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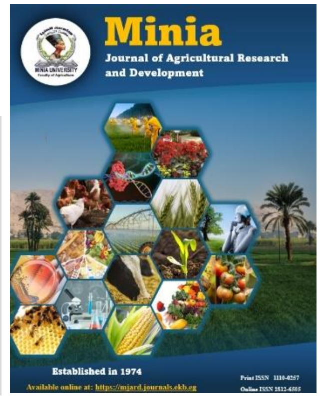

Spatial Analysis of Land Capability and Crop Suitability Assessment in West El-Minya, Egypt for Sustainable Agricultural Development.

K. Haroon., H. A. Sawy, W. S. Mohamed, A. S. Ahmed , Abd El-Aziem M. M.

Soil Science Department, Faculty of Agriculture, Minia University

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ABSTRACT

Land evaluation in arid regions is a critical prerequisite for sustainable agricultural development, especially in countries such as Egypt where desert reclamation projects represent the main strategy for horizontal expansion. This study aimed to evaluate land capability and crop suitability in a newly reclaimed area of about 29,000 feddans (≈12,180 ha) west of El-Minya, Western Desert, through the integration of intensive soil survey, laboratory characterization, and GIS-based spatial modeling. A total of 1,934 soil profiles were examined using a systematic grid survey, and representative samples were analyzed for key physical and chemical properties. Land capability was calculated via the modified Storie Index and land suitability for twenty major crops was calculated using Land Use Suitability Evaluation Tool (LUSET). Land capability assessment showed that only 10% of the land falls into grade 3, while about 75% is grade 4 and only 2.6 % poor or non-agricultural (grade 5), indicating that careful management is required to achieve viable productivity. Crop suitability analysis highlighted that field crops were the most promising: wheat and barley were highly to moderately suitable in nearly 68% of the area, while sorghum reached over 50% in S1. Oil crops such as sunflower and sesame showed strong potential with more than 70% of the land rated S1–S2, while soybean and groundnuts were largely confined to S2–S3. Vegetable crops showed moderate suitability: onion achieved the best performance (≈78% S2), whereas potato, tomato, and watermelon were restricted to S2–S3 classes. Fruit crops were the most limited crops, with olive showing adaptability (≈80% S2), while citrus and mango were mostly marginal (S3) and peach was marginally suitable (>95% S3). The study concludes that land capability in the investigated area is constrained primarily by salinity, carbonate accumulation, and shallow depth. However, significant opportunities exist for sustainable production if proper management practices are adopted, particularly salinity control, soil fertility improvement through organic amendments, efficient irrigation systems, and careful crop zoning. The results provide a robust scientific basis for guiding agricultural investment and land use planning in Egypt's Western Desert, and they emphasize the importance of combining classical evaluation frameworks with modern geospatial tools.

Keywords: Storie Index; Land capability; LUSET; Land suitability; GIS; Arid lands.

* Corresponding author: H. A. Sawy

E-mail address: hager.ali@mu.edu.eg

1. INTRODUCTION

Land is one of the most vital natural resources underpinning human survival and socio-economic development. It provides the foundation for agricultural production, ecological stability, and food security. However, increasing global pressures from population growth, urban expansion, industrialization, and climate change have heightened the demand for finite and fragile land resources. According to recent estimates, more than 20% of cultivated lands worldwide are considered degraded, with soil erosion, salinization, and nutrient depletion being the primary forms of deterioration (Jain et al., 2024; Yousif et al., 2025). This situation is particularly acute in arid and semi-arid regions, where climatic limitations combine with anthropogenic pressures to reduce land productivity. Arid and semi-arid ecosystems occupy more than 40% of the Earth’s surface and are home to nearly two billion people, many of whom depend directly on agriculture for their livelihoods. These regions face multiple constraints: limited rainfall, poor soil fertility, salinity, shallow soil depth, and high evapotranspiration. Egypt, situated in the heart of the arid belt, exemplifies these challenges. More than 95% of its territory consists of desert, yet the country’s food security strategy relies heavily on reclaiming and cultivating these marginal lands (Abdel Khalek et al., 2023). Without proper assessment, reclamation efforts risk inefficient land use, environmental degradation, and economic losses.

Land evaluation offers a systematic approach to bridge the gap between land potential and agricultural demand. As conceptualized by the Food and Agriculture Organization (FAO, 1976, 1985, 2007), land evaluation integrates soil, climate, topography, and management factors to determine the capability of land for different agricultural uses. Early frameworks, such as the FAO guidelines and the land capability classification developed by Klingebiel and Montgomery (1961), have provided widely accepted methods. The Storie Index, initially introduced in the 1930s and later modified by O'geen (2008), is another parametric system that evaluates soil productivity based on profile characteristics, surface texture, slope, and limiting factors. Similarly, Sys et al. (1991) developed crop-specific suitability criteria widely applied in Africa and Asia. These classical approaches, while foundational, often rely on qualitative assessments and generalized criteria, which may be inadequate for capturing the high spatial variability of desert soils. The past three decades have witnessed a revolution in land evaluation methodologies through the integration of geospatial tools. Remote sensing (RS) provides multi-temporal, synoptic data on land cover, vegetation condition, and soil properties, while Geographic Information Systems (GIS) enable the storage, analysis, and spatial modeling of diverse datasets. This combination has transformed land evaluation from static, map-based approaches into dynamic, data-rich assessments. Studies have demonstrated the value of GIS-based land evaluation in identifying suitable areas for specific crops, integrating soil and water data, and monitoring land use changes (Bocco et al., 2001; Selmy et al., 2024). In Egypt, the application of Landsat, Sentinel, and other satellite data has proven useful in mapping soil salinity, texture variability, and groundwater potential (Yousif & Ahmed, 2024).

Digital soil mapping, which uses terrain attributes derived from Digital Elevation Models (DEM), remote sensing indices, and machine learning, has further refined the spatial prediction of soil properties. These approaches provide high-resolution datasets that can be integrated into parametric and expert-based models such as ALES (Rossiter, 1996) or MicroLEIS (De la Rosa et al., 2004). In arid regions, where soil variability is high and ground surveys are costly, geospatial approaches provide cost-effective and scalable solutions. Several studies have assessed land capability and suitability in Egypt's desert reclamation zones. Khatter et al. (1988) applied a soil rating index in Wadi El-Rayan, revealing severe limitations due to salinity and soil depth. Metwally and Beshay (1997) used a modified Storie Index in Baris Oasis, classifying large areas as poorly productive due to salinity and shallow profiles. More recently, Yousif (2019) evaluated soil suitability in Wadi El-Heriga using the MicroLEIS model, identifying olives and barley as the most suitable crops under calcareous and saline conditions. Selmy et al. (2024) combined GIS and crop water requirement models to assess land suitability for 20 crops, concluding that water scarcity is the most critical limiting factor in arid Egypt.

Other studies emphasized integrating multiple evaluation systems. Yousif et al. (2020 a) compared FAO, Storie, and Sys methods in coastal soils, highlighting discrepancies and recommending multi-model approaches. Abdel Khalek et al. (2023) developed a capability index combining Storie and Sys ratings, classifying 50% of new reclamation soils as poor to fair. Abdullahi et al. (2025a) assessed newly reclaimed soils in western Minya, finding that cereals (wheat, barley) and oil crops (sunflower, sesame) had the greatest potential despite soil carbonate and salinity limitations. Collectively, these studies underscore both the potential and challenges of agricultural expansion in Egypt's desert lands. Despite significant advances, several gaps persist in current land evaluation practices. Many studies rely primarily on secondary data or small-scale surveys, limiting their representativeness for large-scale reclamation projects. Others apply single evaluation frameworks, which may not fully capture the complexity of soil–crop interactions in heterogeneous desert environments. Moreover, while GIS and RS have been increasingly applied, few studies systematically combine detailed field surveys, laboratory analyses, and spatial modeling across extensive reclamation zones. This limits the ability to generate accurate, site-specific maps of land capability and crop suitability that are essential for sustainable planning.

In response to these gaps, the present study aims to conduct a comprehensive evaluation of land productivity and crop suitability in a representative arid reclamation zone. The approach integrates intensive field soil surveys, laboratory characterization of physical and chemical properties, and GIS-based spatial modeling. Classical parametric models (modified Storie Index) and suitability frameworks (LUSET and FAO criteria) are combined with geospatial interpolation techniques to assess land capability and suitability for major field, vegetable, oil, and fruit crops. By doing so, the study aims to (i) classify land according to its capability, and (ii) determine crop suitability under arid conditions. Ultimately, the findings aim to provide a scientific basis for sustainable land management and agricultural development strategies in desert reclamation projects.

2. MATERIALS AND METHODS

2.1. **Study Area**

The study area is located west of El-Minya Governorate in the Western Desert of Egypt, covering approximately 29,000 feddans (≈12,180 hectares), as illustrated in Figure 1. Geographically, it lies between longitudes 30°05′–30°32′ E and latitudes 27°40′–27°50′ N, forming part of the state-sponsored reclamation zones aimed at expanding Egypt's agricultural frontier.

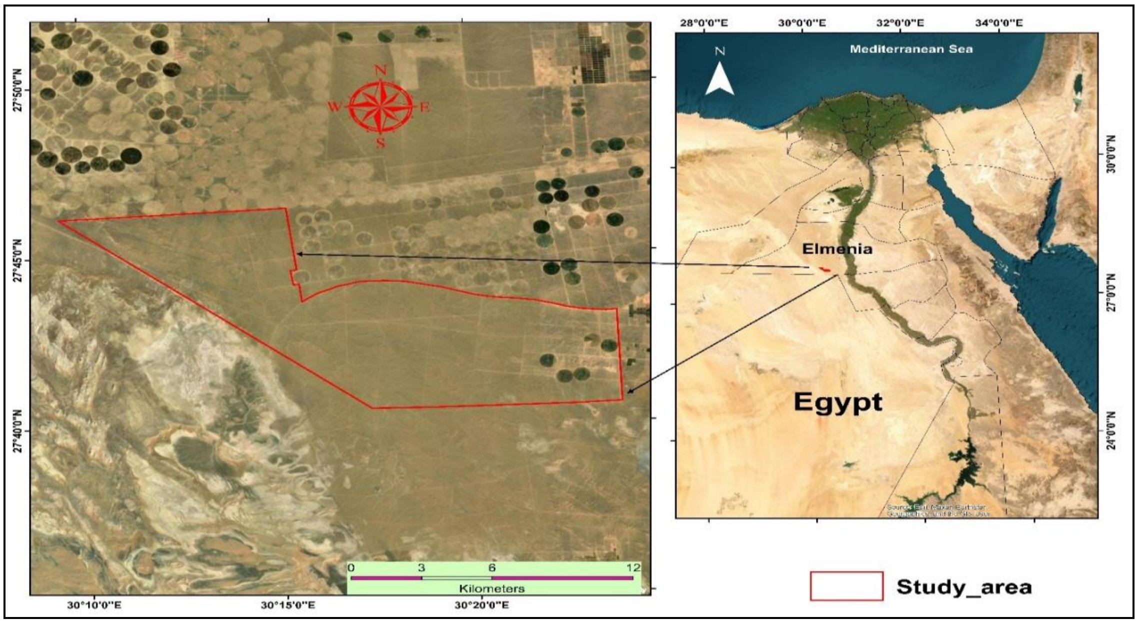

Figure 1. Location map of the study area.

Climatology, The mean annual temperature is about 20.3°C, ranging from 12.1 °C in January to 29.1°C in July. Relative humidity averages 36–64%, with frequent dust storms during spring. Such climatic conditions impose significant constraints on agricultural production, making irrigation indispensable.

Table (1): Meteorological Data of the Study Area (El-Minya Meteorological Station).

Climate Element	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Avg.
Max Temp (°C)	20.4	22.4	25.7	31	34	36.7	36.7	36.2	33.9	31.4	26.2	21.5	29.7
Min Temp (°C)	4	5.3	8.2	12.4	16.6	19.3	21.5	20.4	18.7	15.8	10.9	6.3	13.3
Temp Range (°C)	16.2	17.1	17.5	18.6	18.3	17.4	15.2	15.8	15.2	15.6	15.3	15.2	16.5
Mean Temp (°C)	12.1	13.9	16.9	21.7	25.3	28	29.1	28.3	26.3	23.6	18.6	13.9	20.3
A. P. (b)	1.019	1.017	1.015	1.012	1.011	1.009	1.007	1.008	1.011	1.014	1.017	1.018	1.013
W. S.(km/h)	9.5	10.8	12.8	14.7	15.8	16.7	13.8	11.5	13.2	11.9	10.6	9.1	12.5
Sunshine (hr/day)	8.2	9.1	9.3	10	11.1	12.3	12.5	11.8	10.6	9.9	8.9	7.8	10.1
R. H. (%)	61	55	50	41	36	40	46	51	54	55	61	64	51.2
Eva. (mm)	4.5	5.8	7.8	10.9	14.5	15.8	13.8	11.7	10	8.6	6	4.9	9.5

A. P. =Atmospheric Pressure (b); W. S. = wind speed; R. H. = relative humidity; Eva. = evapotranspiration

Geologically, the area is underlain by Eocene limestone formations, interbedded with marl and clay lenses, overlain in places by Quaternary deposits of sand and gravel. The surface materials are mainly derived from weathered limestone and aeolian sand, resulting in soils with variable depth, stoniness, and carbonate content (Said, 1990). The presence of high calcium carbonate content ($CaCO_3$ often >30%) constitutes one of the key soil limitations for plant growth.

Hydrology, Groundwater is the sole source of irrigation in the study area. It is mainly extracted from the Eocene fractured limestone aquifer, which extends widely in the Western Desert. The aquifer is recharged partially by upward leakage from deeper Nubian Sandstone aquifers and by limited local infiltration. Depth to groundwater ranges between 90 and 150 m, with salinity values typically between 500 and 1,200 mg L^{-1}, making it generally suitable for irrigation with appropriate management (Ghnia, 1997; Hamdan & Sawires, 2013; Rosenthal et al., 1992). However, increasing abstraction rates for large-scale reclamation projects raise concerns regarding the sustainability of this resource.

Topographically, the area is characterized by a flat to gently undulating surface, with elevations ranging from 99 to 149 m above sea level (Figure 2). According to the DEM-derived slope analysis, the study area is overwhelmingly dominated by very gently to gently sloping lands (1–5%), which represent 80.2% of the total area. Flat to nearly level surfaces (0–1%) occupy about 4.9%, while 14.7% of the land falls under sloping conditions (5–10%). Only 0.2% of the land is strongly sloping (>10%). This distribution indicates that most of the area is topographically suitable for mechanized farming and efficient irrigation, with only limited zones requiring special soil conservation measures.

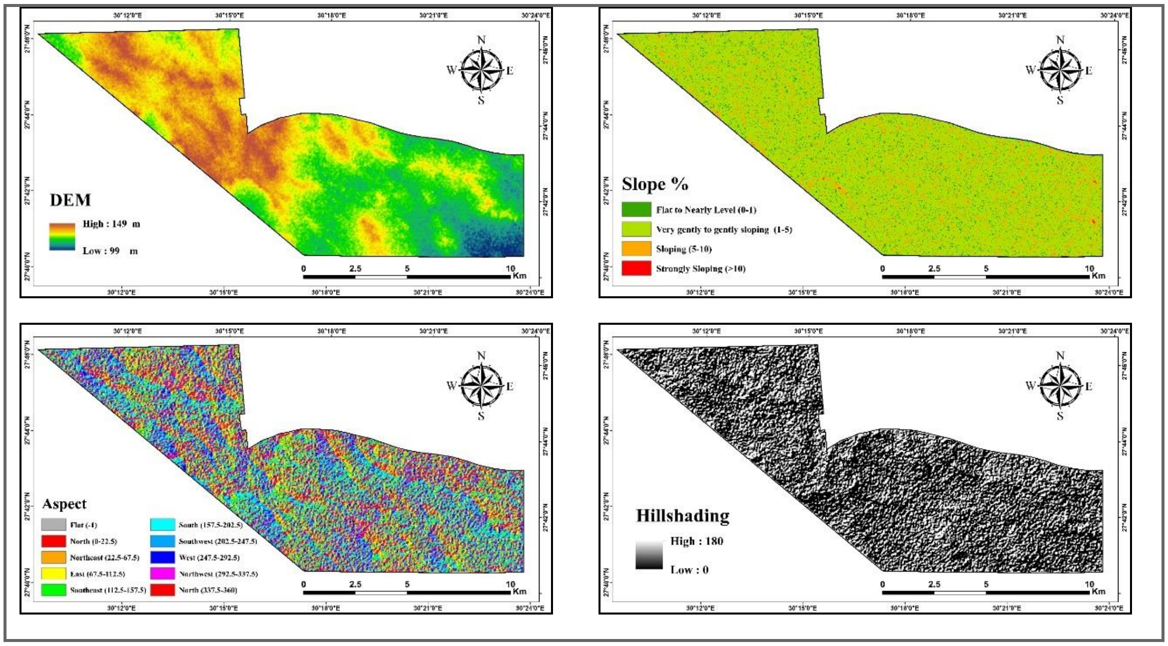

Figure 2. Topographical analysis of the study area

3.2. Field Studies, Soil Sampling, laboratory work.

By going on a field trip to conduct the studies and gather soil samples, a thorough soil survey of the research region was accomplished. In the field, a 250 250 m sample grid was used to identify the soil profile locations, and a Garmin GPS device was used to record the coordinates of the soil profiles. Soil sampling locations across the research region were depicted in Figure 3 by projecting these profile coordinates onto a map. Using a sample grid technique with 250 m spacing, a total of 1934 soil profiles were dug, as shown in Figure 3. The physical characteristics of the soil profiles were subsequently documented in accordance with the FAO standards for soil description (FAO, 2006). The El-Minia University Faculty of Agriculture's Soil Science Lab received soil samples taken from various profile horizons and sent them there. The soil samples were crushed, air-dried at room temperature, and subsequently analysed for physical and chemical characteristics after passing through a 2 mm filter. In accordance with guidelines set out by the USDA, 2014, the soil samples were analysed for their physical and chemical properties. Soil EC, pH, sand, silt, clay, CEC, $CaCO_3$, ESP, SAR, and texture were among the physical and chemical characteristics evaluated.

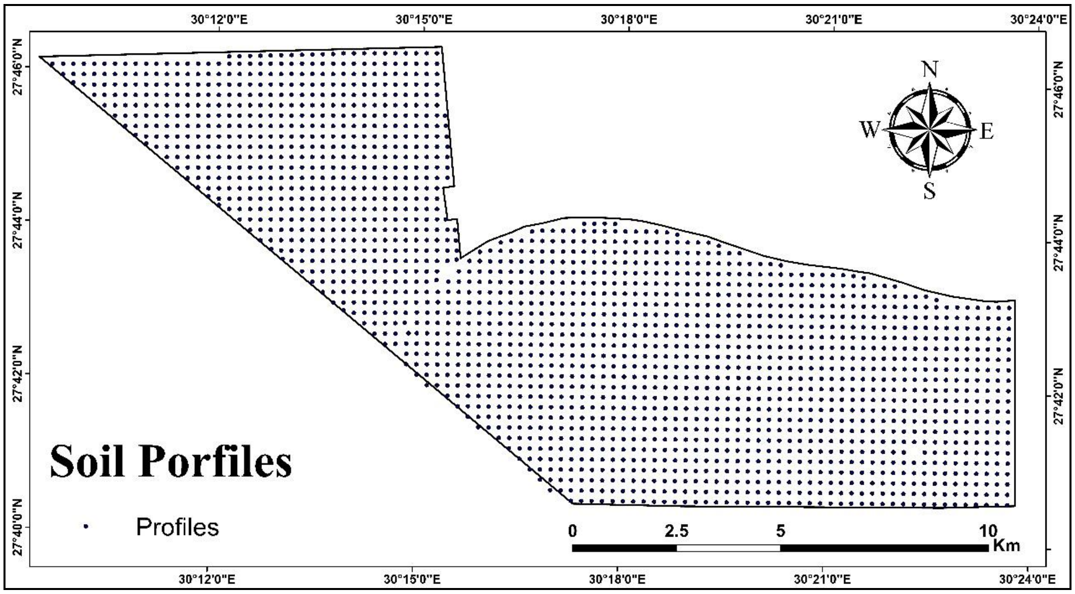

Figure 3. Soil sampling system of the study area.

For each studied soil profile, the weighted mean (WM) values of each soil property dataset were computed as follows:

$$WM = \frac{\sum_{i=1}^{n}(v_i * v_t)}{T} \quad (1)$$

When n is the number of horizons in a soil profile, vi is the value of the soil property associated with soil horizon i, WM is the weighted mean value of soil properties, and T is the total depth of the soil profile. The land evaluation techniques made use of the weighted mean values of soil attributes that were generated.

3.4. Land Evaluation Procedures

3.4.1. Land Capability Assessment

The modified Storie index model (O'geen, 2008) was used to evaluate the land's productive capacity and possible agricultural applications. The Storie index, an earlier version of this method, was created as a parametric technique; O'geen (2008) modified it to provide digital scores. Soil characteristics, topography, and environmental factors that impose long-term constraints on land use were the primary criteria for land capacity categorisation (Ditzler et al., 2017). In addition, one method for evaluating land is the modified Storie index model, which takes into account landscape and soil characteristics that regulate land use and production. Coarse fragments, soil pH, soil salinity, and sodium adsorption ratio (SAR) were the additional soil and landscape variables that were included in this study (Factor X). Each component was rated using the criteria established by Storie (O'geen, 2008) and applied to the model in question. The Storie index is determined by assigning a score between zero and one hundred percent to each of the four components, which are then multiplied by each other with a weight of one, as illustrated in Equation (2). Microsoft Excel's Visual Basic for Applications was used to execute and code the calculation. An evaluation based on the Storie index (SI) was then determined using Equation (2). Additionally, Table 2 displays the land capacity categories, grades, and productivity ratings according to the modified Story index model (O'geen, 2008).

Table 2 shows that there is a continuum from Grade 1 (very good) to Grade 5 (not suitable for agriculture).

$$SI = [(A/100) \times (B/100) \times (C/100) \times (X/100)] \times 100 \quad (2)$$

X stands for many soil and landscape aspects including topography, drainage, fertility, erosion, salinity, alkalinity, etc., while SI stands for the Storie Index rating, A for soil depth, B for surface texture factor, and C for slope factor.

Table 2. Land capability classifications, ratings, and productivity assessments based on the modified Storie index model (O'geen, 2008).

Capability grade	Capability Category	Productivity rating (%)	Description
Grade 1	Excellent	80-100	Soils with few or no limitations
Grade 2	Good	60-79	Soils with limitations that reduce the choice of crops or require simple soil conservation practices
Grade 3	Fair	40-59	Soils with severe limitations that reduce the choice of crops and/or require special conservation practices
Grade 4	Poor	20-39	Soils with very severe limitations that restrict the choice of crops and/or require very careful management
Grade 5	Non-agricultural	< 20	Soils with very severe limitations that restrict their use in agriculture

3.4.2. Land Suitability Assessment

This research looked at seventeen different crops to find out which soils were most suited to cultivating them. There were four categories used to classify the seventeen crops that were evaluated: Wheat, barley, sugar beetroot, alfalfa, and sorghum are examples of field crops. Oil crops include peanuts, sunflower, sesame, soybeans, and watermelons. Vegetable crops include potatoes, tomatoes, onions, and watermelons. Citrus, peaches, olives, and mangoes are examples of fruit trees.

According to Yen et al. (2006), a computer software called LUSET was used to determine if the land was suitable for use. Sys et al. (Sys et al., 1991) states that this method takes crop growth needs into account while selecting the variables that affect land suitability. According to Sys et al. (1991), this study selected the following characteristics as influencing factors on land suitability for land suitability index scoring: slope, drainage, texture, coarse fragments, CEC, depth, $CaCO_3$, pH, EC, and ESP. Equation (3) shows how the LUSET model uses the exponent approach to determine the land suitability index final score.

$$SI = (SF_1 \times SF_2 \times SF_3 \times \ldots \times SF_n)^{1/N} \quad (3)$$

where SI is the final score of land suitability index, S suitability score of the selected factors (F1,…,Fn), N is number of factors selected.

The FAO framework (ELIASSON, 2007; FAO, 1976) distinguishes between two land suitability orders: crop-suitable land (S) and crop-unsuitable land (N). Suitable land order is divided into three categories: (S1) highly suitable, (S2) moderately suitable, which requires several inputs on land to sustain the crop, and (S3) marginally suitable, which requires numerous inputs on land. Land suitability indices, classes, and limitations for the seventeen crops were determined by matching standard crop requirements (internally coded data in the model) with soil parameter scores. Finally, land suitability classes were determined by assigning each land suitability index score to the confined category, as shown in Table 3.

Table 3. Suitability scores for the different suitability classes (Yen et al., 2006).

Suitability Grade Symbol	Suitability Score	Suitability Class
S1	85-100	Highly suitable
S2	60-85	Moderately suitable
S3	40-60	Marginally suitable
N	0-40	Not Suitable

3.5. Mapping Soil Properties, Capabilities, and Suitability Classes

Spatial distribution maps of soil characteristics, land capability classes, and soil suitability classes were created in ArcGIS 10.8 software (ESRI Co., Redlands, USA) using the Inverse Distance Weighted (IDW) interpolation method. The IDW is commonly employed in soil research because surface interpolations are easily implemented using it (Aldabaa & Yousif, 2020; Jantaravikorn & Ongsomwang, 2022; Mallah et al., 2022; Saraswat et al., 2023; Shokr et al., 2022).

The IDW approach requires a large number of sampling points (more than 14 points) for representative interpolation outcomes (Yousif et al., 2020). It performs best when sampling points are evenly distributed throughout the study region (Yousif et al., 2020). Therefore, this study employed sufficient sampling points (1934 points) and a systematic grid sampling technique to ensure that all variations in soil properties investigated in the study area were represented. This technique (IDW) is typically used to generate a surface map of a variable whose location influences it, with the premise that the influence of the variable diminishes as the distance from the sample point increases. Therefore, the local effect of the measurement site declines with distance, as illustrated in the following equation:

$$Z_S = \frac{\sum_{i=1}^{n}\left(\frac{z_i}{d_i^p}\right)}{\sum_{i=1}^{n}\left(\frac{1}{d_i^p}\right)} \qquad (4)$$

where ZS is the value predicted at site S, zi is the z value at measured site i, di is the distance between site S and site i, and p describes the distance power, that determines the degree to which nearer points are preferred over more distant points.

4. RESULTS AND DISCUSSIONS

4.1. Spatial distribution of different soil characteristics

Soil depth: The analysis of soil profiles across the study area revealed significant variation in effective soil depth. As illustrated in Table (4) and Figure (4), approximately 66.7% of the soils were classified as moderately deep (50–100 cm), 17.6% were classified shallow (25–50 cm), and only 3.6% exceeded 100 cm in depth and categorized as a deep soils. The moderately deep soils, distributed mainly along the northern and western parts of the area, represent the most promising areas for crop production, as they allow adequate root penetration and water storage. In contrast, shallow soils overlying hard limestone layers or affected by erosion present serious limitations for cultivation, restricting root growth and reducing available moisture capacity. These findings are consistent with previous research in the Western Desert, where soil depth was identified as a key determinant of land capability. Mohamed et al. (2023) reported that shallow soils in desert reclamation projects significantly constrained crop performance, especially deep-rooted perennials such as fruit trees. Similarly, Nada et al. (2022) emphasized that soil depth plays a decisive role in the ALES-arid model for land evaluation in Egypt, highlighting that shallow profiles are often classified as marginal or unsuitable. Thus, the spatial variability of soil depth in the study are requires differentiated management strategies, with shallow soils better suited to shallow-rooted annuals and moderately deep soils prioritized for intensive reclamation.

Table 4. Areas of Soil Profiles Depth in the Study Area.

Soil depth class	Area	
	Feddan	%
Deep soil (100-150 cm)	1051.85	3.65
Moderately deep soil (50-100 cm)	19210.55	66.72
Shallow soil (25-50 cm)	5082.51	17.65

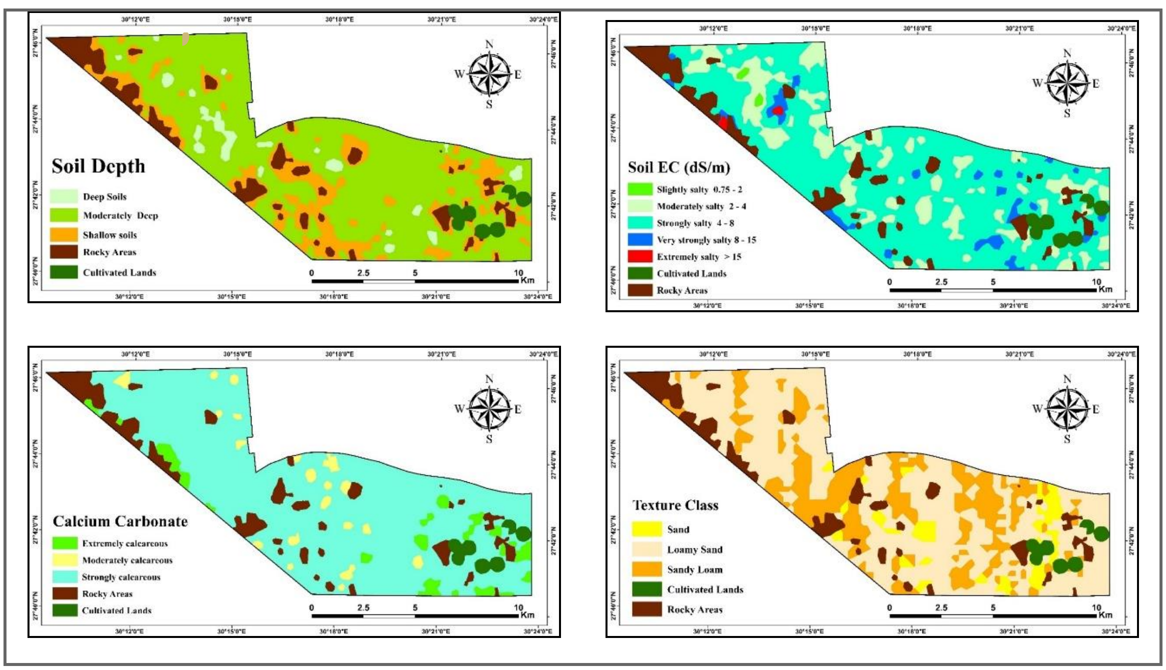

Figure 4. Spatial distribution of some soil properties.

Soil EC: Electrical conductivity (EC) measurements indicated that 64% of the soils were classified as strongly saline (4–8 dS/m), 19% moderately saline (2–4 dS/m), and 6% non-saline (<2 dS/m), as displayed in Table 5 and Figure 4. Soil salinity, soil depth, and texture are the most critical significant factors of agricultural priorities. The results of this investigation indicated that soil salinity varies across the study area. Salinity is the most critical element in desert areas and in the research area due to groundwater constraint and the forced use of contemporary irrigation systems. The high values of EC in some cases are due to the lack of leaching in the soil profile due to the scarcity of rainfall and the arid nature of these soils, in addition to the hot weather in the region, which worsens the situation (Abdullahi et al., 2025a; Yousif et al., 2025a). Therefore, an appropriate irrigation policy should be followed to prevent soil salinization. To remove dissolved salts and reduce their concentration in the soil to the limits that allow their cultivation, it is necessary to leach the soil with water and drain the leaching water away from the root zone. These results align with El Nahry et al. (2010) and Fadl and Abuzaid (2017), who reported that salinity was the most critical limiting factor in Egypt’s Western Desert, significantly reducing land capability classes and constrained land suitability despite otherwise favorable soil depth and texture. In global contexts, Shin et al. (2022) emphasized that managing salinity through leaching, gypsum application, and efficient irrigation remains fundamental for sustainable agriculture in arid regions. For the study area in West El-Minya, targeted reclamation of saline zones is essential for expanding the productive land base.

Table 5. Salinity degrees in the study area.

Salinity Class	Area	
	Feddan	%
Slightly saline (0.75 – 2 dS/m)	99.87	0.35
Moderately saline (2 – 4 dS/m)	5442.20	18.95
Strongly saline (4 – 8 dS/m)	18505.77	64.44
Very strongly saline (8 – 15 dS/m)	1129.98	3.93
Extremely saline (> 15 dS/m)	93.63	0.33

Calcium carbonate: Calcium carbonate affects many soil properties such as soil moisture regime, nutrient availability, pH, decomposition of organic matter, soil water movement, soil texture, vegetation type and quantity, and soil crust formation. Soils in arid or semi-arid conditions in Western desert have a high calcium carbonate content in most areas. Calcium carbonate content in soils has been identified as an important soil criterion for agricultural crops (Yousif et al., 2025a). In dry regions, due to the scarcity of precipitation compared to annual evapotranspiration, less water is available for leaching of soluble calcium, carbonate or bicarbonate ions (Sharaky et al., 2017; Yousif et al., 2022). As explained in Table 6 and Figure 4, the soils of the investigated area are strongly calcareous, with approximately 80% containing 10–25% $CaCO_3$, while 3.36 % and 4.88 % of the study area were classified as moderately and extremely calcareous, respectively. This calcareous nature reflects the underlying Eocene limestone formations and has a strong influence on soil fertility (El Shazly, 1977). High calcium carbonate content reduces the availability of essential nutrients, particularly phosphorus and micronutrients such as Fe, Mn, and Zn (Prasad et al., 2016; Singh & Dahiya, 1976). Moreover, the physical properties of calcareous soils, including their tendency to form hard pans, further restrict root growth and water movement (Xu et al., 2022; Yousif et al., 2020 a). These observations are consistent with Abdullahi et al. (2025b), who identified high $CaCO_3$ as a dominant limiting factor in Egypt's reclaimed lands, and Zayed and EL-Tapey (2024), who highlighted nutrient deficiencies in calcareous soils of the Nile Valley fringes. According to FAO (2020), soils with more than 15% $CaCO_3$ require careful nutrient management, including localized fertilization and the use of organic amendments. In the investigated area, addressing calcareous constraints is therefore a prerequisite for improving crop yields.

Table 6: Calcium carbonate contents of the study area.

Class	Area	
	Feddan	**%**
Moderately calcareous (2-10 %)	964.39	3.36
Strongly calcareous (10-25 %)	22961.90	79.78
Extremely calcareous (>25 %)	1405.35	4.88

Soil texture: Soil texture analysis indicated a predominance of sandy loam texture class (58%) and loamy sand (25%), with smaller part of sandy clay loam and clay loam (Table 7 and Figure 4). Sandy loam soils dominate the central and southern sectors, whereas loamy sand occurs more extensively in the eastern zones. These textures, derived mainly from limestone and sandstone parent materials, are characterized by low water-holding capacity, rapid drainage, and high infiltration rates (Osman, 2018). While these properties facilitate mechanized agriculture and reduce waterlogging risks, they also increase irrigation demands and nutrient leaching (HUSSEIN, 2020; Wassif & Wassif, 2021). Comparable results were obtained by Yousif et al. (2020 a), who found that sandy-textured soils in Egypt's northwestern coast required frequent irrigation to sustain crop yields. Mohamed et al. (2023) and Yousif (2024) similarly concluded that sandy loam soils in arid Egypt, although suitable for cereals under modern irrigation, demand significant soil amendments and precise water management to ensure sustainability. In the study area, the dominance of sandy textures underscores the need for drip irrigation systems, organic matter addition, and mulching to improve water retention and soil fertility.

Table 6. Soil texture of the study area.

Texture class	Area	
	Feddan	**%**
Loamy Sand	16601.63	57.61
Sand	1696.06	5.89
Sandy Loam	7071.91	24.54

4.2. Land Capability Evaluation

The land capability assessment of the study area was carried out using the modified Storie Index (Aldbaa, 2012; O'geen, 2008). As shown in Table 7 and Figure 5, the findings revealed that the study area is dominated by low to grade 4, reflecting the combined effects of soil depth, salinity, calcareousness, and texture limitations.

The classification results can be presented as follows:

- Grade 3 occupied an area of 3028.31 fadden (10.5%), mainly located in the northern and western parts of the area. These soils are moderately deep sandy loams with reasonable salinity, representing the most promising zones for immediate reclamation and cultivation of cereals and forage crops.
- Grade 4 covered an area of 21559.23 fadden (74.9%), distributed across the central and southern parts. Although extensive in area, these soils are strongly saline, highly calcareous, and coarse texture. Their use requires intensive management, including salt leaching, gypsum application, and precision irrigation.
- Grade 5 covered an area of 749.34 (2.6%) and considered very marginal soils with severe constraints such as shallow depth, high salinity, or rocky outcrops. These areas are considered unsuitable for intensive agriculture but may be utilized for limited rangeland or afforestation projects.

The prevalence of Class C4 demonstrates the challenges of large-scale reclamation in the study area, as most of the land requires significant investments in soil improvement and water management. Nevertheless, the presence of C3 soils (over 3,000 feddans) provides a starting point for prioritizing reclamation activities with higher expected returns. These results are consistent with other studies in Egypt’s Western Desert. Abdullahi et al. (2025a) found that more than 70% of desert reclamation areas in western Minya fall within grade 4 due to salinity and calcium carbonate content. Similarly, (2024) reported that only a small area of reclaimed desert soils could be classified as grade 3, while the majority required intensive reclamation efforts. Land capability classification in the study area emphasizes the importance of zoning-based land use planning, in which highly capable soils are prioritized for immediate agriculture expansion, marginal lands are gradually reclaimed, and unsuitable lands are reserved for non-agricultural uses.

Table 7. Land capability grades of the study area.

Capability Grade	Area	
	Feddan	**%**
Grade 3	3028.31	10.52
Grad 4	21559.23	74.90
Grade 5	749.34	2.60

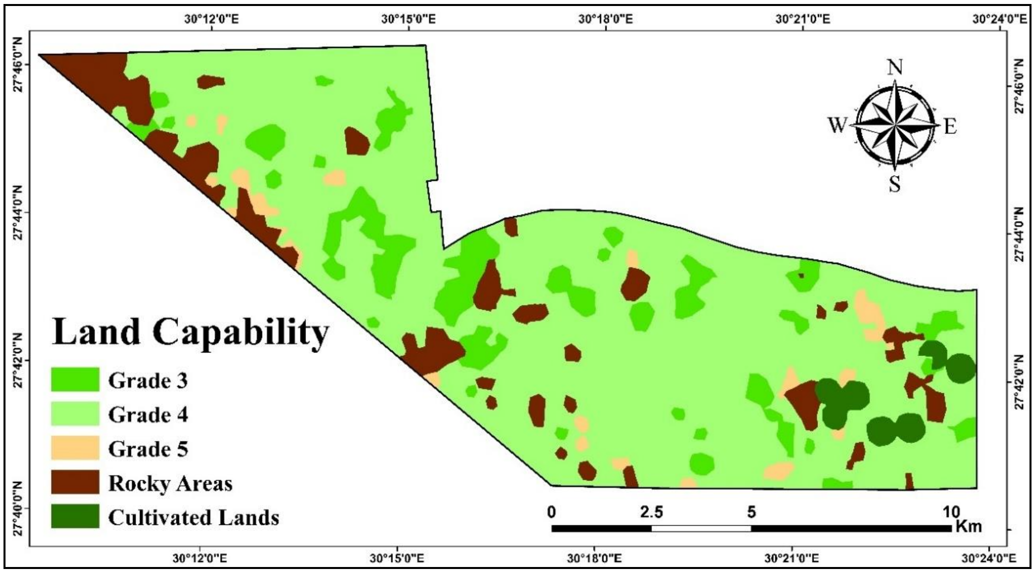

Figure 5. Land Capability map of the study area.

4.3. Land Suitability Evaluation

Field crops:

The land suitability evaluation for selected field crops in the studied area indicated varying classes of suitability, primarily controlled by soil salinity, depth, and calcareousness (Table 8 and Figure 6). Wheat and barley emerged as the most suitable field crops, with 68.1% of the land classified as highly suitable (S1) and an additional 19.9% as moderately suitable (S2). Wheat and barley adaptability to moderate alkaline soils and relative tolerance to salinity explain its strong performance under local conditions. Sorghum also demonstrated high suitability, with 53.7% of the area classified as S1 and 34.3% as S2. Its drought and salinity tolerance make it an excellent summer crop for the region. The crop's adaptability to sandy loam soils with limited water-holding capacity further supports its suitability. Sugar beet was classified as moderately suitable (S2) across the majority of the area (79.6%), with only 8.4% of the area considered highly suitable (S1). The crop's performance is constrained mainly by soil salinity, which exceeds its tolerance threshold in large parts of the area. Despite these limitations, sugar beet remains feasible as an industrial crop under controlled irrigation and salt management, as demonstrated by Said et al. (2020), who found it moderately successful in calcareous soils of the northwestern coast of Egypt. Alfalfa showed a predominantly moderate suitability (S2, 85.1%), with 2.6% classified as highly suitable (S1) and a marginal fraction (0.3%) as S3. While alfalfa is relatively tolerant to salinity, its long-term productivity is hindered by shallow soils and high $CaCO_3$ levels, which restrict root growth and nutrient uptake. Nonetheless, its importance as a forage crop for livestock systems makes it strategically valuable. Studies by Selmy et al. (2024) confirm that alfalfa is sustainable in desert environments when cultivated with appropriate fertilization strategies. This finding is consistent with Rashed (2020), who highlighted field crops as a key crops in

West El-Minya desert region due to their broad adaptability and strategic role in Egypt's food security. The findings clearly indicate that wheat, barley, and sorghum are the most promising field crops for large-scale cultivation in West Minya, given their adaptability and resilience. Sugar beet and alfalfa occupy intermediate positions, where successful cultivation depends on intensive soil and water management practices. Together, these crops provide a diversified cropping system that enhances food security and supports livestock production.

Table 8. Land suitability classes of some field crops.

Crop	Land suitability classes					
	S1		S2		S3	
	Feddan	%	Feddan	%	Feddan	%
Suagrbeet	2434.60	8.45	22919.45	79.58		
Sorghum	15454.35	53.70	9878.09	34.32		
Alfalfa	748.30	2.60	24498.06	85.08	98.54	0.34
Wheat & Barley	19607.58	68.12	5730.03	19.91		

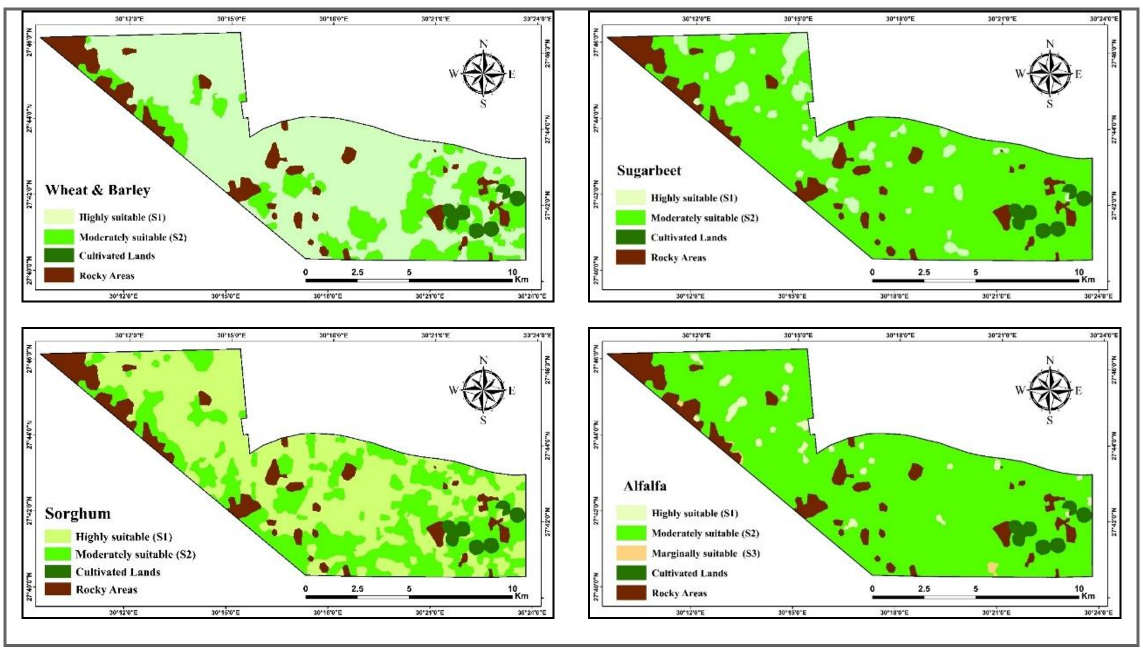

Figure 6. Land suitability classes for some field crops.

Oil crops.

The land evaluation for oil crops in the study area, as illustrated in Table 9 and Figure 7, revealed that while some crops show promising adaptability, most are constrained by salinity, soil depth, calcareous, and sandy texture. Soybean crop showed limited suitability, with only 2.75% of the land classified as highly suitable (S1), and the vast majority (82.8%) classified as moderately suitable (S2). A smaller area (2.5%) was classified as marginally suitable (S3). Soybean's moderate tolerance to salinity explains why its performance is limited in saline areas but acceptable in moderately deep sandy loam soils. These findings agree with Mohamed (2021), who noted soybean's potential in desert reclamation if salinity is managed through controlled irrigation and fertilization. Sesame crop was classified predominantly as moderately suitable (S2, 73.2%) and marginally suitable (S3, 13.9%), with only 0.98% unsuitable (N). Sesame's relative tolerance to drought and its adaptability to sandy soils explain its wide suitability across the area. However, its sensitivity to high salinity reduces its potential in the study area. Similar results were reported by Zakarya et al. (2021), who confirmed sesame's success in calcareous sandy soils of Upper Egypt under modern irrigation systems. Sunflower crop displayed the best overall performance among oil crops, with 7.3% of the land classified as highly suitable (S1) and 78% as classified moderately suitable (S2). Only 2.7% was marginally suitable. Sunflower's ability to tolerate moderate salinity, coupled with its shallow rooting system, enables it to adapt to a wide range of soils in the study area. Yousif and Ahmed (2024) highlighted sunflower as a promising oil crop for sandy loam soils in arid regions, provided irrigation scheduling is optimized. Groundnut crop was the least suitable among oil crops, with the majority of land classified as moderately suitable (S2, 91%), followed by marginally suitable (S3, 18.5%), and 1% unsuitable (N). Groundnuts are highly sensitive to both salinity and calcareous soil, which explains their restricted suitability. Metwally et al. (2018) also reported groundnut as marginal in calcareous saline soils, confirming its limited potential under both salinity and calcareous soil conditions. The overall analysis indicates that sunflower and sesame are the most promising oil crops, benefiting from their moderate salinity tolerance and adaptability to sandy loam soils. While soybean has limited potential but remains viable in moderately saline areas with intensive management. Moreover, groundnuts are poorly suited for large-scale cultivation due to their sensitivity to salinity and calcium carbonate, making them a low-priority crop. This ranking aligns with broader regional findings (Selmy et al., 2024; Yousif et al., 2024), which emphasized sunflower and sesame as strategic oil crops for Egypt's arid reclamation areas.

Table 9. Land suitability classes of some oil crops.

Crop	Land suitability classes							
	S1		S2		S3		N	
	Feddan	%	Feddan	%	Feddan	%	Feddan	%
Soya bean	792.66	2.75	23827.54	82.77	721.16	2.50	--	--
sesame	--	--	21057.57	73.16	3994.58	13.88	282.11	0.98
Sunflower	2110.17	7.33	22468.67	78.03	767.63	2.67	--	--
Groundnuts	--	--	20864.42	91.03	4246.33	18.53	228.19	1.00

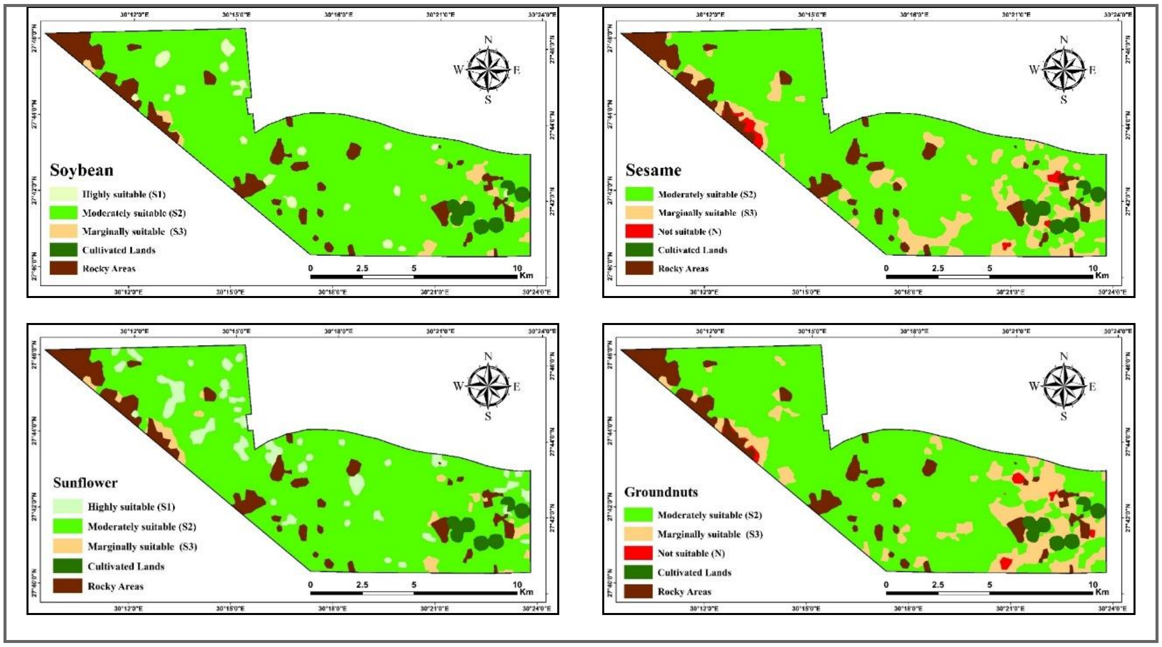

Figure 7. Land suitability classes for some oil crops.

Vegetables crops.

The suitability evaluation of vegetable crops (Table 10 and Figure 8) indicated that most of the studied crops fall within the moderately suitable class (S2), reflecting the combined constraints of salinity, alkalinity, sandy texture, and calcium carbonate content. Despite these limitations, the results suggest that vegetable production is feasible under improved management practices. Onion performed best among vegetables, with 7.5% of the area classified as highly suitable (S1) and the majority (78.3%) classified as moderately suitable (S2). Only 2.2% was classified as marginal (S3). Onion's adaptability to moderately saline and alkaline soils explains its relatively high suitability compared to other vegetables. Similar findings were reported by Yousif and Ahmed (2024), who identified onion as a priority vegetable crop for arid reclamation projects due to its tolerance to a wide range of soil conditions and high market value. Potato was classified primarily as moderately suitable (S2, 71.9%), with 16.1% marginally suitable (S3). The crop is moderately sensitive to salinity, which explains its restricted suitability in the areas with high EC levels. Zakarya et al. (2021) also noted that potato yields in calcareous sandy soils of Egypt declined significantly without intensive fertilization and irrigation management. Nonetheless, potato remains a viable industrial and export crop under controlled conditions. Tomato showed a similar pattern, with 78.6% of the land classified as moderately suitable (S2) and 9.5% as marginally suitable (S3). Tomato is highly sensitive to salinity and calcium carbonate, factors that reduce its suitability in most of the study area. Alsafadi et al. (2022) confirmed the vulnerability of tomato to alkaline-saline soils in Egypt, stressing the importance of site-specific fertigation strategies to sustain yields. Watermelon was also predominantly moderately suitable (S2, 81%), with 7% marginally suitable (S3). Like tomato, watermelon is sensitive to both salinity and calcareousness, but its shorter growth cycle makes it more adaptable to sandy soils with proper irrigation scheduling. Overall, the results indicate that vegetable cultivation in the study area is generally constrained by soil salinity, alkalinity, and low fertility, which prevent most crops from reaching high suitability (S1). Among the studied crops, onion offers the highest potential, both in terms of adaptability and economic importance. While Potato and tomato are feasible but require intensive management to overcome salinity and nutrient limitations. Watermelon is moderately suitable and can serve as a complementary cash crop in sandy soils under drip irrigation. These findings align with broader regional studies (Alsafadi et al., 2022; Yousif & Ahmed, 2024; Zakarya et al., 2021), which stressed that vegetable production in reclaimed desert soils requires integrated soil amendments, precision irrigation, and site-specific fertilization to achieve economic viability.

Table 10. Land suitability classes of some vegetable crops.

Crop	Land suitability classes					
	S1		S2		S3	
	Feddan	%	Feddan	%	Feddan	%
Watermelon	--	--	23331.16	81.05	2007.84	6.97
Tomato	--	--	22613.02	78.55	2726.27	9.47
Potato	--	--	20693.09	71.90	4638.03	16.12
Onion	2150.67	7.47	22554.03	78.34	638.08	2.22

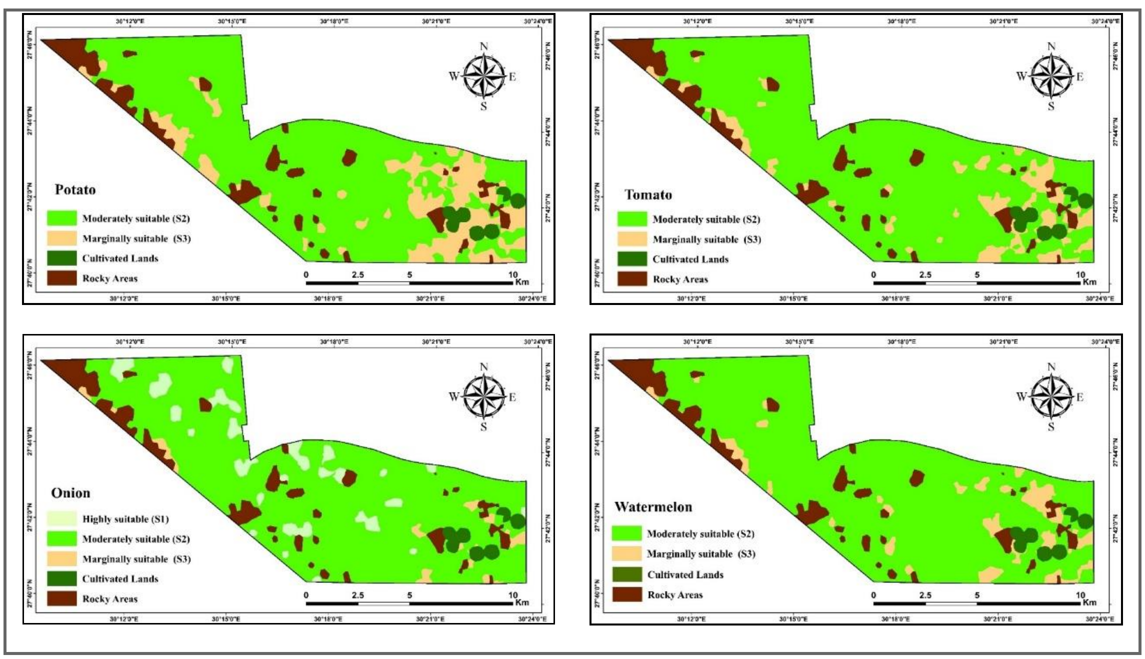

Figure 8. Land suitability classes for some vegetable crops.

Fruit crops.

Land evaluation of fruit crops (Table 11 and Figure 9) in the study area revealed substantial variability in suitability, largely controlled by soil salinity, shallow depth, high $CaCO_3$ content, and alkalinity. While some perennial crops showed promise, others were heavily constrained. Olive was identified as the most adaptable fruit crop. Although only 0.8% of the area was classified as highly suitable (S1), the majority (79.9%) fell into the moderately suitable class (S2), with 7.2% marginal (S3). Olive's well-known tolerance to salinity, drought, and calcareous soils explains its predominance in the moderate category and its potential for long-term investment. Previous studies confirm this adaptability: Taha and Khalifa (2025) emphasized olives as one of the most strategic tree crops for sustainable agriculture in Egypt's reclaimed lands. Citrus showed moderate performance, with 42.8% of land in S2 and 43.5% in S3. Only 1.7% was classified as unsuitable (N). Citrus crops are moderately sensitive to salinity and require deeper rooting zones, which explains their limited suitability in the study area. Abdel Khalek et al. (2023) similarly reported that citrus yields decline sharply in alkaline-saline soils of Egypt's desert regions, necessitating intensive fertigation and variety selection. Mango was classified as moderately suitable (S2, 40.9%) and marginally suitable (S3, 44.6%), with only 2.5% classified as unsuitable. Mango is more sensitive to both salinity and shallow soils compared to olives, which limits its suitability across most of the area. This finding aligns with El Tabey et al. (2022), who concluded that mango cultivation in south Giza, Egypt was constrained by shallow, saline, and calcareous soils. Peach performed the worst among fruit crops. The majority (95.6%) of the area was classified as marginal (S3), and only 10% was moderately suitable (S2). With approximately 5% classified as unsuitable land, peaches are highly vulnerable to the combined stresses of salinity, alkalinity, and $CaCO_3$. Similar results were reported by Fadl and Sayed (2020), who found that stone fruits in arid Egypt were rarely viable without intensive soil reclamation and nutrient management. Finally, the results demonstrate that Olive is the most promising perennial crop, benefiting from its high adaptability and long-term sustainability. While Citrus and mango are feasible but restricted to zones with lower salinity and deeper soils, requiring advanced management (fertigation, salt-tolerant varieties). Peach is unsuitable for large-scale cultivation due to its extreme sensitivity, making it a low-priority option. This prioritization reflects broader findings in Egypt's desert reclamation projects (Selmy et al., 2024; Yousif & Ahmed, 2024), which consistently recommend olives as the backbone of perennial cropping systems, with citrus and mango limited to carefully selected niches.

Table 11. Land suitability classes of some fruit crops.

Crop	Land suitability classes							
	S1		S2		S3		N	
	Feddan	%	Feddan	%	Feddan	%	Feddan	%
Peach	--	--	2309.71	10.08	21913.14	95.61	1123.52	4.90
Mango	--	--	11773.71	40.91	12829.51	44.57	731.31	2.54
Citrus	--	--	12314.72	42.80	12517.39	43.50	494.41	1.72
Olive	240.90	0.84	22990.93	79.86	2078.14	7.22	30.64	0.11

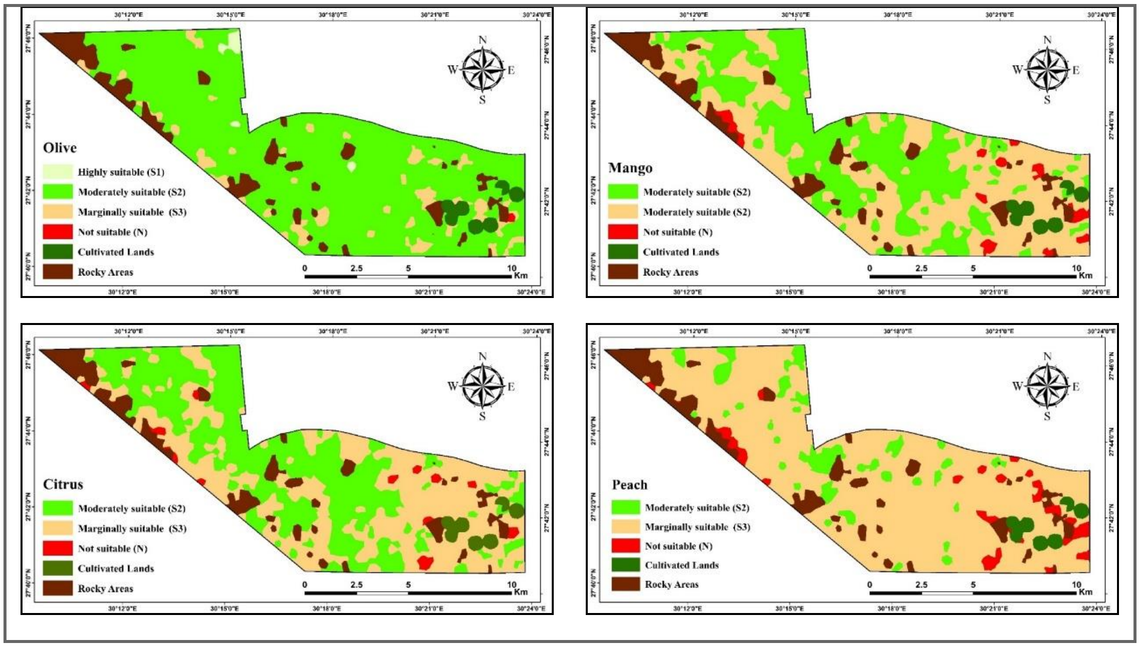

Figure 9. Land suitability classes for some fruit crops.

5. Conclusion

This study evaluated land productivity and crop suitability across nearly 29,000 feddans (≈12,180 ha) in a newly reclaimed zone west of El-Minya, using a combination of 1,934 soil profiles, laboratory analyses, and GIS-based modeling. The results revealed a high degree of spatial variability, with key limitations including salinity, high calcium carbonate, shallow soil depth, and low organic matter. According to the modified Storie Index, only about 10% of the area was classified as good capability (grade 3), while nearly 75% fell into marginal capability (grade 4). This clearly indicates that most of the land requires careful management to be productive. The crop suitability analysis demonstrated significant variability among crop groups. Field crops exhibited the highest potential, with wheat and barley achieving over 68% of the land in S1 and sorghum covering 53.7% S1, confirming their dominance as staple crops. Sugar beet and alfalfa were largely moderately suitable (≈٧٩–85% S2), highlighting their feasibility under controlled management. Oil crops showed mixed performance: sunflower emerged as the most promising with 7.3% S1 and 78% S2, followed by sesame (73% S2). Soybean was restricted to S2 (82.8%) with limited S1 (2.75%), while groundnuts were the least suitable, with 91% S2 and 18.5% S3. Vegetable crops were generally constrained by salinity and $CaCO_3$, with onion performing best (7.5% S1, 78.3% S2), while potato, tomato, and watermelon were mostly confined to S2–S3 classes. Fruit crops were the most restricted group: olive showed adaptability (79.9% S2) and citrus and mango occupied mid-range suitability (≈40–45% S2–S3), whereas peach was the least viable with 95.6% of the land only marginally suitable (S3). It can be concluded that cereals and oil crops should form the backbone of reclamation strategies, while vegetables and fruit trees require selective zoning and intensive management to be viable. The major soil and water limitations identified in the study are quantitatively significant. Approximately 68% of the surveyed soils exhibit salinity levels exceeding 4 dS m^{-1}, which strongly restricts the cultivation of sensitive crops and necessitates intensive management practices. Calcium carbonate content is another widespread constraint, with nearly 80% of the studied area are strongly calcareous (10-25 % $CaCO_3$), reducing nutrient availability and aggravating physical barriers to root development. Effective soil depth was also limiting factor, about 66% of the study area were moderately deep soil (50-100 cm), restricting rooting depth and water storage capacity, while only 3.6% were classified as deep (>100 cm). Soil Texture and Water-Holding Capacity, with 58% sandy loam and 25% loamy sand, the soils exhibit low water-holding capacity and high infiltration rate. While these textures facilitate mechanized cultivation and reduce risks of waterlogging, they necessitate frequent irrigation and organic matter amendments. Despite these constraints, the findings confirm that significant portions of the area have promising agricultural potential if appropriate management practices are adopted. These include salinity control through leaching and drainage, fertility enhancement via organic amendments and balanced fertilization, and efficient irrigation systems to conserve groundwater. By prioritizing resilient crops such as wheat, barley, sunflower, sesame, and olive, land productivity can be maximized while reducing environmental risks. In conclusion, this research demonstrates the value of integrating classical evaluation methods with modern GIS-based spatial tools to produce accurate, quantitative assessments of land capability and suitability. The results provide a clear framework for guiding agricultural investment and land use planning in arid reclamation zones. They also highlight the urgent need for continuous monitoring of soil and water resources, as well as adaptive management strategies, to ensure the long-term sustainability of reclamation projects in Egypt’s Western Desert.

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الملخص العربي

التحليل المكاني لقدرة الأراضي وتقييم ملاءمة المحاصيل في غرب المنيا، مصر من أجل التنمية الزراعية المستدامة.

كوثر هارون محمد - هاجر علي حسن – وجيه سيد محمد – أحمد سيد أحمد – محي الدين محمد عبدالعظيم
قسم الأراضي والمياه – كلية الزراعة – جامعة المنيا - مصر

تهدف الدراسة إلى تقييم قدرة الأراضي وصلاحيتها للمحاصيل في منطقة جديدة مستصلحة غرب المنيا بمساحة تقارب ٢٩ ألف فدان، وذلك كخطوة أساسية لتحقيق التنمية الزراعية المستدامة في الصحراء المصرية. اعتمدت الدراسة على ١٩٣٤ قطاعًا أرضيًا أُخذت منها عينات وحُللت معمليًا، ثم جرى توظيف نظم المعلومات الجغرافية (GIS) ونماذج التقييم الكلاسيكية مثل مؤشر ستوري (Storie Index) وأداة LUSET لتقدير القدرة الإنتاجية ومدى ملاءمة المحاصيل المختلفة.

أهم النتائج:

قدرة الأرض: أظهرت النتائج أن ١٠% فقط من الأراضي تقع في الدرجة (٣) "متوسطة"، بينما نحو ٧٥% في الدرجة (٤) "ضعيفة" و ٢.٦% في الدرجة (٥) "غير صالحة".

المحددات الرئيسة:

الملوحة المرتفعة، تراكم كربونات الكالسيوم، وعمق التربة الضحل، بالإضافة إلى قوام التربة الرملي الذي يقلل من قدرتها على الاحتفاظ بالماء.

المحاصيل الحقلية: القمح والشعير كانا الأكثر ملاءمة، إذ يغطيان أكثر من ٦٨% من الأراضي بدرجات عالية إلى متوسطة، يليهما الذرة الرفيعة (٥٣% بدرجة عالية). أما بنجر السكر والبرسيم فكانا ملائمين بدرجة متوسطة.

المحاصيل الزيتية: عباد الشمس والسمسم أظهرا أفضلية واضحة (٧٠–٨٠% بدرجات بينما كانت الصويا والفول السوداني أقل ملاءمة بسبب حساسيتها للملوحة والكربونات.

الخضر: كانت الملاءمة عامة متوسطة، حيث تفوق البصل (≈٧٨% ملائم متوسط)، بينما البطاطس والطماطم والبطيخ تراجعت إلى درجات متوسطة

أشجار الفاكهة: الزيتون كان الأنسب (≈٨٠% ملائم متوسط) لقدرته على تحمل الظروف الصحراوية، بينما الحمضيات والمانجو ملاءمتهما محدودة، والخوخ كان الأقل قابلية للزراعة

التوصيات:

يمكن تحقيق إنتاجية جيدة عبرتحسين خصوبة التربة بإضافة المواد العضوية والأسمدة المتوازنة والتحكم في الملوحة بالغسيل والصرف و استخدام نظم ري حديثة (مثل الري بالتنقيط) لترشيد المياه والتركيز على محاصيل أكثر قدرة على التكيف مثل القمح، الشعير، الذرة الرفيعة، عباد الشمس، السمسم، والزيتون.