الاقتصادية للدولة؛ على النحو التالي: (١) أولوية أولى لزراعة محاصيل الحقل مع الخضروات على مساحة ٤٧٦٠ فدان والتي تشمل أراضي الوحدة الأولى SMU1، (٢) أولوية ثانية لزراعة محاصيل الزيت وإشجار الفاكهة على مساحة ٤٧٤٠ فدان بأراضي الوحدة الثانية SMU2، (٣) أولوية ثالثة لزراعة النباتات الطبيعة والعطرية مع محاصيل الأعلاف على مساحة ٣٣٥٠ فدان والتي تغطي أراضي الوحدة الثالثة SMU3. بينما الأولوية الرابعة فتشمل كيفية الإستفادة من الأراضي غيرالقابلة للتنمية الزراعية بتنميتها في مجال البنية التحتية والتعمير مثل إنشاء شبكة الطرق والكباري، وإقامة مدينة أبو سمبل الجديدة بطراز ذكي إليكتروني Smart city شاملة كافة المرافق والخدمات؛ وذلك لخدمة أهالي أسوان وخاصة أهل النوبة. كما ويجب تنفيذ التنمية الزراعية بنظام الزراعة الذكية لتحقيق أعلى عائد من وحدتي الأرضي والمياه، بالتزامن مع التنمية العمرانية في خطوات متوازية كلاً على حدة وبصورة صحيحة، تساعد على إستدامة الموارد الصحراوية لأجيال قادمة. أوصت الدراسة بأن النظام المستخدم لتقييم وتخطيط الأراضي بمنطقة الدراسة هو نظام متكامل وحديث وملائم لظروف الأراضي الصحراوية ويمكن إستخدامه بشكل معنوي على مستوى العالم فيما يخص بتنمية موارد البيئة الصحراوية في المناطق الجافة وشبه الجافة.