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Sustainable Agriculture as Influenced by Landform in Qena Governorate, Egypt

Mohamed Ahmed Elsaid Saeed[1], **Ahmed Ibrahim El-Desoky**[2] and **Yasser Abdel-Aal Sayed**[2]

[1] *Soils and Water Department, Faculty of agriculture, Al-Azhar University, Nasr City, Cairo, 11884, Egypt*
[2] *Soils and Water Department, Faculty of Agriculture, Al-Azhar University, Assiut, 71524, Egypt*

Ensuring sustainability of agricultural is imperative for Egypt's modest national income, with a focus on improving land production and conserving natural resources. The urgency arises due to population growth and new land reclamation, posing sustainability challenges such as soil characteristics, alkalinity, salinity limitations, socio-economic factors, and environmental hazards. This study evaluates the sustainability of agricultural status of some soils in Qena Governorate, integrating biophysical, economic viability, and social acceptability aspects, and examining their correlation with landform types. The sustainability framework encompasses five factors: productivity, security, protection, economic viability, and social acceptability. The productivity index ranges from 0.29 to 0.43, protection factors exhibit values from 0.49 to 0.90, security factors range between 0.56 and 0.90, economic viability index spans from 0.45 to 0.80, and social acceptability varies from 0.47 to 1.00. The study classifies the investigated area into two classes (S3 and S4) based on the sustainable agricultural framework. The region faces challenges in local infrastructure, health facilities, and education. The results underscore a distinct correlation between sustainability indices and geomorphological units, with the Plain Valley consistently displaying the highest values, followed by the Low River terraces, Moderate River terraces, and High River terraces, while the Overflow basin consistently exhibits the lowest values. The findings emphasize that decision-makers can enhance land sustainability in the study area by focusing on two key factors: social and economic considerations, while also accounting for the impact of landform.

Keywords: Sustainability agriculture, Landform, Spatial distribution, GIS, and RS.

1.Introduction

Following advancements in food production and the bolstering of engineering structures, soil science research shifted its focus. Over time, the demands on soil resources expanded to include various objectives: (1) enhancing agricultural production to meet the escalating global food demands, (2) fostering timber production by utilizing marginal soils, (3) rehabilitating degraded soils to promote biodiversity and environmental improvement, (4) mitigating the impact of atmospheric carbon dioxide by sequestering it within ecosystems, (5) enhancing water use efficiency and mitigating the risks of water pollution, and (6) establishing natural reserves for species conservation and recreational purposes (Lal, 2008). Two pivotal stages contribute to establishing the conceptual framework for defining sustainable agriculture. Initially, in the early 1980s, the emergence of regenerative agriculture concepts and the formulation of sustainable agriculture laid the groundwork. Subsequently, there was a surge in the usage of the term "sustainable," commencing in 1987, denoting a "stable" agriculture globally, encompassing all aspects of agriculture and its interface with society (Harwood, 1990; Rusdiyana et al, 2024). Sustainable agriculture endeavours to achieve long-term objectives by identifying environmental challenges and limitations that hinder the economic viability, environmental appropriateness, and social acceptance of land resource utilization (Rashed, 2022). Thus, sustainable agriculture aims to ensure

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*Corresponding author e-mail: Dr.MohamedSaeed84@gmail.com, elansary0man@gmail.com
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the fulfilment of current and future generations' food and feed requirements within a healthy and secure ecosystem, with agricultural practices evolving to support this goal (Mohamed et al, 2014).

Many approaches have been explored to enhance sustainable agriculture. For example, nanofibers have been used for seed coating, plant protection, encapsulating agrochemicals, and filtration in irrigation systems (Badgar et al, 2021). On the other hand, we can employ plant physiology and the role of plant hormones, such as the hormone melatonin, , in sustainable agriculture by enhancing plant tolerance to unfavorable environmental factors, reducing the effects of chemical pollutants, thus protecting plants from pathogens, reducing the use of agricultural pesticides, increasing crop productivity, and enhancing nutritional values (Sharma et al, 2024).

In the context of sustainable agriculture, precision farming utilizes AI through sensors, drones, and satellite imagery to monitor crop health, soil conditions, and weather patterns. Confronting challenges like population growth and climate change, AI enhances sustainability and productivity by enabling precise irrigation, fertilization, and pest control, thus reducing environmental impact. Machine learning algorithms predict crop health and potential threats, facilitating early intervention. Additionally, AI-powered robots improve operational efficiency and reduce labor costs, thereby promoting sustainable agricultural development (Son et al, 2024).

Although agriculture serves as a fundamental pillar for global sustainable development and ecosystem preservation, achieving this at the local level necessitates adaptation to local environmental, structural, social, and economic conditions (Björklund et al, 2012; Tscharntke et al, 2012). In Egypt, the elements of production, security, and protection, alongside social and economic considerations, are leveraged to address impediments to sustainability of agricultural (El Bastawesy et al, 2013).

In Egypt's Halayeb region, agro-ecological zones (AEZ) were delineated using soil, topographical, and climate data to assess land suitability for crops. AEZ applications aid policymakers in formulating informed development strategies by considering climate, soil, and landform conditions. With the adoption of proper reclamation methods and management practices, Halayeb's natural resources could support successful agricultural expansion, promoting sustainable development in the area (Jalhoum et al, 2022).

In agriculture and sustainable development, soil degradation poses significant challenges to global food security and ecosystem resilience due to climate variability, overgrazing, deforestation, and erosion. To address this, proactive interventions like afforestation, soil reclamation, and improved agricultural practices are crucial for mitigating degradation and promoting sustainability (Abdullahi et al, 2023). Landforms represent extensive, contiguous regions characterized by shared geomorphological history and chemical and physical attributes (Zinck, 2023). The correlation between soil properties and landscape positioning is notable, particularly concerning soil and water movement, and has been instrumental in delineating uniform mapping units for soil surveying, management, and productivity assessments (Dazzi and Monteleone, 2002).

The placement of soil profiles within a landform directly influences the type and thickness of soil horizons by regulating the evaporation or percolation of rainfall (Jalhoum et al, 2014). Mulugeta and Sheleme (2010) highlighted that various soil quality indicators, particularly at surface horizons, are significantly impacted by different landscape positions. Slope position significantly influences many physical and chemical soil properties (Dinku et al, 2014; Teshome et al, 2016). The variation in soil properties across landscapes affects plant production patterns, litter production, and decomposition rates, consequently impacting the carbon and nitrogen content of soils (Mulugeta et al, 2012). The impact of landforms on soil properties was investigated in the Amiriya region North of the Western Desert. The study focused on two distinct physiographic units, represented by nine soil profiles. Through the evaluation of various soil properties, including color, texture, structure, presence of carbonates or gypsum, dissolved salts, and pH levels, a significant correlation was observed between the type of physiographic units and soil characteristics (Zayed et al. 2021). A study in Bahariya oasis, Egypt, focused on agricultural sustainability development amidst resource scarcity and environmental degradation. Using multispectral Sentinel-2 imagery and soil profiles, the research assessed soil productivity, environmental security, and economic viability through the Framework for Evaluating Sustainable Land Management. Findings revealed shortcomings in productivity, economic viability, and social acceptability, suggesting the need for modernized farming techniques, improved healthcare and education, and financial support for farmers. The study provides valuable insights for decision-makers to enact sustainable management practices in the region (Shokr et al, 2022). Comprehending the dynamics and distribution of soil characteristics influenced by landscape features and land use is crucial for making informed decisions regarding crop production and appropriate land use practices (Beyene, 2017).

The primary objective of this study is to assess the utilization of sustainability of agricultural for agricultural development and its association with landform types in the Qena area.

2. Materials and Methods

2.1. Study Area

The research site is situated in the central region of Qena Governorate on the western bank of the Nile River in Egypt, encompassing an area of approximately 132.47 km2. Its geographical coordinates range from latitudes 25°58'00" to 26°08'00" N and longitudes 32°32'00" to 32°38'00" E (Figure 1). The climate in the study area is characterized as hot, featuring prolonged periods of drought, extremely high temperatures during summer, and cold conditions in winter. Precipitation is infrequent throughout the year, coupled with a high rate of evapotranspiration (National Oceanic and Atmospheric Administration, 2019). According to the Soil Survey Staff (2022), the soil temperature regime within the area can be classified as hyperthermic, while the soil moisture regime is categorized as Torric or Aridic.

2.2. Remote sensing and geomorphological units

The spectral characteristics of bands extracted from satellite imagery were utilized to delineate the road networks and urban landscape features within the study area. Digital Elevation Models (DEMs) with a resolution of 30 meters were generated from data obtained from the Shuttle Radar Topography Mission (SRTM) and processed using ArcGIS 10.4 software (Farr et al, 2007).

These DEMs were then utilized to construct a topographic map of the study region (Dobos et al, 2002), from which physiographic units were delineated following the methodology described by Zink and Valenzuela (1990).

2.3. Soil sampling and Laboratory Analyses

Soil sampling was conducted across various geomorphological units within the study area, including the Plain Valley (36.231 km2), Low River terraces (30.984 km^2), Moderate River terraces (21.772 km^2), High River terraces (17.271 km^2), and Overflow basin (26.213 km^2). A total of 16 soil profiles were established across these geomorphological units, as illustrated in Figure 2. The physical and chemical analyses utilized the fine earth fraction, which consists of particles with a diameter less than 2 mm. These analyses, outlined in Table 1, were conducted on samples that had been air-dried, crushed, and sieved through a 2-mm screen.

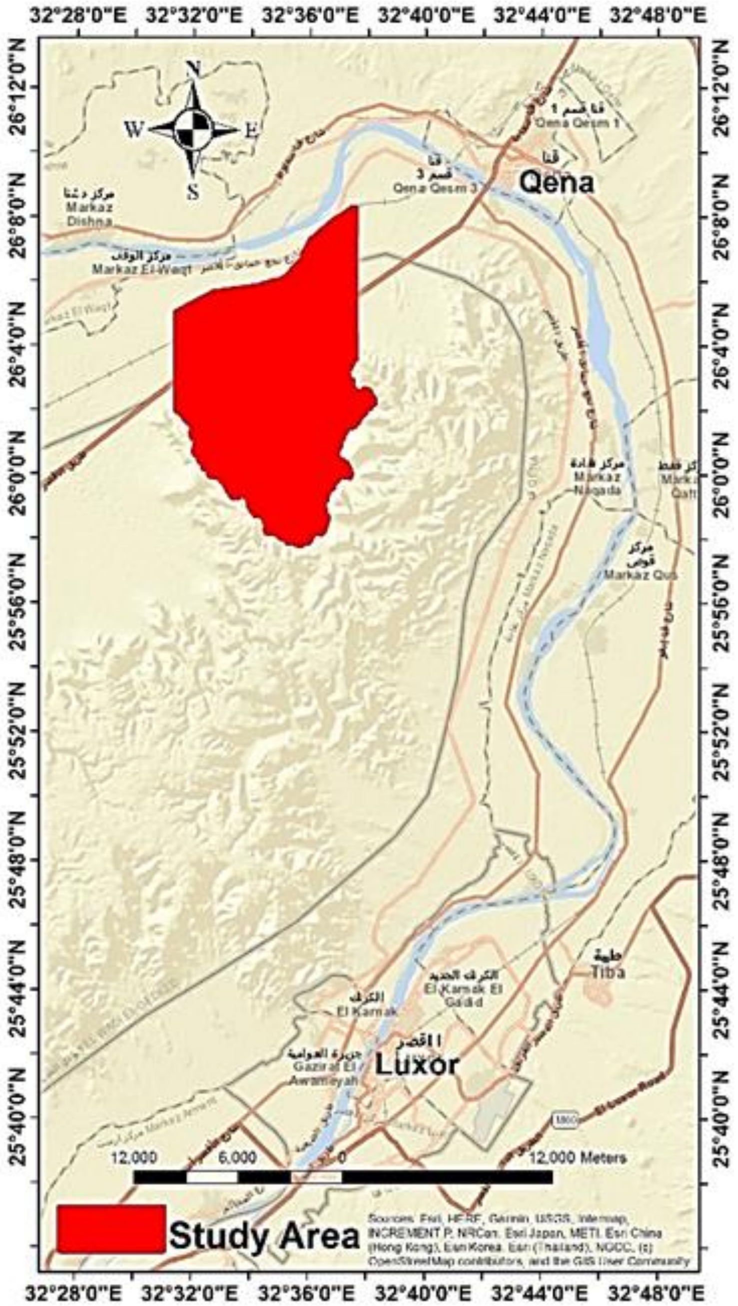


Fig. 1. Location of the study area.

2.4. Sustainable agriculture

To assess the present status of sustainability of agriculture within the research area, the sustainable land management framework outlined by Smith and Dumanski (1993) was employed. This framework, as adapted by El-Nahry (2001) to align with Egyptian conditions, evaluates a range of factors pertaining to soil and environmental characteristics, economic viability, and societal acceptance. These factors are categorized into five distinct elements: productivity, protection, security, economic feasibility, and social acceptance. The assessment involves the individual calculation of each factor's value, which is subsequently integrated to determine the overall agricultural sustainability, as detailed in Tables 3 and 4.

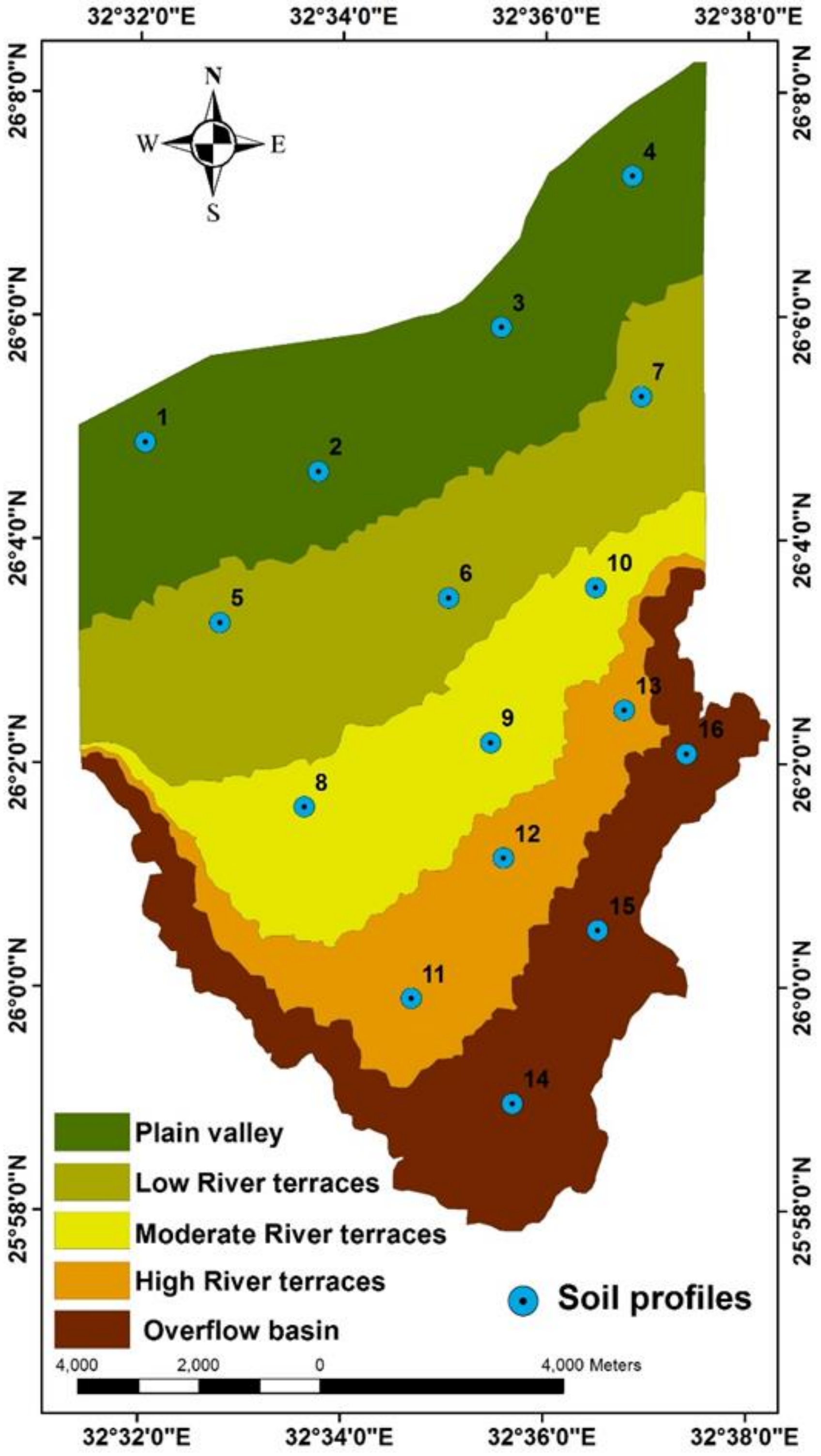


Fig. 2. Geomorphological units of the study area are marked with soil profiles.

2.5. Spatial distribution of soil properties

spatial interpolation, a commonly employed technique, is utilized to generate seamless datasets from discrete data points, such as soil profiles. The ordinary kriging model is adopted, considering both the proximity of known data points and the broader geostatistical relationships among these points to predict values at unsampled locations. In this investigation, Arc-GIS 10.4 software was employed for ordinary kriging to interpolate soil properties across various landforms.

Table 1. The soil properties analyses, analysis methods, and references.

Property	**Unites**	**Method**	**References**
Mechanical analysis		Pipette method.	Piper (1950)
Electrical conductivity (EC_e)	dS m^{-1}	Measured in the soil paste extract using the EC-meter.	Jackson (1958)
Soil reaction (pH)		Measured in the soil suspension 1:2.5 using the pH meter.	Klute (1986).
Cation exchange capacity or CEC	cmolc(+)/kg	Extracted by sodium acetate (1.0 N, pH=8.2) and ammonium acetate (1.0 N, pH=7) and measured on the flame photometer.	Chapman (1965)
Exchangeable sodium percentage (ESP)	%	Calculated as a ratio from the cation exchange capacity (CEC) values.	
Soil organic matter (SOM)	(%)	Measured as a ratio from the solid soil using Walkley and Black method	Cottenie et al, (1982)

Table 2. Equations of sustainability of agricultural and each factor separately.

Calculation equation	Inputs
Land sustainability index = ___3 ___3 ___3 ___3 ___ ه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِ	Where: A, productivity; B, protection; C, security; D; economic viability; E, social acceptability.
Productivity index = ___3 ___3 ___3 ___3 ___3 ___3 ه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِ ___ 3 ___3 ___ 3 ___ 3 ___ ه ى ى ه ى ىه ى ى ه ى ى ه ى ى	Where: A, soil texture; B, soil color; C, pH; D, cation exchange capacity (CEC); E, profile depth; F, salinity (EC_e); G, alkalinity (ESP); H, relative yield %; I, soil nutrient nitrogen (N); J, available phosphorous (P); K, available potassium (K).
Protection index = ___3 ___3 ___ ه يِ يِه يِ يِه يِ يِ	Where: A, cropping system; B, flooding hazards; C, erosion hazards.
Security index = ___3 ___3 ___ ه يِ يِه يِ يِه يِ يِ	Where: A, moisture availability; B, water quality; C, biomass.
Economic index = ___3 ___3 ___3 ___3 ___ ه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِ	Where: A, benefit-cost; B, market price; C, arm labor; D, size of farm; E, sold in the market.
Social acceptability index = ___3 ___3 ___3 ___3 ___3 ___ ه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِه يِ يِ	Where: A, land tenure; B, extension services; C, health and educational; D, training of farmers; E, agro-inputs; F, village road access.

According to El-Nahry (2001)

Table 3. Agriculture sustainability class, value, and threshold

No.	Class	Value (Rate)	Threshold
1	S1	0.6 to 1.0	Agriculture management practices comply with sustainability standards.
2	S2	0.3 to 0.6	Agriculture management practices slightly exceed the sustainability threshold.
3	S3	0.1 to 0.3	Agriculture management practices are slightly below the sustainability threshold.
4	S4	< 0.1	Agriculture management practices fall short of meeting sustainability requirements.

According to El-Nahry (2001).

3. Results

3.1. Soil properties in the study area

The soil data presented in Table 4 and illustrated in Figures 3 to 7 indicate considerable depth across all soil profiles, spanning from 130 to 150 cm. Soil texture demonstrates variability within the study area, encompassing classifications such as loamy sand (LS), sandy loam (SL), gravelly loamy sand (GLS), and very gravelly loamy sand (VGLS). The cation exchange capacity (CEC) ranges from 7.03 to 15.5 cmolc(+)/kg, with clay content varying between 5.6 and 11%. Volumetric content of gravel and gravelly components ranges from 2 to 8. Despite this variability, gypsum and organic matter contents generally remain low across the studied soils, with levels ranging from 0.27% to 1.33% and 0.14% to 0.30%, respectively. Soil pH values range from 8.13 to 8.64 across different soil profiles.

Table 4. Characteristics of soil in the studied area.

Units	Profile No.	Depth (cm)	Gypsum %	O.M. %	CaCO3 %	Texture	EC_e (dS/m)	pH	CEC cmolc (+)/ kg	ESP %	N mg/kg	K mg/kg	P mg/kg
Plain valley	**1**	**150**	**0.51**	**0.3**	**8.5**	**SL**	**7.22**	**8.55**	**15.5**	**15**	**43.9**	**96**	**7.32**
	2	**150**	**0.2**	**0.21**	**10**	**SL**	**15.08**	**8.60**	**13.3**	**15**	**41**	**90**	**5.75**
	3	**150**	**0.66**	**0.22**	**7.1**	**SL**	**12.95**	**8.43**	**13.8**	**15**	**47.9**	**79**	**6.5**
	4	**150**	**0.75**	**0.27**	**8.8**	**LS**	**10.8**	**8.43**	**13.5**	**15**	**45**	**89**	**5.75**
Low River terraces	**5**	**150**	**0.33**	**0.16**	**12**	**GLS**	**7.32**	**8.59**	**13.8**	**17**	**30.3**	**##**	**5**
	6	**150**	**0.38**	**0.19**	**10**	**GLS**	**5.32**	**8.58**	**10.8**	**17**	**30.3**	**82**	**5.38**
	7	**150**	**0.27**	**0.18**	**8.3**	**GLS**	**7.54**	**8.65**	**9.5**	**18**	**29.3**	**86**	**5.5**
Moderate River terraces	**8**	**150**	**0.34**	**0.17**	**9.5**	**SL**	**6.69**	**8.62**	**10.5**	**16**	**27.4**	**78**	**5.9**
	9	**150**	**0.49**	**0.23**	**8.5**	**SL**	**5.75**	**8.55**	**8**	**17**	**33.5**	**69**	**5.5**
	10	**150**	**0.44**	**0.17**	**10**	**LS**	**4.93**	**8.65**	**10**	**17**	**30.3**	**72**	**6**
High River terraces	**11**	**140**	**0.5**	**0.17**	**9.6**	**GLS**	**24.83**	**8.62**	**9.25**	**17**	**30.8**	**73**	**5.75**
	12	**135**	**0.89**	**0.17**	**11**	**GLS**	**25.71**	**8.36**	**8.81**	**14**	**22.5**	**70**	**6.94**
	13	**140**	**0.83**	**0.14**	**9.9**	**GLS**	**16.28**	**8.44**	**7.96**	**15**	**20.1**	**74**	**6.59**
Overflow basin	**14**	**140**	**0.9**	**0.14**	**11**	**VGLS**	**24.72**	**8.36**	**7.49**	**14**	**21**	**69**	**6.76**
	15	**130**	**1.33**	**0.15**	**13**	**VGLS**	**21.19**	**8.13**	**7.12**	**12**	**19.3**	**67**	**7.44**
	16	**135**	**0.83**	**0.16**	**13**	**VGLS**	**27.5**	**8.55**	**7.03**	**14**	**18.1**	**67**	**6.11**

Sandy Loam, SL; Loamy Sand, LS; Sandy Clay Loam, SCL; Gravely Loamy Sand, GLS; Very Gravely Loamy Sand, VGLS;

Furthermore, the soils exhibit electrical conductivity values ranging from 4.9 to 25.7 dS/m, with exchangeable sodium percentage (ESP) ranging between 11.79% and 17.50%. Essential nutrient content, particularly nitrogen (N), phosphorus (P), and potassium (K), varies within the ranges of 18.06–47.87 mg/kg, 5.00–7.44 mg/kg, and 66.78–104.25 mg/kg, respectively.

In the Plain valley, there are moderate to high levels of gypsum, organic matter, and calcium carbonate, with sandy loam and loamy sand textures prevailing. The Low River terraces exhibit similar textures but with slightly lower component levels compared to the Plain valley. The Moderate River terraces show further variations with decreased levels of gypsum, organic matter, and calcium carbonate. Conversely, the High River terraces and Overflow basin display higher component levels compared to preceding landforms.

Addressing salinity issues and improving soil fertility through appropriate practices are crucial for sustainable agriculture in the region. Additionally, soils in the southern geomorphological units generally exhibit higher levels of nitrogen, CEC, organic matter, and clay content, with lower salt percentages.

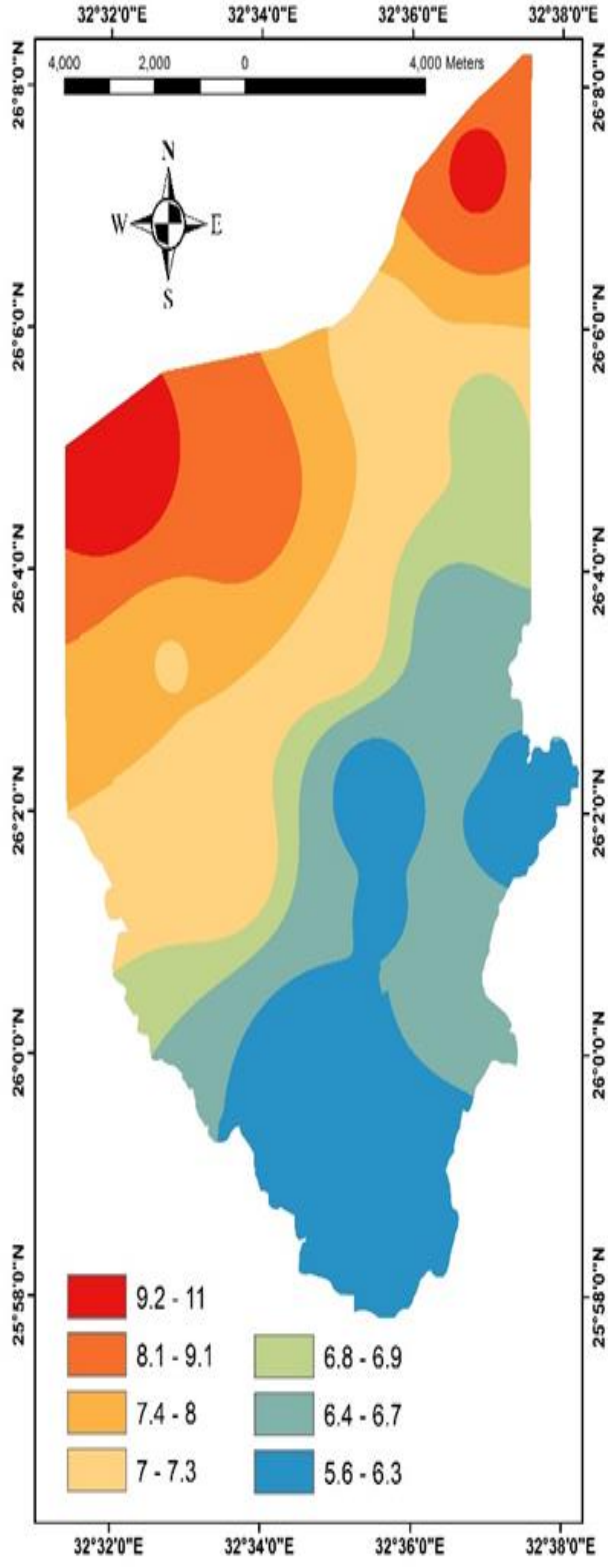


Fig. 3. Spatial distribution of clay (%).

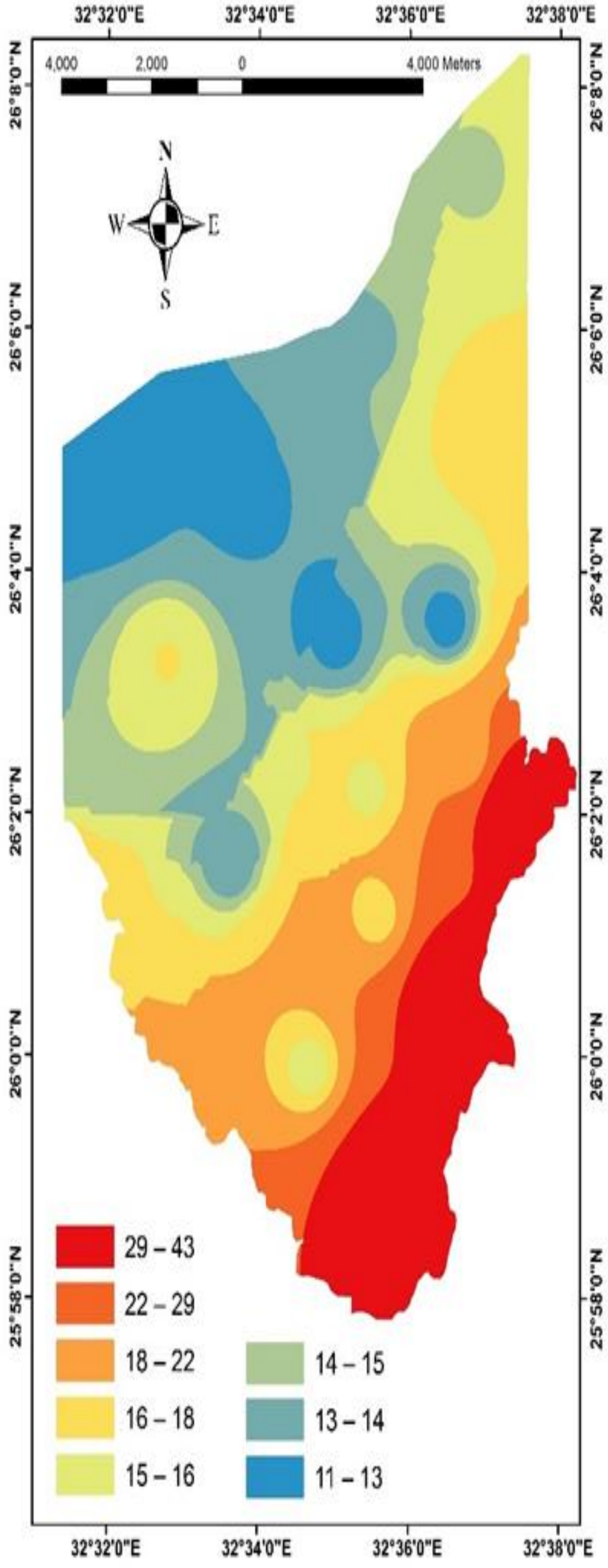


Fig. 4. Spatial distribution of gravel.

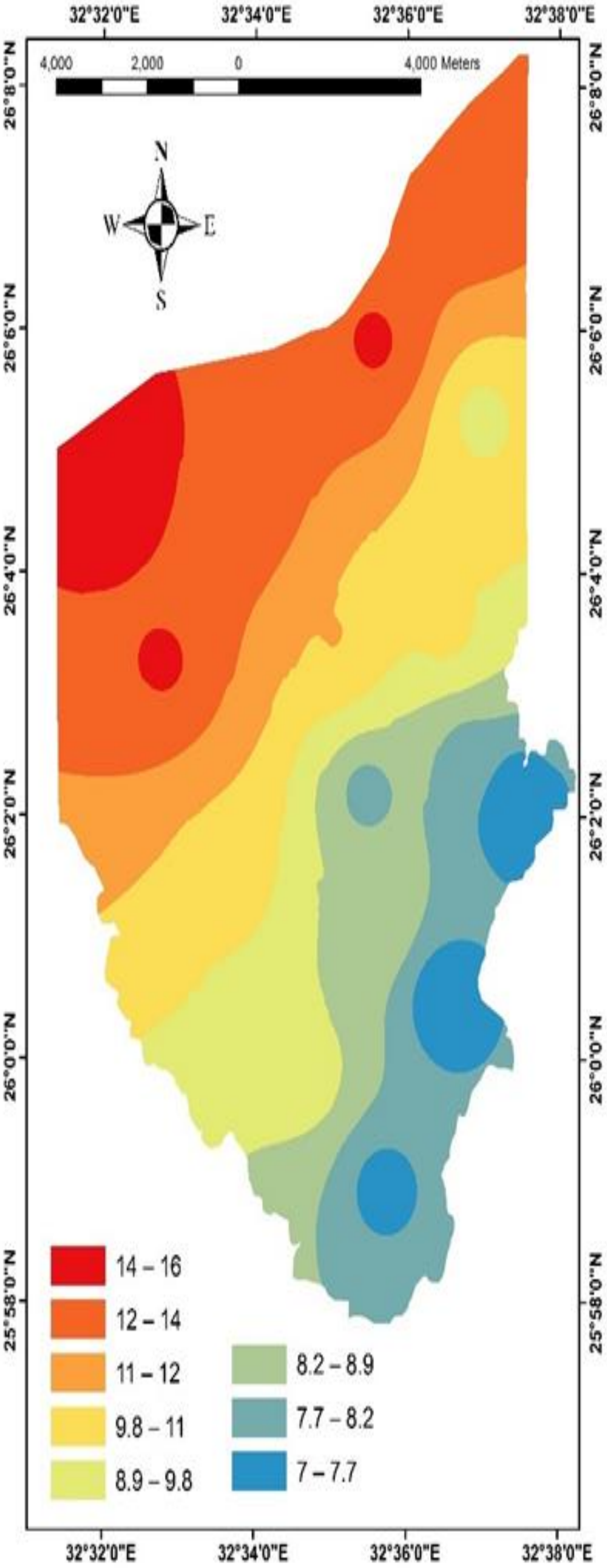


Fig. 5. Spatial distribution of CEC.

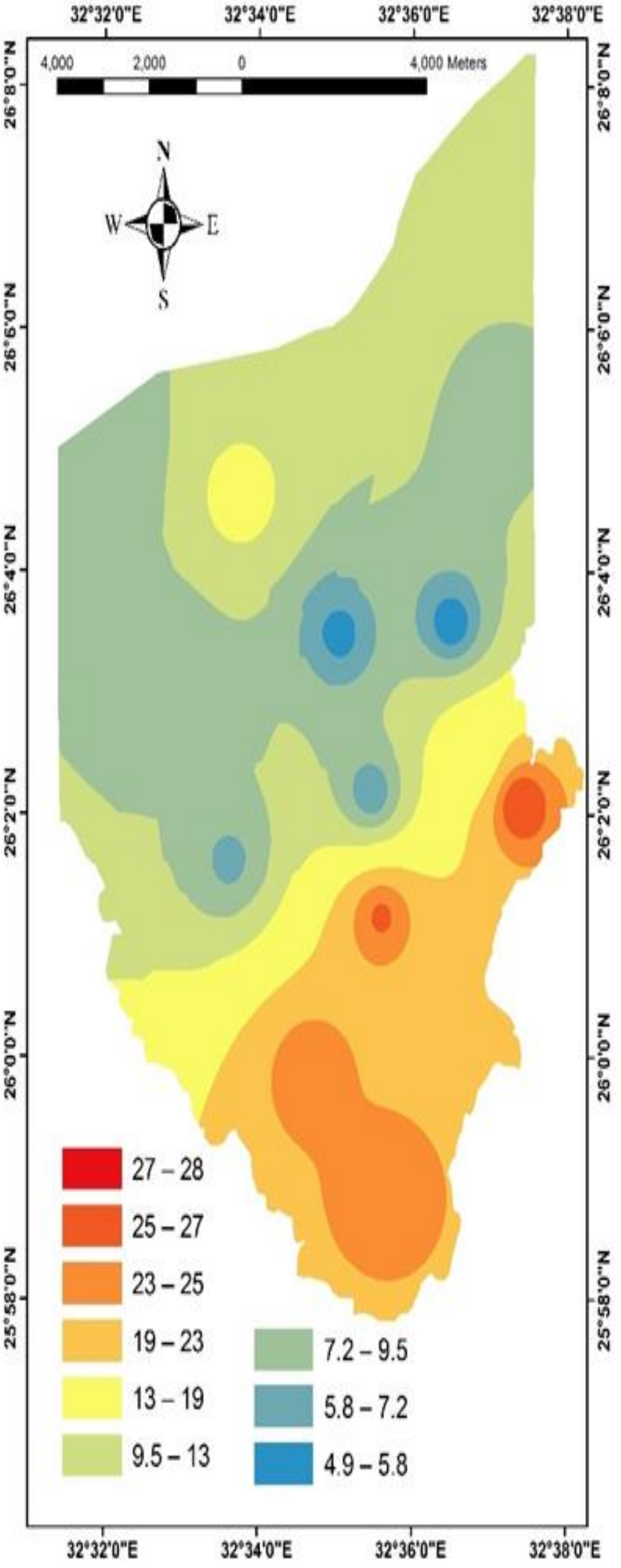


Fig. 6. Spatial distribution of ECe.

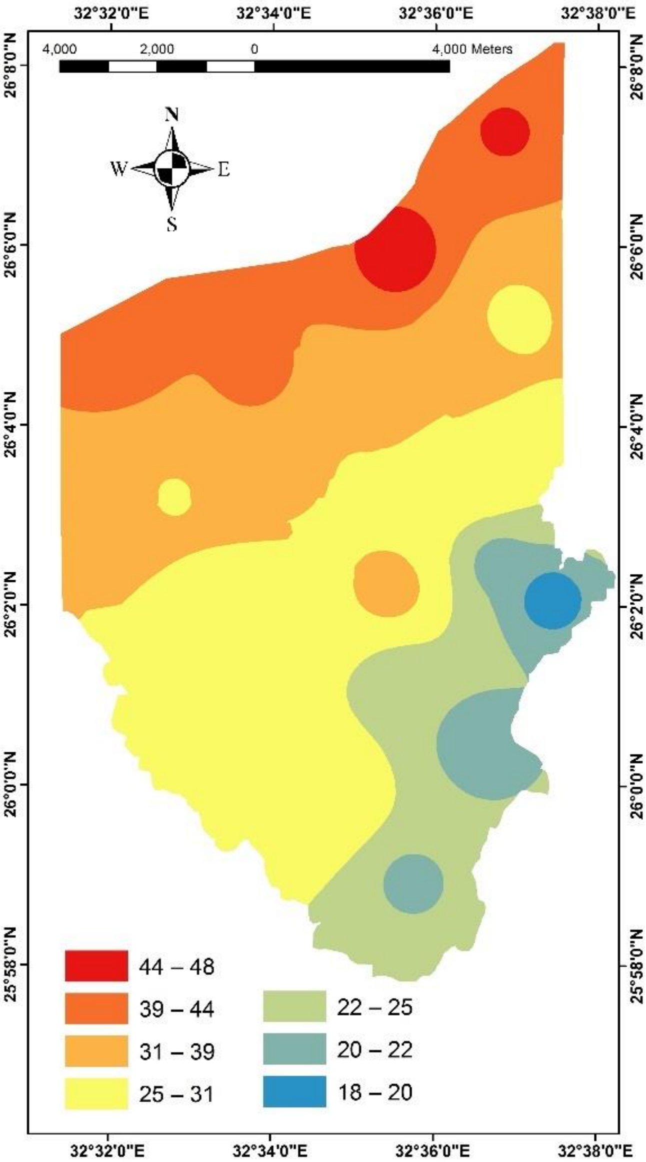


Fig. 7. Spatial distribution of N.

3.2. Evaluation of sustainability agriculture.

The sustainability framework employed in this study encompasses five principal indicators, each evaluated individually based on diverse soil properties, environmental factors, and agricultural processes, as outlined in Table 2.

The productivity index exhibited a range from 0.29 to 0.43, indicating varying levels of productivity across the area, as illustrated in Table 5 and Figure 8.

Similarly, the protection index ranged from 0.49 to 0.90, while the security index varied from 0.56 to 0.90, depicting diverse levels of security and protection within the region, as presented in Table 5 and Figures 9 and 10.

The economic viability index ranged from 0.45 to 0.80, providing insights into benefit-cost ratios influenced by market conditions, as depicted in Figure 11 and detailed in Table 5.

Moreover, the social acceptability index exhibited variations between 0.47 and 1.00, reflecting different levels of social acceptability across the area, as outlined in Table 5 and depicted in Figures 12 and 13.

3.3. Sustainability indices and Geomorphological units

Table 5 provides a comprehensive analysis of five sustainability indices across diverse landforms in the study area, offering insights into agricultural sustainability across various profiles.

In the Plain valley (profiles 1 to 4), high values of the productivity index led to classification under S3.

Transitioning to the Low River terraces (profiles 5 to 7), a slight decline in the productivity index suggests a moderate decrease in agricultural potential. However, favorable scores in other indices lead to classification under S3.

In the Moderate River terraces (profiles 8 to 10), a noticeable reduction in the productivity index indicates a further decline in agricultural output. Lower scores in other indices result in classification under S4, indicating lower sustainability. Moving to the High River terraces (profiles 11 to 13) and Overflow basin (profiles 14 to 16), decreased values of the productivity index indicate a significant reduction in agricultural output. Diminished scores in other indices lead to classification under S4.

4.Discussion

This study evaluates the agricultural sustainability of soils in Qena Governorate by integrating biophysical factors, economic viability, and social acceptability aspects, and examining their correlation with landform types. The sustainability framework employs five principal indicators: productivity, protection, security, economic viability, and social acceptability. The geological composition of the study area significantly influences soil particle size and composition, shaping the distribution of sand, silt, and clay through fluvial sedimentation. The substantial depth observed in soil profiles is attributed to topographical factors (Yang et al, 2021).

Soil texture in the study area varies, including loamy sand (LS), sandy loam (SL), gravelly loamy sand (GLS), and very gravelly loamy sand (VGLS), influencing water infiltration, drainage, and root penetration. Sandy loam soils generally offer better water-holding capacity and nutrient availability (Wang et al, 2023).

Cation exchange capacity (CEC) ranges from 7.03 to 15.5 cmolc(+)/kg, indicating the soil's ability to retain and supply essential nutrients, with higher values associated with greater fertility. However, low clay content (5.6 to 11%) suggests limited nutrient-holding capacity and structural stability. Gravel content (2 to 8%) affects soil aeration and root growth; moderate levels enhance drainage, while excessive gravel can hinder root development and water retention (Junchao et al, 2023).

Despite variations in other properties, gypsum (0.27% to 1.33%) and organic matter (0.14% to 0.30%) levels remain consistently low, characteristic of dry climates, indicating limited nutrient availability and poor soil structure. Low organic matter content is particularly concerning, affecting soil fertility, water-holding capacity, and microbial activity, all crucial for sustainable agriculture. Soil texture variability is influenced by the characteristics of the parent material. The CEC demonstrates a positive relationship with texture type and clay percentage, further underscoring the importance of soil composition in nutrient retention and supply.

The range of soil pH values, from 8.13 to 8.64, reflects moderately to strongly alkaline conditions across different profiles, influenced by minimal precipitation levels. These alkaline conditions pose challenges for nutrient availability, especially for micronutrients like iron, manganese, and zinc. (Brady and Weil, 2008).

Moreover, the soils display diverse salinity levels, Electrical conductivity (EC) values range from 4.9 to 25.7 dS/m, indicating salinity levels that can limit water uptake and cause ion toxicity. Exchangeable sodium percentage (ESP) indicating slight to moderate sodicity wher ranges from 11.79% to 17.50%, indicating sodic conditions that hinder plant growth. Nutrient content varies: nitrogen (18.06–47.87 mg/kg), phosphorus (5.00–7.44 mg/kg), and potassium (66.78–104.25 mg/kg). Nitrogen content in the soil tends to be lower compared to other nutrients . The study highlights significant variations in soil properties across different landforms in the area .These conditions necessitate targeted soil fertility management for sustainable agriculture. (Sayed and Fadl, 2021).

In summary, while the soils exhibit considerable depth and texture variability, low gypsum and organic matter levels, coupled with alkaline pH, suggest potential nutrient availability and soil fertility limitations. These factors must be considered for effective soil management and crop production strategies.

Table 5. The metrics of the five sustainability indices in the examined area.

Units	Profile No.	Productivity index	Protection index	Security index	Economic index	Social acceptability index	Land sustainability index	Class
Plain valley	1	0.41	0.90	0.90	0.80	1.00	0.27	S3
	2	0.41	0.90	0.90	0.80	1.00	0.27	S3
	3	0.43	0.90	0.90	0.80	1.00	0.28	S3
	4	0.43	0.90	0.90	0.80	1.00	0.28	S3
Low River terraces	5	0.34	0.80	0.80	0.58	0.90	0.12	S3
	6	0.33	0.80	0.80	0.58	0.90	0.11	S3
	7	0.31	0.80	0.80	0.58	0.90	0.10	S3
Moderate River terraces	8	0.37	0.54	0.63	0.73	0.52	0.05	S4
	9	0.37	0.54	0.63	0.73	0.52	0.05	S4
	10	0.37	0.54	0.63	0.73	0.52	0.05	S4
High River terraces	11	0.29	0.54	0.63	0.51	0.52	0.03	S4
	12	0.33	0.54	0.63	0.51	0.52	0.03	S4
	13	0.31	0.54	0.63	0.51	0.47	0.02	S4
Overflow basin	14	0.31	0.49	0.56	0.45	0.47	0.02	S4
	15	0.31	0.49	0.56	0.45	0.47	0.02	S4
	16	0.29	0.49	0.56	0.45	0.47	0.02	S4

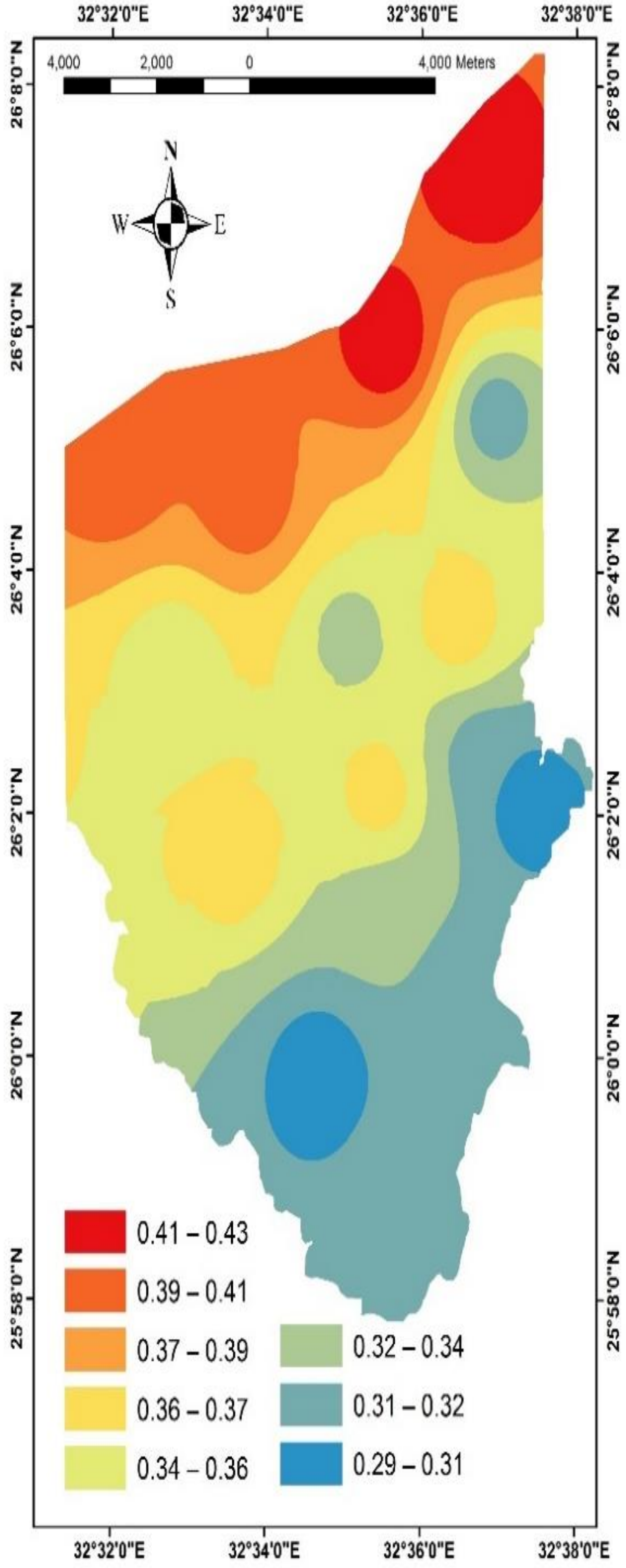


Fig. 8. Spatial distribution of Productivity index.

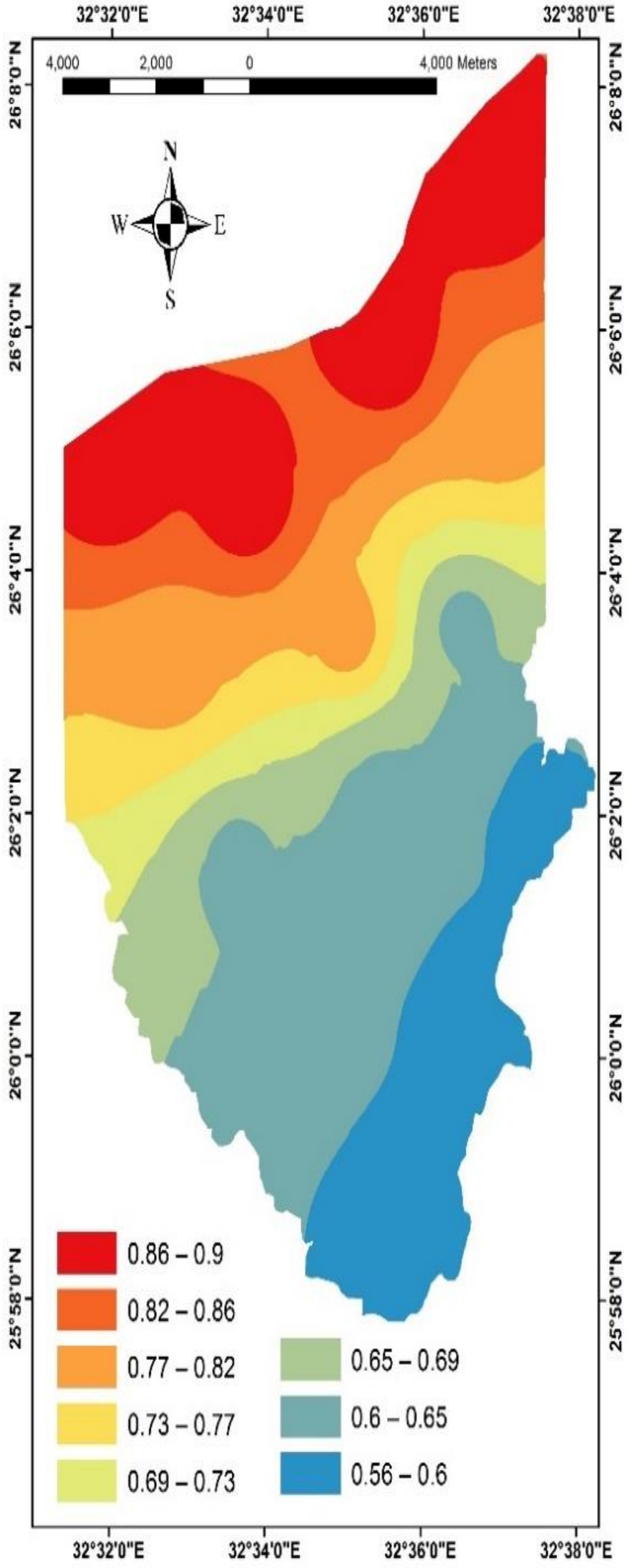


Fig. 9. Spatial distribution of Security index.

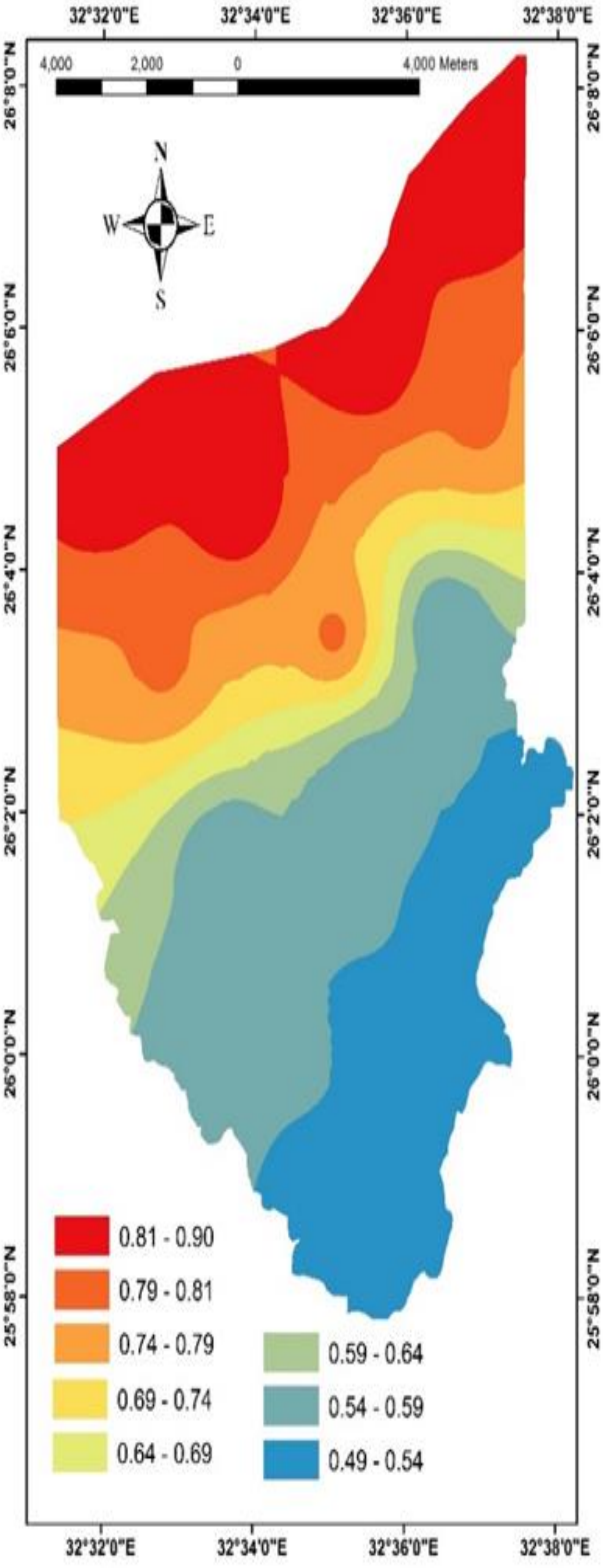


Fig. 10. Spatial distribution of Protection index.

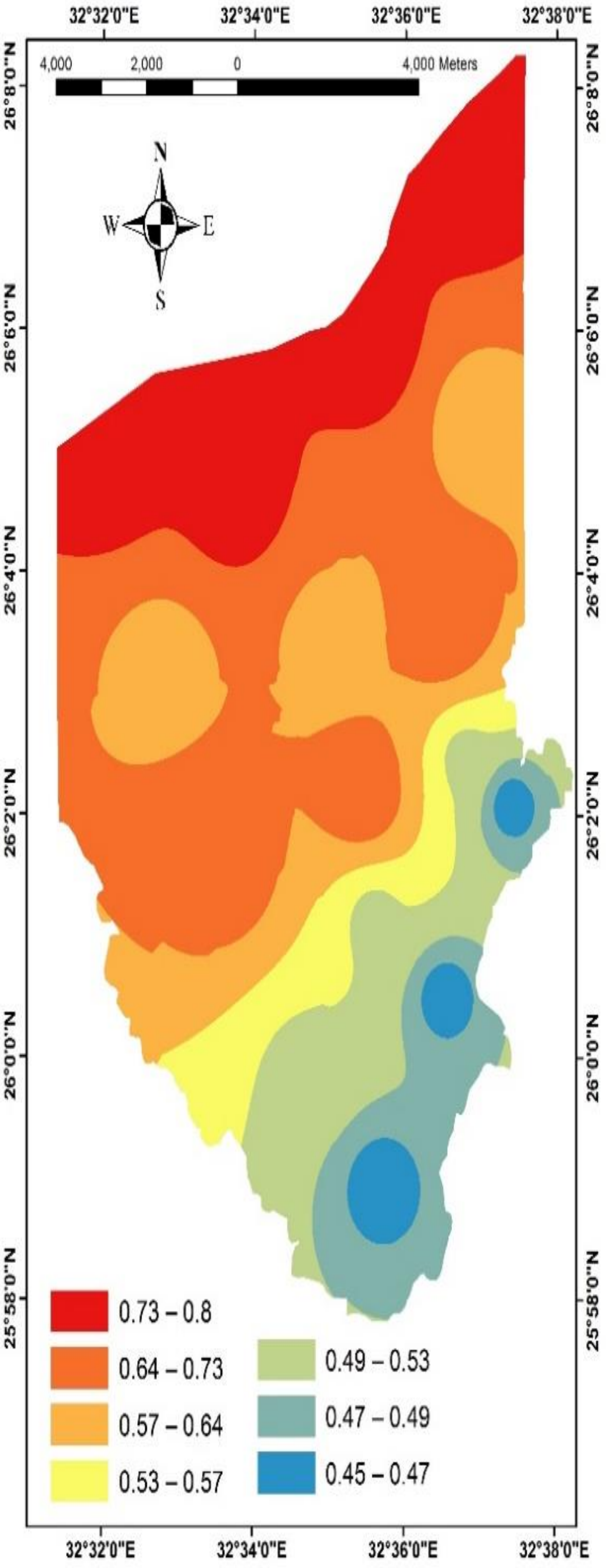
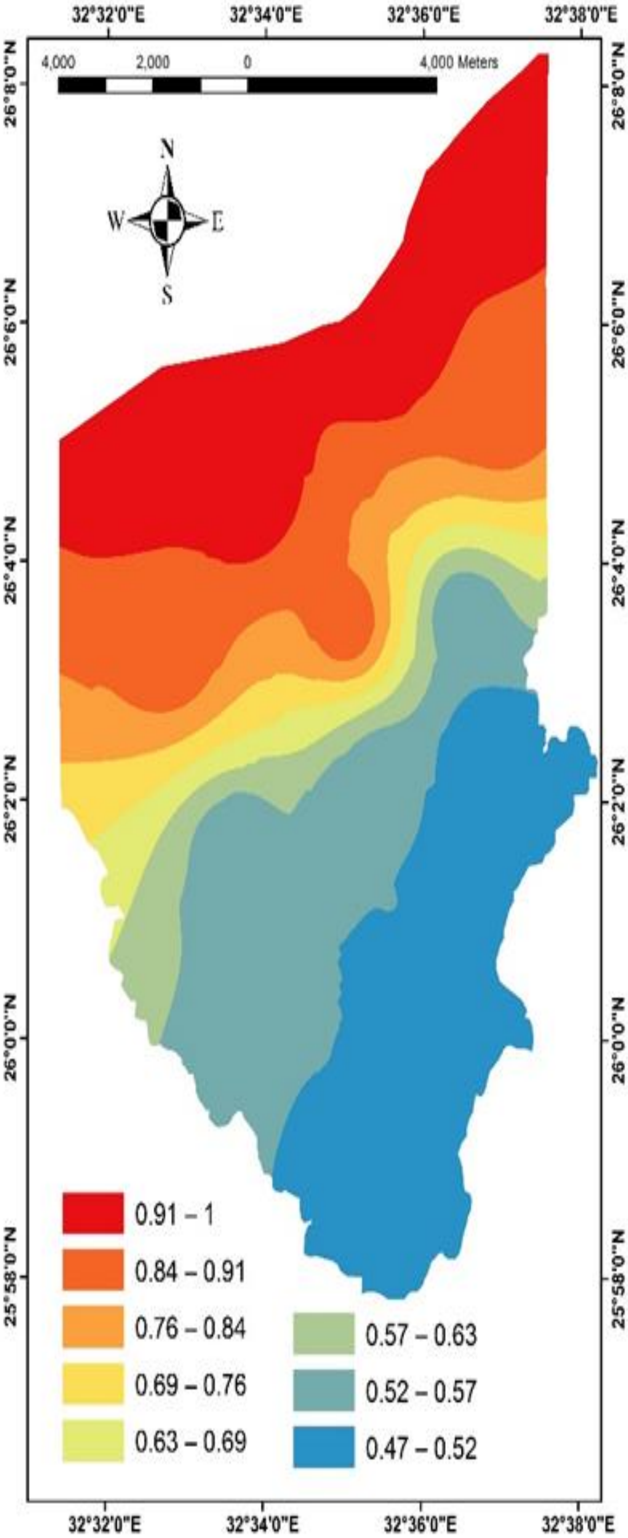


Fig. 11. Spatial distribution of economic index.



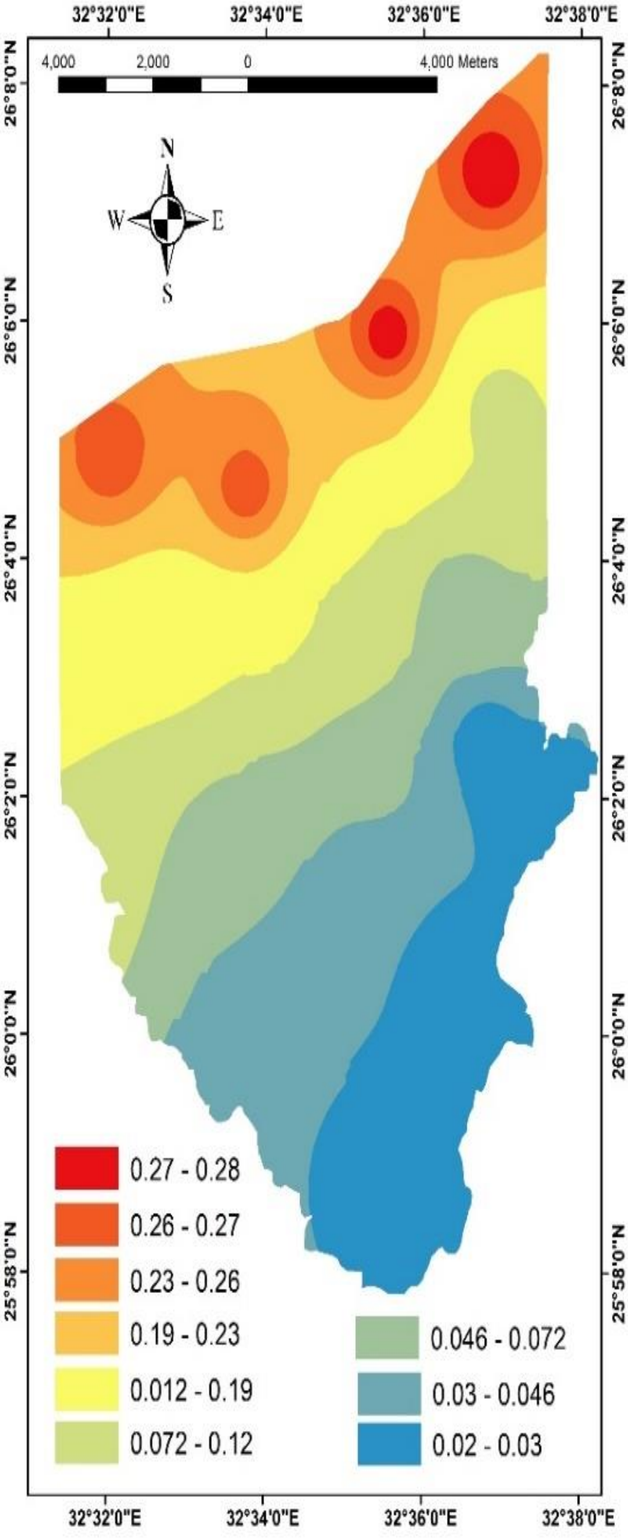
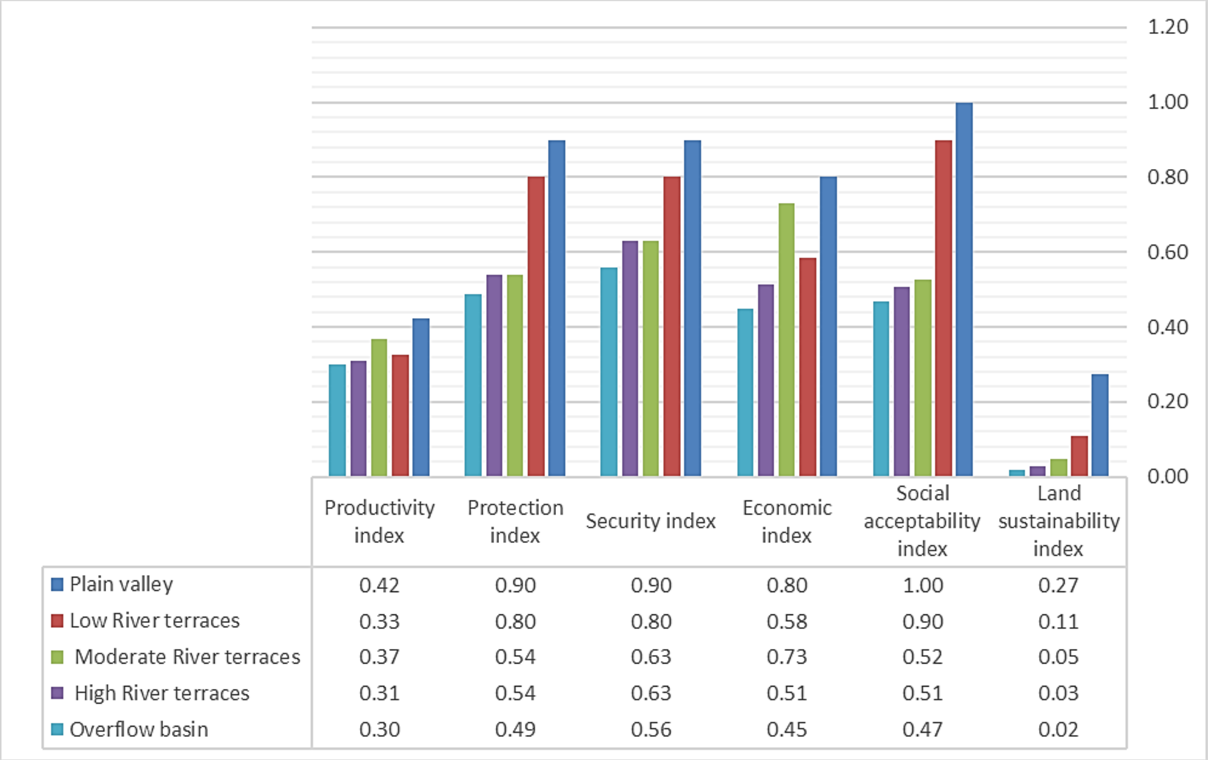


Fig. 12. Spatial distribution of Social acceptability index.

Fig. 13. Spatial distribution of Land sustainability index.



	Productivity index	Protection index	Security index	Economic index	Social acceptability index	Land sustainability index
Plain valley	0.42	0.90	0.90	0.80	1.00	0.27
Low River terraces	0.33	0.80	0.80	0.58	0.90	0.11
Moderate River terraces	0.37	0.54	0.63	0.73	0.52	0.05
High River terraces	0.31	0.54	0.63	0.51	0.51	0.03
Overflow basin	0.30	0.49	0.56	0.45	0.47	0.02

Fig. 14. Values of Sustainability Indices in the Mapping Units.

These findings emphasize the necessity of considering soil properties across diverse landforms for sustainable agricultural management (Davis et al, 2021). The study's sustainability framework evaluates five key indicators independently, taking into account various soil properties, environmental factors, and agricultural practices (Castellini et al, 2021).

Factors contributing to declining soil productivity include increased salinity levels, pH fluctuations, significant lime presence, reduced yield, diminished nutrient availability, and inadequate management practices.

The protection and security indices indicate varying levels of security and protection across the area, influenced by factors such as moisture stress, erosion risks, and inappropriate cropping systems (Soulé et al, 2021).

Fluctuations in economic viability index values reflect changes in benefit-cost ratios affected by market conditions and constraints, including limited market access, labor shortages, and farm size limitations.

Lower scores in the social acceptability index result from deficiencies in extension services, healthcare, and education within villages, along with limited training opportunities for land users.

Sustainability indices and geomorphological units: Overall, these findings underscore variations in sustainability indices across landforms, emphasizing the importance of considering landform characteristics in agricultural management for sustainability. Addressing challenges in lower-scoring profiles is essential for overall agricultural sustainability (Zhu et al, 2021).

Moreover, the study employs a sustainability framework with five principal indicators, aiding informed decision-making for sustainable land management and agricultural development. It also reveals a relationship between sustainability indices and geomorphological units within the study area (Yang et al, 2021).

While this study delves into soil properties and topography's roles in sustainable agriculture, it also guides future research on soil health, environmental protection, social acceptance, terrain-specific management, and integrated sustainability. Addressing these areas can enhance agricultural productivity, environmental conservation, economic viability, and societal acceptance.

5. Conclusion and Future Prospective

In this research, the soil data yielded significant insights into soil properties across diverse profiles within the study area, uncovering notable depth and varied textures that impact nutrient retention and fertility potential. Fluctuations in salinity levels, gypsum content, and organic matter also played a role in influencing soil productivity.

The study was centered on assessing sustainable agriculture in Qena Governorate, dividing the region into Class 3, representing areas with relatively enhanced social and economic services, alongside accessible land and water resources, and Class 4, highlighting deficiencies in land management practices. To achieve sustainable agriculture in the area, collaborative efforts from both governmental entities and the public are essential, entailing improvements in infrastructure, as well as enhancements in social and economic aspects to attract residents. Educating farmers about sustainable agricultural practices is also deemed pivotal for advancement. Furthermore, the study underscored a significant association between landforms and soil sustainability levels, offering valuable insights for decision-making processes and agricultural management strategies to optimize sustainability and productivity was emphasized. In conclusion, the integration of soil properties, sustainability indices, and landform characteristics emerges as crucial for advancing agricultural sustainability and productivity in Qena Governorate. The study contributes valuable insights to informed decision-making and lays groundwork for future research endeavors aimed at bolstering agricultural sustainability in analogous geographical contexts.

Authors' contributions: The authors participated in approximately equal proportions in the various stages of the research, including the research idea and protocol, conducting, and implementing the research, analyzing and discussing the results, and writing the research and preparing it for publication and there is no disagreement or conflict between the authors.

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