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Mapping Soil Types in the North El Bahrya Oases, Egypt, using Remote Sensing and GIS for Agricultural Planning

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ONE OF EGYPT'S top targets for future agricultural development is the Northern El Bahrya Oases region. The current study aims at digitally mapping the soils of the area under consideration and producing land capability and suitability digital maps. The considered region lies between longitudes 29° 9' 28.433", 29° 22' 32.785" East and latitudes 28° 57' 38.309", 28° 58' 41.324" N. The region is covering roughly 46228 Fed. The Digital Elevation Model (DEM) is utilized along with the thematic maps of soil properties to produce digital land capability and suitability maps. The spatial analysis tool in the Arc-GIS 10.8 software generated thematic layers. Physiographic mapping units were created and showed that the studied area has one landform which is plateau. The land capability was evaluated by the method of Storie index where the studied area was classified into three capability grades, namely; grade 2, 3 and 4. The soils of grade 2 (66.41 % of the whole region) have moderate limitations for agricultural crops and texture is the main limiting factor. The area of grade 3 (25.59%), has soils with texture and salinity limiting factors, while the soils of grade 4 (7.99%), have texture, depth and salinity main limiting factors. Land suitability was done according to Sys and others for some crops and transferred to GIS to produce digital maps. The fertility maps of soil nutrients for N, P, K, Fe, Mn, Zn, and Cu are included. The study established a detailed database to serve decision-makers and help in sustainable development.

Keywords: Soil properties, nutrient status, land evaluation, RS, and GIS technical.

1. Introduction

Egypt's agricultural policies are currently focusing on expanding the arable land in order to secure the increasingly demand for food and clothing. The main goal is to add one and half million feddan of arable land by reclaiming desert and desert fringes land (MCIT, 2020). Moreover, these policies aim to lessen the pressure on food imports and boost agricultural product exports in order to increase the national revenue, according to the strategy of sustainable development.

Among those areas, the Western Desert are the most interesting region to achieve its goal. However, due to desert diverse characteristics of land and water resources, North El Bahrya Oases is one of the most promising areas of the Egypt's Western Desert. Its soil and groundwater have some prospective potentialities for agriculture. Nevertheless, Elnaggar (2014) using the Mediterranean Desertification and Land Use (MEDALUS) model, assessed the environmental sensitivity to desertification in Bahariya Oasis. He found that the soils are susceptible to desertification due to low precipitation, low vegetation cover, poor soil properties and high soil erosion. Therefore, he recommended to take certain measures to protect and sustain land resources against desertification. These measures include enhancement of soil and vegetation as well as applying adequate farming practices. Land evaluation systems are generally interpretative classification relevant to agricultural management and planning, based on the effects of combinations in use, productive capacity and soil management requirements.

Land suitability classification is an approach in land evaluation that concerns the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). These methods

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established several ways to estimate the potential crop production from either land characteristics or qualities. Such approaches are the Storie Index method (Storie, 1978) and the Sys' Parametric method (Sys et al, 1993).

Dealing with massive detailed soil data requires simulation models and specific methodologies to evaluate their properties. Remote sensing offers a magnitude number of information that of great help in interpreting land resources. GIS has the capacity to integrate numerous amounts of information, including satellite imagery and traditional maps (Ossai and Oliha, 2024). In addition, it produces the spatial distribution maps of both thematic maps of soil properties and integrated maps of land evaluation status as well as digitally manages georeferenced data.

The integration of remote sensing and GIS are defined as efficient and dynamic techniques for analyzing and monitoring soil characteristics as well as evaluating land (Ismail et al., 2019; Ganzour et al., 2020; Abou Kota et al., 2021; Yousif, 2023; Abd El-Aziz et al., 2024; Abd El-Kawy et al., 2024; Abou-Kota et al., 2024; and Yousif and Ahmed, 2024). Abdel-Hamid et al. (2022) employed remote sensing and GIS to identify the potential of some soils in North East El Bahrya Oases.

The current study aims at digitally mapping the soil types of North El Bahrya Oases and evaluate their capability for agricultural use and suitability for some selected crops. The development strategy will be established for each soil unit by the aid of the spatial distribution maps.

2. Material and Methods

2.1. Location

The studied area is virgin, situated in the Giza Governorate's North El Bahrya Oases. The site is approximately 46228 Fed., and is represented by Figure 1. About 235 km separate it from Cairo.

2.2. Satellite data

Data from Sentinel 2 (T35RQN) acquired on 17 March 2023 with a spatial resolution of 10 m and spectral bands; 8, 4, and 3 (Figure 2) was used for field investigation.

2.3. Digital Elevation Model (DEM)

The contour lines map and spot heights from the semi-variogram (Stein, 1998) were employed to build the DEM using geostatistical analysis techniques. Converting contour lines into point's shipfile and by combining it with spot heights shipfile, an increase of accuracy was done leading to interpolation.

2.4. Physiographic map

The physiographic map was created by overlaying the Sentinel 2 image with DEM (Zinck, 1988). The mapping unit boundaries were checked, corrected, and modified using the minipits from the fieldwork. Using the physiographic map and all of the soil properties, a physiographic soil map was created in GIS (Stein, 1998).

2.5. Field work

Thirty-four monitoring sites were selected and soil profiles were digged to collect soil samples representing the studied region.

2.6. Laboratory analyses

The soil samples were analyzed according to the USDA (2004) methodology where, they were air-dried, crushed and processed for laboratory analyses which include particle size distribution (by pipette method), pH, ECe, CEC, ESP, calcium carbonate and gypsum contents. The available and total N were determined by microkjeldahel method (Jackson, 1973), available P, K, Zn, Mn, Fe, and Cu were extracted by Diethylene Triamine Penta Acetic (DTPA) following Soltanpour (1985) and measured using Inductively Coupled Plasma (ICP) Plasma 400. Total P and K were extracted by digestion in an HF-$HClO_4$ acid mixture (Jackson, 1976) and measured by ICP.

2.7. Water sample analyses

From the distributed wells in the research region, five water samples were taken, and each sample was examined to determine its chemical characteristics according to USAD methodology (USDA, 2004), such as pH, TDS, cations, anions, EC and SAR.

2.8. Production of soil thematic maps

Thematic maps of the soil depth, texture, salinity, sodicity, lime, gypsum, and CEC were produced using Arc GIS 10.8. To map the parameters of the geostatistical technique of the soil surface layer by Kriging interpolation of the thematic soil properties using the components of a semi-variogram to create a more suitable model (Stein, 1998).

2.9. Production of fertility maps

Applying the geostatistical analyses (Stein, 1998), the digital maps for several nutrients were created using the classes in Table 1. The levels of macronutrients summarized by Page et al. (1982) and improved to suit the prevalent conditions in Egyptian soils as revealed by Baker et al. (1999) range of micronutrients Lindsay and Norvell (1978) and Baker et al. (1999).

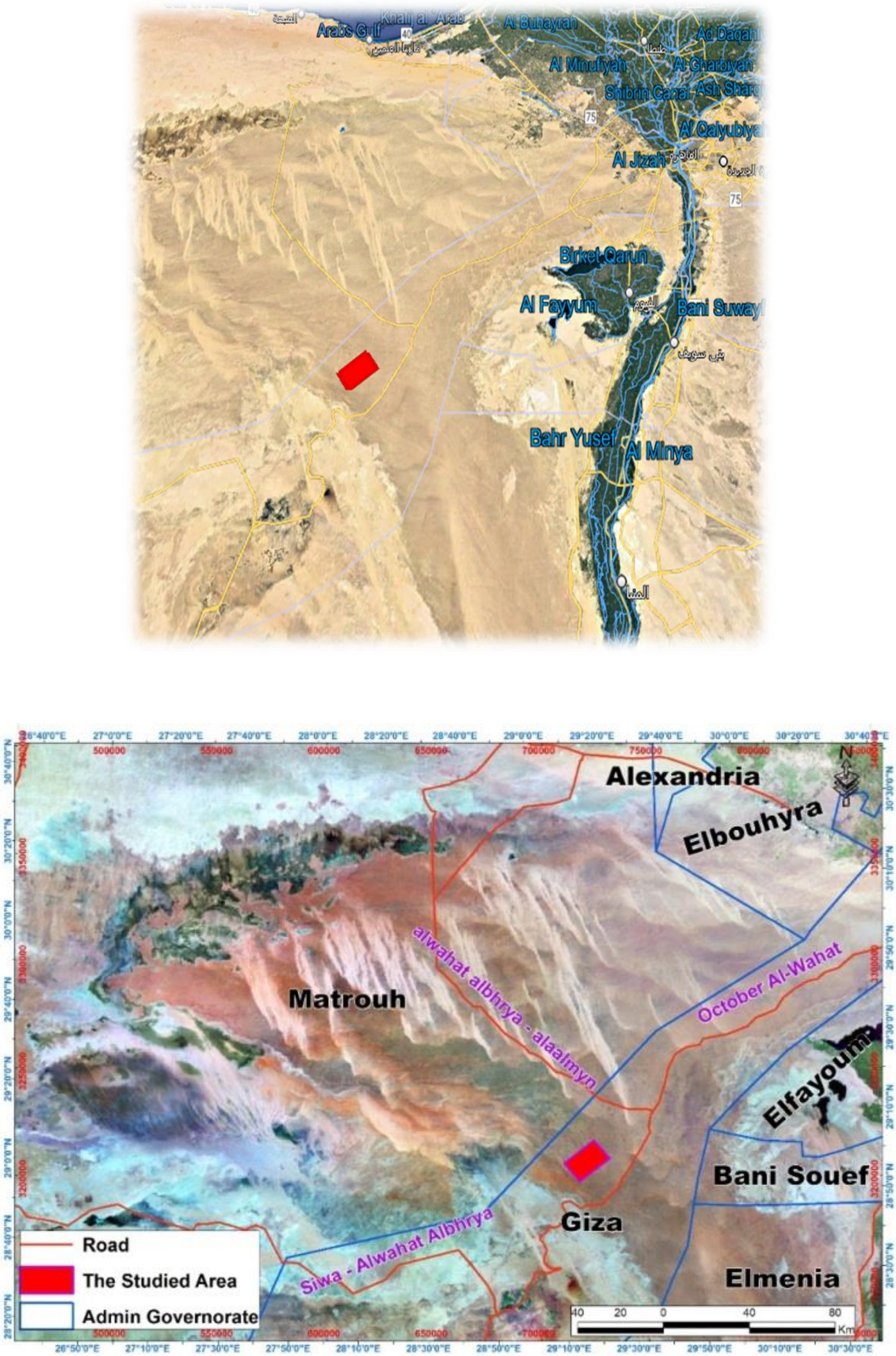

Fig. 1. General location of the studied area.

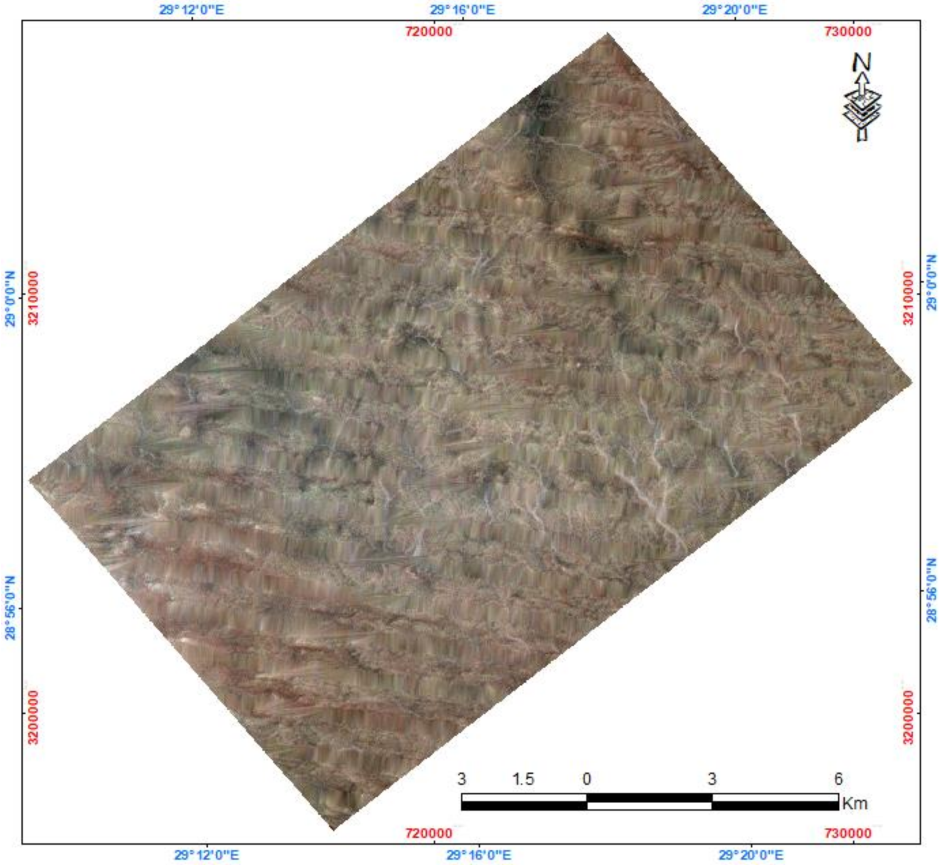

Fig. 2. Sentinel-2 color composite image (bands 8, 4, and 3) of the studied area.

Table 1. The classes of macro and micronutrients availability status.

Available nutrients (mg kg $^{-1}$)	Low	Medium	High
N	< 40	40-80	>80
P	< 5.0	5.0-10	>10
K	< 200	200-400	>400
Fe	< 4.5	4.5 – 9.0	> 9.0
Mn	< 2.0	2.0-5.0	>5.0
Zn	< 1.0	1.0-2.0	>2.0
Cu	< 0.5	0.5-1.0	>1.0

2.10. Land capability

The Storie Index, a technique for analyzing land supplied in the equation, was used to evaluate land capabilities (O'Geen and Southard, 2005). The Storie index is:

SI= A x B/100 x C/100 x D/100 x X/100 x 100, where, soil depth (A), surface soil texture (B), slope (C), and other restricting elements (X) (salts and drainage) are some examples of these. We rate each of these four general factors from "100 percent". Table 2 shows that a condition with a value at "100 percent." is the most ideal, or perfect, condition, while conditions with a lower percentage rating are less beneficial for crop growth.

2.11. Land suitability for crops

Following the FAO Framework for Land Evaluation (FAO, 1976), soil units have had their appropriateness for four different land use types assessed (Sys et al., 1993). The needs of every crop were matched with the soil properties of the various mapping units.

Table 2. Capability grades are classified according to the value of the Storie Index (O'Geen and Southard, 2005).

Grade	description	Index Rating	Definition
1	Excellent	80 - 100	Soils are completely suitable for extensive crop cultivation under irrigation.
2	Good	60 - 79	Soils are good for farming.
3	Fair	40 - 59	The overall agricultural usage of soils is limited, and their suitability is only somewhat.
4	Poor	20 - 39	The soils are not suitable. Their potential for agriculture is very limited.
5	Very Poor	10 - 19	Soils are rarely cultivated because they are particularly poorly suited for agriculture.
6	Non-agricultural	< 10	Soils have significant to extreme physical constraints that make them completely unsuitable for agriculture.

3. Results

3.1. DEM

Figure 3 shows the elevation classes of the studied area as DEM, which is ranging from 145 to 232 m. In the north-western side, the elevation ranged from 209 to 232 meters above sea level which represents 87% of the total area. The low areas are located in the south side, where the elevation ranged between 145 and 201 meters above sea level and represented an area of 13% of the total area. Moreover, there are some scattered high-elevated areas in the low areas in the middle parts.

3.2. Physiographic map

Utilizing the sentinel-2 image (T35RQN) acquired on 17 March 2023, the DEM, the topography, and the field check, the physiography of the studied area has been produced (Figure 4). One landscape unit was defined as plateau (PU) which was classified because of relief into two classes namely; Undulating (PU1) with lithology of Moghra Formation which covers 69.61% of the total area, and Gently Undulating (PU2) with lithology of Gable Qatrani formation which covers 30.39% .

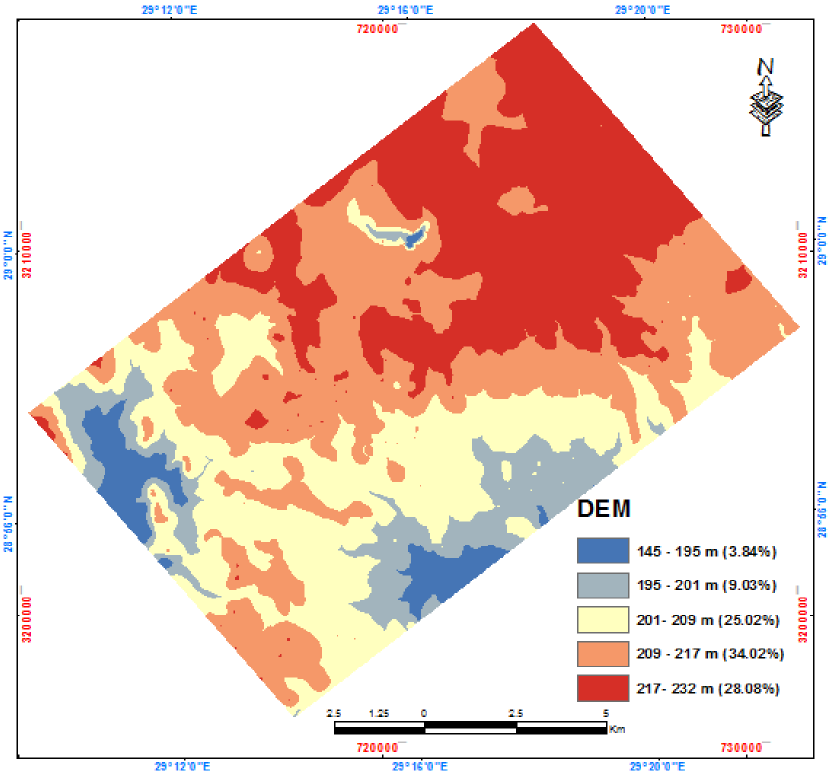

Fig. 3. The DEM of the studied area.

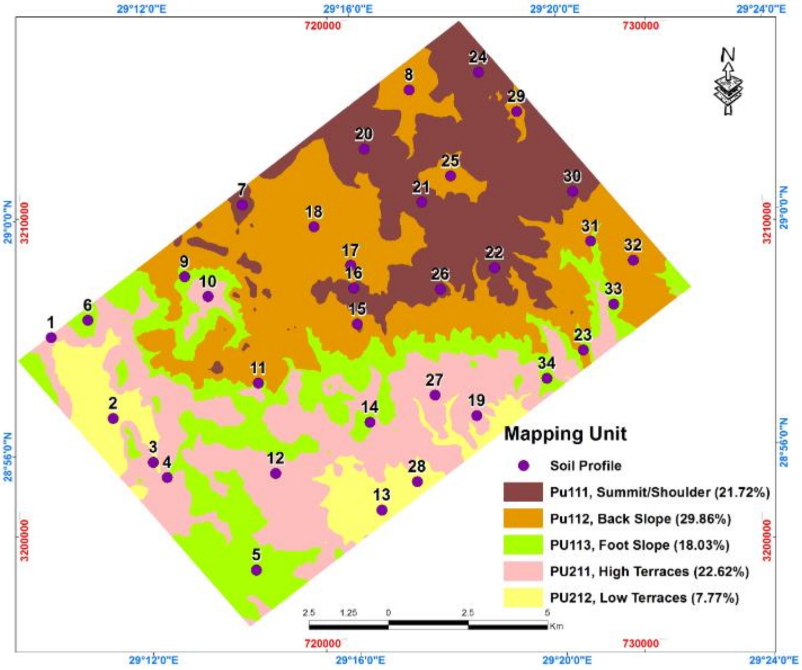

Fig. 4. Physiographic map of the studied area.

3.3. Soil Properties

The recorded data in Table 3 and are shown in Figures 5-11 reveal that the surface layers of thirty-four soil profiles had characteristics to be discussed in the following points.

3.3.1. Soil depth

The depth of the soil profiles was ranging between 60 and 150 cm. Figure 5 shows that the very deep soils cover approximately 38427 Fed. (83.13%) of the total studied area, while the deep soils represent almost 4105 Fed. (8.88%), with depths varied from 100 to 120 cm. The moderately deep soils account for nearly about 3695 Fed. (7.99%), with depths were between 60 and 100 cm.

3.3.2. Soil texture

As shown in Figure 6 and Table 3 the soil texture of the surface layer was loamy sand in an area of about 16102 Fed. (34.83% of the total area). However, the sandy loam soils covered about 23872 Fed. (51.64%) while, the sand texture soils accounted for nearly 6254 Fed. (13.53%).

3.3.3. Soil salinity

The geostatistical method (Kriging interpolation) was utilized for the top layer 34 soil samples. The ECe value was ranging from 1.59 to 46.60 dS m^{-1}. Figure 7 showed that the soils which were slightly saline covered about 6.87% of the total studied area. The soils that were moderately saline covered a region of roughly almost 28.02% of the whole studied area. Whereas, the highly saline soils occupied an area of roughly about 38.29%. The very highly saline soils (16-32 dS m^{-1}) and extremely saline soils (>32 dS m^{-1}) were found in an area of about 18.19% and 9.13% of the total area, respectively.

3.3.4. Soil sodicity

The distribution pattern for surface layers of ESP ranged between 3.22 and 16.86. Figure 8 show that the non-sodic soils (ESP < 15) cover about 94.36% of the total studied area. But the soils of sodic-affected soils (ESP > 15) cover approximately 5.64% of the total investigated area.

3.3.5. Soil lime content

The surface layers contained $CaCO_3$ content varied from 4.62 to 19.45%. According to the classification of the USDA (2004), Figure 9 cleared that the soils of moderately calcareous which had $CaCO_3$ ranged from 2 to 10% were covering about 48.71% of the total studied area (22516 Fed.). The strongly calcareous having $CaCO_3$ between 10 and 25 occupied 51.29% of the total studied area (23711 Fed.).

3.3.6. Soil gypsum content

Soil gypsum contents in the studied area are presented in Table 3 and Figure 10. Gypsum content ranged between 0.06 and 10.76% for surface layers within a mean of 2.57%, and the standard deviation is 2.83%. Accordingly, the area could be classified into 2 classes; slightly gypsiric with <5%, occupying almost 38915 Fed. (84.18 % of the total studied area) and moderately gypsiric 5–15%, covering about 7312 Fed. (15.82%).

3.3.7. Soil CEC

The CEC of soils in the studied area were listed in Table 3 and seen in Figure 11. The CEC ranged between 3.50 and 24.80 meq 100g^{-1}. About 45322 Fed. (98.04% of the total examined area), were classified as low class <20%, while the remaining 905 Fed. (1.96% of the total studied area), were of moderate class 20–40%.

Table 3. Some physiochemical properties of the surface layers of the studied area.

No	Depth (cm)	Texture classes	pH (1:2.5)	EC (dS m^{-1})	CaCO$_3$ (%)	Gypsum (%)	Na Exch.	CEC (meq 100g^{-1})	ESP
1	150	LS	7.70	9.70	5.90	3.90	0.40	5.50	7.27
2	60	SL	8.76	9.17	10.20	0.52	2.80	16.60	16.87
3	150	S	7.30	6.00	5.80	0.10	0.10	4.10	3.23
4	150	LS	8.20	8.84	9.35	0.92	1.38	9.10	15.16
5	150	LS	7.99	46.60	10.20	10.00	0.90	6.20	14.52
6	150	SL	8.16	38.59	11.26	6.08	1.26	11.20	11.21
7	110	SL	8.35	7.09	19.45	10.76	2.72	21.55	12.62
8	150	SL	8.32	4.65	9.44	0.14	2.04	14.35	14.22
9	150	S	7.90	5.54	7.30	0.50	0.30	3.50	8.57
10	150	SL	8.28	15.79	13.08	1.40	1.35	13.30	10.11
11	140	S	7.10	31.10	11.30	1.60	0.42	3.70	11.35
12	150	LS	7.80	5.90	9.60	0.20	0.40	5.40	7.41
13	150	LS	8.23	1.59	9.18	0.06	1.98	7.20	13.03
14	80	SL	8.39	18.03	13.94	0.25	1.68	17.60	9.55
15	150	LS	7.95	13.56	7.99	5.40	0.75	8.30	9.04
16	90	SL	8.38	6.68	9.52	1.75	3.26	23.95	13.15
17	150	SL	8.33	6.31	10.54	0.12	1.96	12.50	15.68
18	150	SL	8.30	2.99	8.33	0.15	2.12	16.20	13.09
19	150	SL	8.62	14.27	10.20	0.11	1.74	19.60	8.88
20	110	SL	8.31	7.50	15.47	3.60	2.18	18.30	11.91
21	100	LS	8.30	5.95	6.80	4.38	0.85	9.10	9.34
22	150	LS	8.22	13.32	7.65	6.50	0.86	10.12	7.64
23	150	SL	8.77	6.24	7.48	6.91	1.85	24.80	7.46
24	110	SL	8.31	6.72	11.14	3.99	1.52	13.70	11.06
25	150	SL	8.14	9.94	9.27	2.76	1.36	11.40	13.03
26	150	LS	7.70	9.22	6.40	0.10	0.80	6.50	12.31
27	150	LS	7.79	9.29	15.40	4.40	1.00	7.50	13.33
28	125	S	8.80	7.90	6.30	1.50	0.20	4.20	4.76
29	150	SL	8.13	8.27	8.16	2.78	1.44	12.25	11.71
30	150	SL	8.12	26.11	8.67	2.03	1.47	16.30	9.02
31	150	SL	8.60	3.32	4.62	0.12	1.54	16.30	9.45
32	150	SL	8.69	4.78	5.95	3.52	1.70	20.55	8.25
33	150	SL	8.71	21.48	12.58	0.43	1.91	16.80	11.31
34	150	SL	8.76	15.76	10.12	0.70	1.90	17.05	11.81

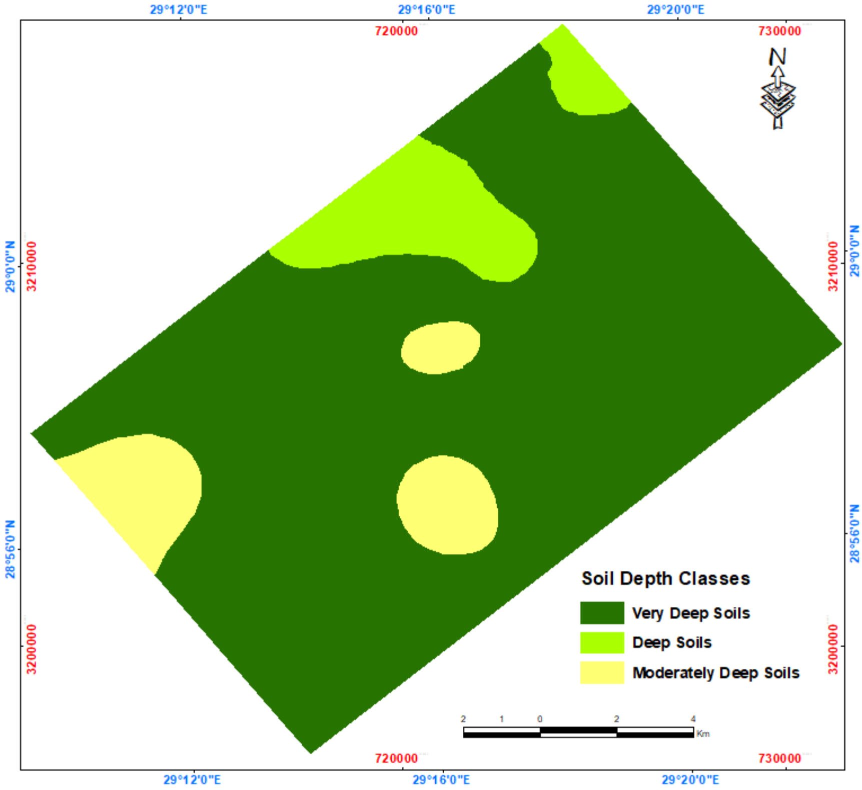

Fig. 5. Spatial distribution of soil depth of the studied area.

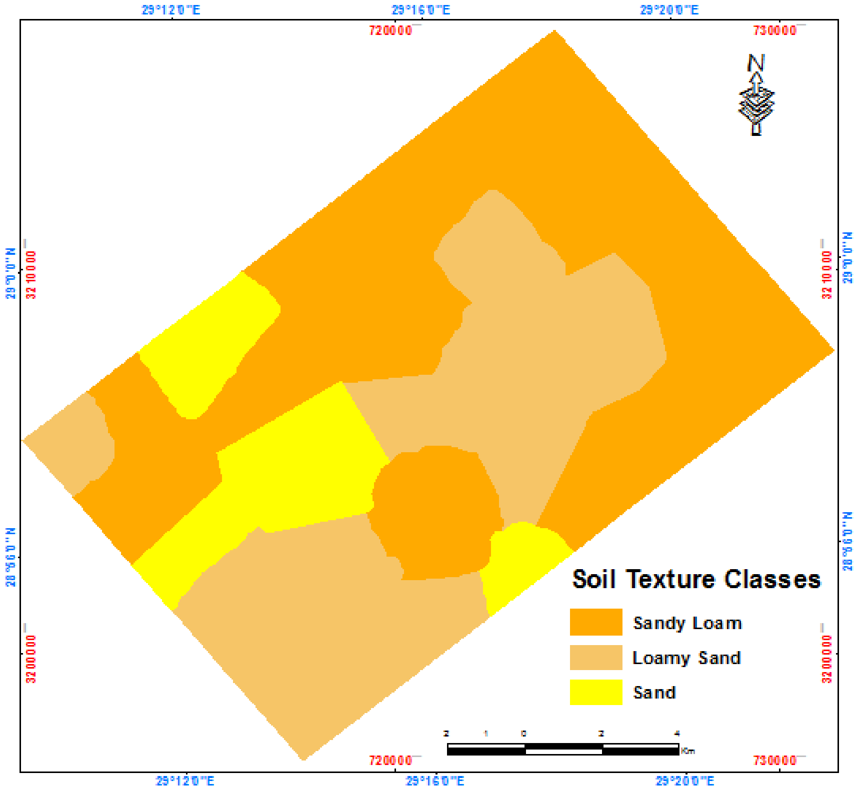

Fig. 6. Spatial distribution of soil texture of the studied area.

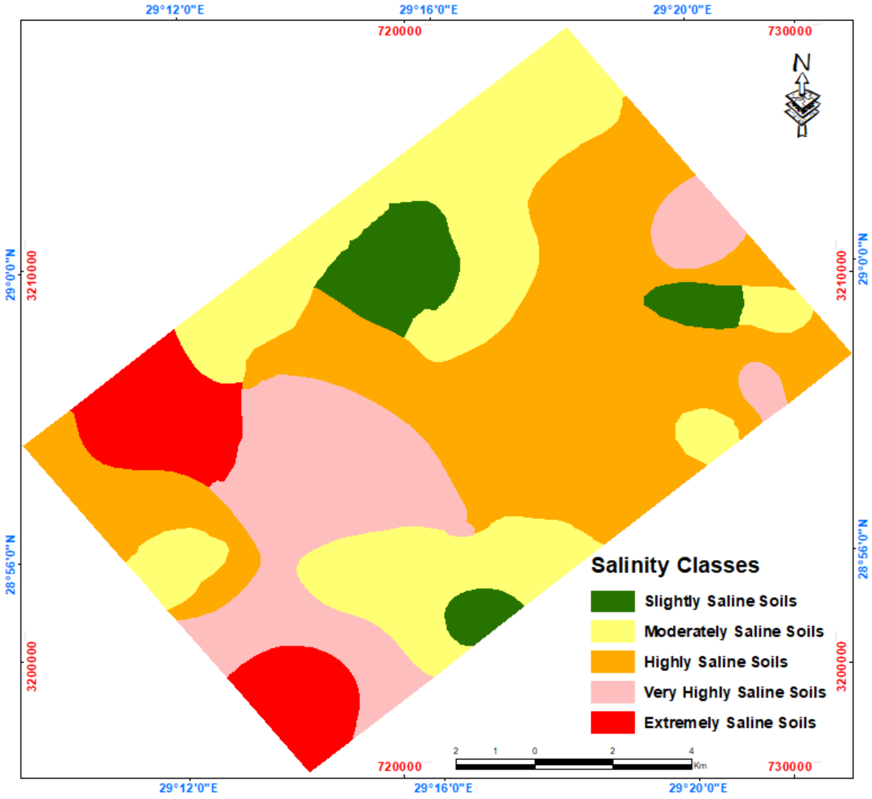

Fig. 7. Spatial distribution of soil salinity of the studied area.

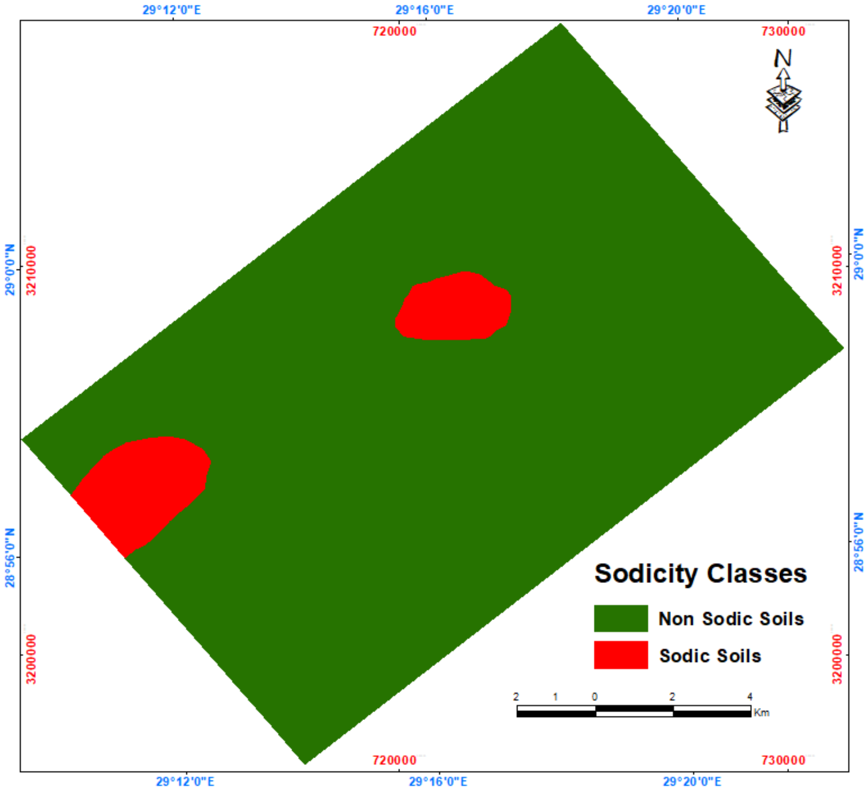

Fig. 8. Spatial distribution of soil sodicity of the studied area.

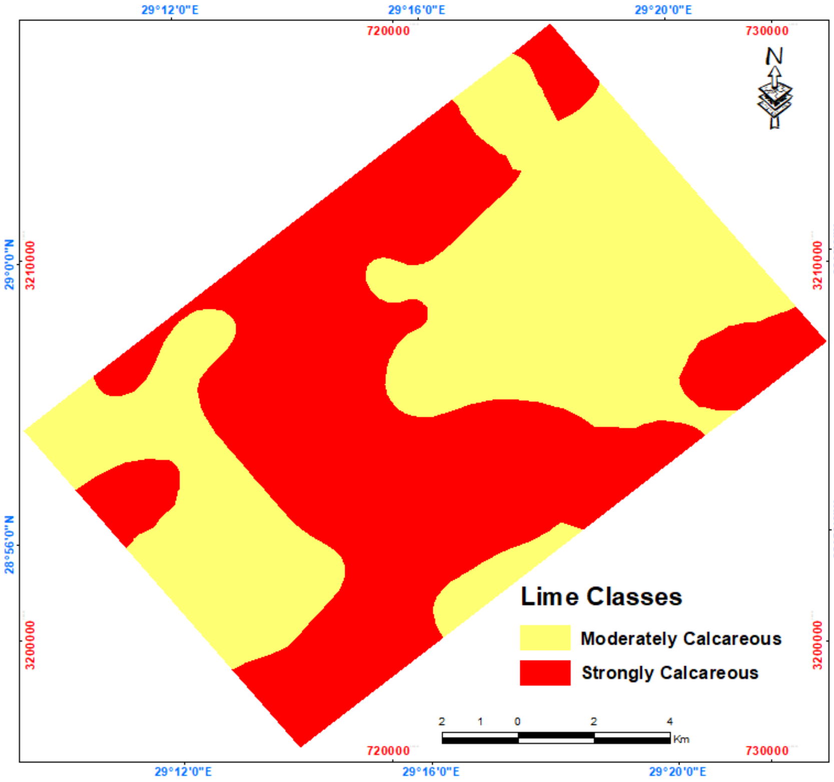

Fig. 9. Spatial distribution of soil lime content of the studied area.

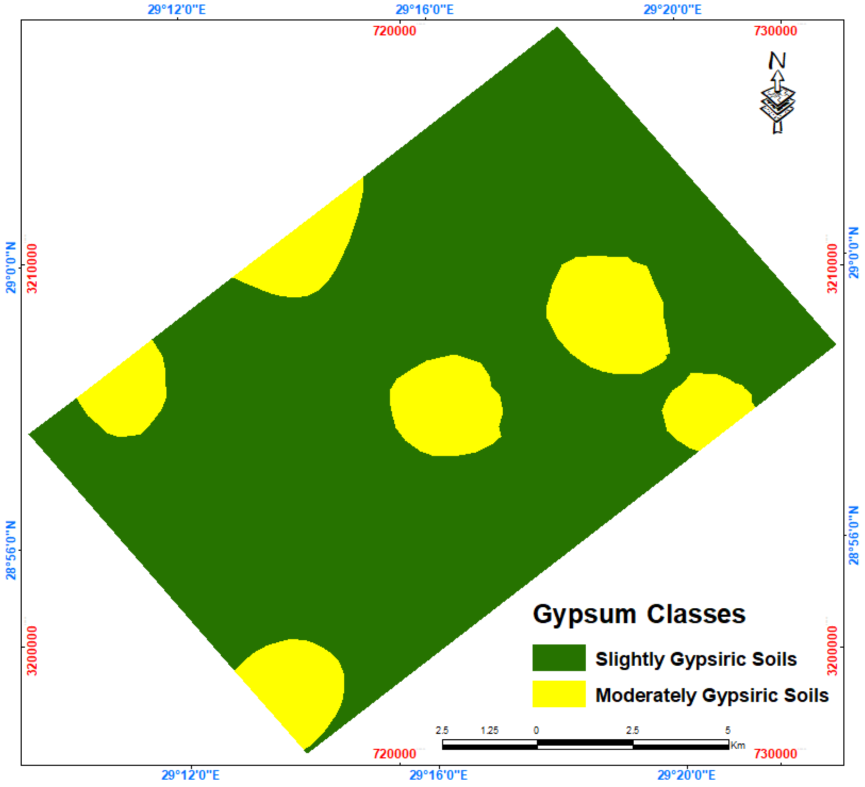

Fig. 10. Spatial distribution of soil gypsum content of the studied area.

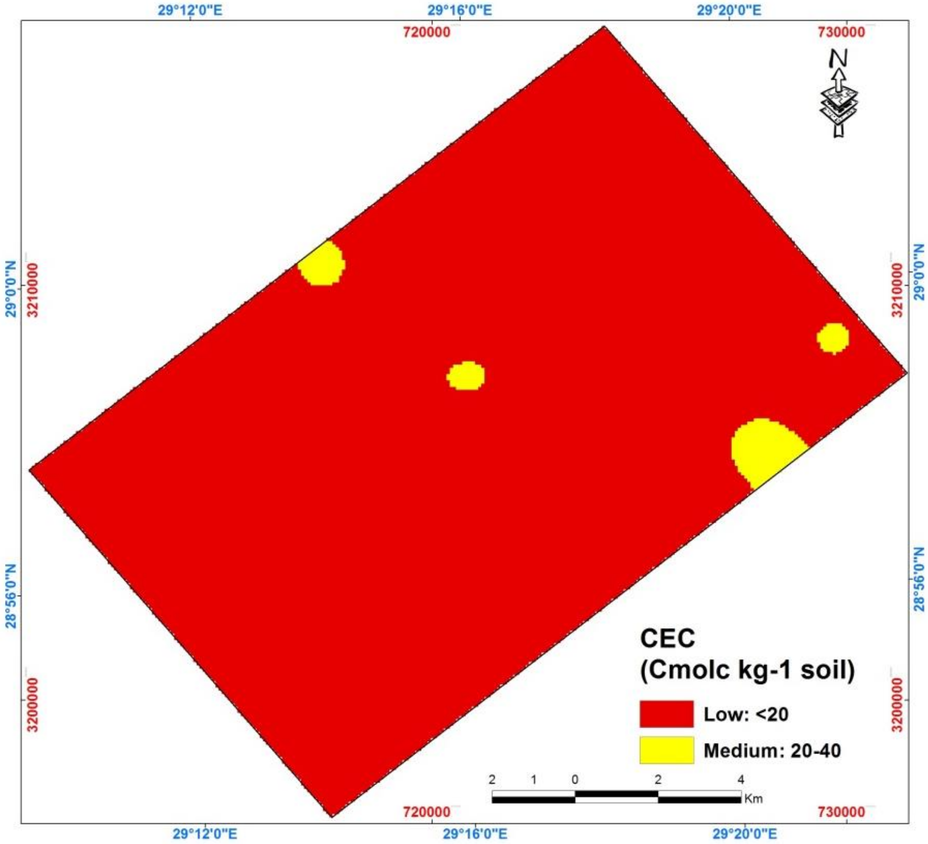

Fig. 11. Spatial distribution of soil CEC of the studied area.

3.4. Production of fertility maps

3.4.1. Available nitrogen

The available nitrogen content was found to be between 7.13 and 84.56 mg kg^{-1}, (Table 4 and Figure 12). The biggest area of 35055.5 Fed. (75.83% of the total examined area) was characterized by low nitrogen content. On the other hand, the smallest areas were the medium and high classes covering 23.92% and 0.25, respectively of the entire examined area.

3.4.2. Available phosphorous

Table 4 illustrates that all soils fall into the same class (poor) as values of available phosphorus were fewer than 5 mg kg^{-1}. The range of available phosphorus was between 0.40 and 3.90 mg kg^{-1}.

3.4.3. Available potassium

Data in Table 4 show that the available potassium content ranged from 43.40 to 402.50 mg kg^{-1} and Figure 13 displays the available potassium contents of surface layer spatially distributed. The majority of the studied region had low and medium available K values of 35.57 and 64.39%, respectively of total area. However, there was a small portion of land in the region having high available K values of more than 400 mg kg^{-1} (0.04%).

3.4.4. Available iron

The solubility of iron is significantly influenced by the redox potential and is primarily found in soils as insoluble Fe (III) oxides. Table 5 exhibits the available Fe data, which ranged from 1.05 to 2.91 mg kg^{-1}. Since all values were fewer than 4.5 mg kg^{-1}, the soil studied was classified as low available Fe-class.

3.4.5. Available manganese

The available Mn values in the study soils are displayed in Table 4, which shows that they did not surpass 1.36 mg kg^{-1}. As a result, the research region is categorized as having low manganese content.

3.4.6. Available zinc

The maximum amount of available zinc was of almost 1.12 mg kg^{-1} for the whole area. Table 4 and Figure 14 indicated that the majority of soils were of low zinc content class, where 46226 Fed., or 99.01% of the overall investigated area was predominately of the low zinc content class. However, the smallest area covered about 0.99% of the entire investigated area) belonged to the medium class.

3.4.7. Available copper

Table 4 and Figure 15 presented the available Cu data. Referring to the obtained data, scarce levels of Cu ranging from 0.10 to 0.44 mg kg^{-1} were determined in 45350 Fed. (98.11% of the soils under study). Nevertheless, only 876 Fed., (1.89% of the entire investigated region) had medium and high classes of available Cu content.

Table 4. Available nutrient contents (mg kg^{-1}) for surface layers of the studied area.

No.	N	P	K	Fe	Mn	Zn	Cu
1	16.28	1.19	153.20	1.90	0.56	0.22	0.17
2	67.20	3.90	372.50	2.64	0.83	0.34	0.25
3	7.13	0.97	52.34	1.00	0.38	0.16	0.10
4	50.40	2.10	170.86	1.25	0.68	0.21	0.14
5	58.80	1.30	244.17	1.08	0.62	0.28	0.14
6	37.19	1.90	250.24	1.76	0.95	0.70	0.26
7	26.68	2.00	322.35	1.73	0.77	0.54	0.19
8	33.24	2.95	271.16	1.91	0.88	0.76	0.26
9	11.41	0.40	43.40	1.50	0.26	0.30	0.12
10	33.60	2.69	209.10	2.19	1.00	0.59	0.34
11	13.92	0.53	60.15	1.21	0.40	1.10	0.11
12	42.10	1.12	97.20	1.60	0.63	0.43	0.22
13	26.35	1.80	134.21	1.94	0.74	0.37	0.14
14	58.60	1.95	364.37	2.62	1.25	0.67	0.33
15	18.14	1.70	208.44	1.31	0.59	0.36	0.17
16	15.65	2.40	302.45	1.44	0.70	0.46	0.30
17	38.42	3.00	252.62	1.63	0.83	0.45	0.22
18	26.10	2.92	340.10	1.80	0.92	0.54	0.31
19	67.20	2.41	338.72	2.03	0.72	0.35	0.18
20	25.83	1.60	342.15	2.52	1.08	0.64	0.29
21	48.44	2.12	200.30	1.24	0.49	0.38	0.19
22	16.28	1.90	250.42	1.05	0.72	0.29	0.14
23	29.21	2.59	280.91	1.48	0.91	0.47	0.26
24	37.88	1.82	271.39	1.93	0.60	0.59	0.24
25	26.32	2.35	245.25	1.47	0.79	0.57	0.33
26	22.40	1.59	91.83	1.10	0.80	1.09	0.42
27	11.90	0.81	114.10	1.46	0.56	1.12	0.29
28	17.10	0.62	48.36	1.13	0.33	0.20	1.30
29	22.38	2.37	314.18	2.56	1.19	0.66	0.37
30	84.56	2.59	402.50	1.64	0.84	0.55	0.24
31	79.45	3.40	356.67	2.82	1.36	0.94	0.44
32	50.43	2.87	268.82	2.65	0.93	0.67	0.25
33	36.21	1.30	318.20	1.83	0.76	0.42	0.12
34	23.80	2.15	228.44	2.91	0.87	0.60	0.33

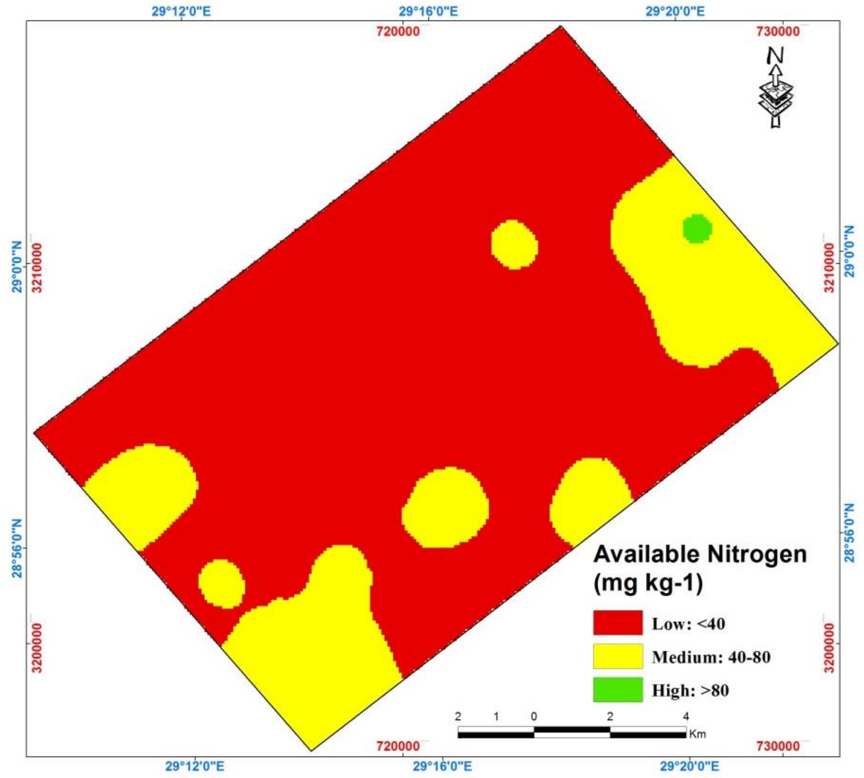

Fig. 12. Spatial distribution of available nitrogen content of the studied area.

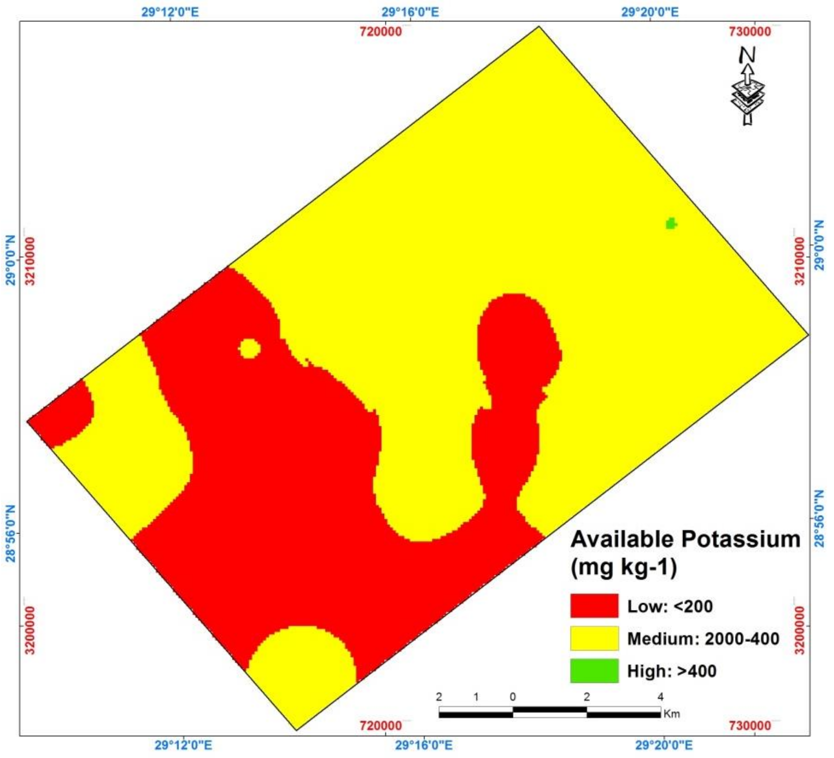

Fig. 13. Spatial distribution of available potassium content of the studied area.

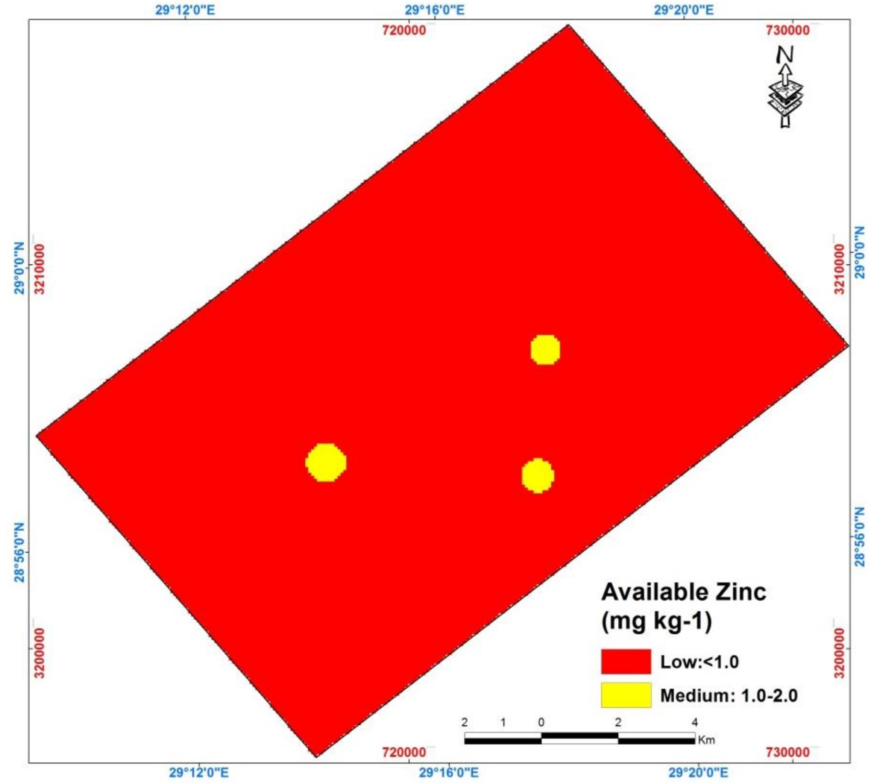

Fig. 14. Spatial distribution of available zinc content of the studied area.

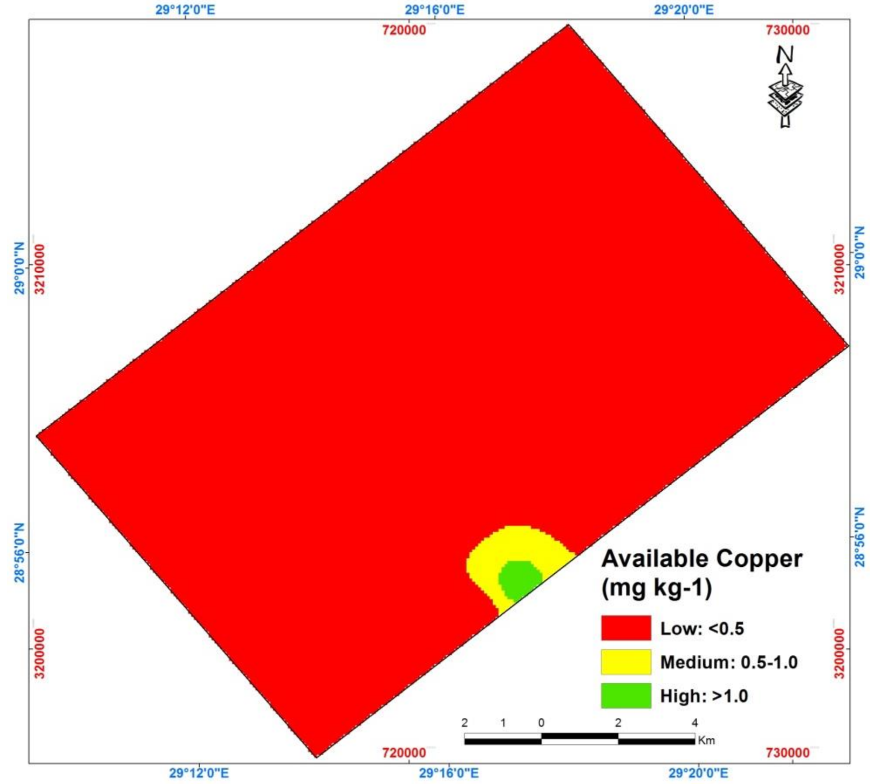

Fig. 15. Spatial distribution of available copper content of the studied area.

3.5. Production of total macronutrient maps

3.5.1. Total nitrogen

In Table 5 and Figure 16 the obtained total nitrogen were presented. The total N levels of the soils were quite low and ranging between 46.5 and 200.0 mg Kg^{-1}. In the light of the determined total N contents, the studied soils could be divided into three classes based on the occupied area. The first class included most of the study area, which amounted of 42440 Fed., (91.81% of the total examined area) had total N levels between 80 and 160 mg kg^{-1}. In contrast, the second class grouped the soils that had more than 160 mg kg^{-1} which covered about 2435 Fed. (5.27% of the entire study region). The third class was that had < 80 mg kg^{-1} in 1082 Fed. (2.92% of the entire study area).

3.5.2. Total phosphorous

In the studied soils, the total phosphorus was higher than the available one due to that most P was fixed in the soil. The total phosphorus levels range from 93.0 to 176.5 mg kg^{-1}. The total P contents ranging from 100 to 150 mg kg^{-1} were determined in 41967 Fed., (90.97% of the total examined area). The area that had >150 mg kg^{-1} total P content was estimated at 3813 Fed., (8.25% of the total area). While the area that had <100 mg kg^{-1} was only 446 Fed., (0.97% of the entire area under investigation).

3.5.3. Total potassium

Concerning the total K, it was ranging between 1014.3 and 3569.1 mg kg^{-1}, (Table 5 and Figure 18). The area with <1500 mg kg^{-1} was amounted to 6313 Fed., (33.66% of the total examined area). The area that having from 1500 to 2500 mg kg^{-1} covered 20265 Fed., (43.84%), and >2500 mg kg^{-1} was found in 19648 Fed., (42.50%). These were the three classes into which the soil under study could fall.

Table 5. Total macronutrient contents (mg kg $^{-1}$) of the surface layer of the studied area.

No.	Total N	Total P	Total K	No.	Total N	Total P	Total K
1	108.5	110.1	1128.0	18	200.4	137.9	2681.6
2	168.3	137.9	2352.0	19	168.3	128.3	3052.4
3	75.6	95.0	1119.0	20	156.5	142.4	2475.5
4	100.5	109.5	1200.0	21	94.5	109.2	1983.4
5	104.2	111.4	1376.0	22	89.2	110.2	2417.8
6	136.2	150.9	2814.0	23	104.1	147.0	2216.7
7	142.8	131.6	3416.5	24	118.2	160.8	3129.2
8	140.7	153.1	2377.0	25	150.9	131.0	2839.5
9	65.3	94.1	1202.4	26	104.3	116.8	2130.4
10	126.4	148.7	2256.8	27	101.7	105.1	2077.9
11	46.5	97.5	1097.5	28	62.5	93.0	1014.3
12	93.6	105.5	1554.5	29	110.1	157.9	3343.5
13	84.9	119.1	1352.2	30	140.7	121.3	2447.1
14	134.5	144.9	3373.0	31	100.2	139.6	3569.1
15	110.4	107.8	1706.3	32	142.4	148.1	2892.5
16	168.5	130.4	2958.9	33	184.3	167.9	3423.7
17	180.2	152.2	3373.7	34	159.6	176.5	3301.3

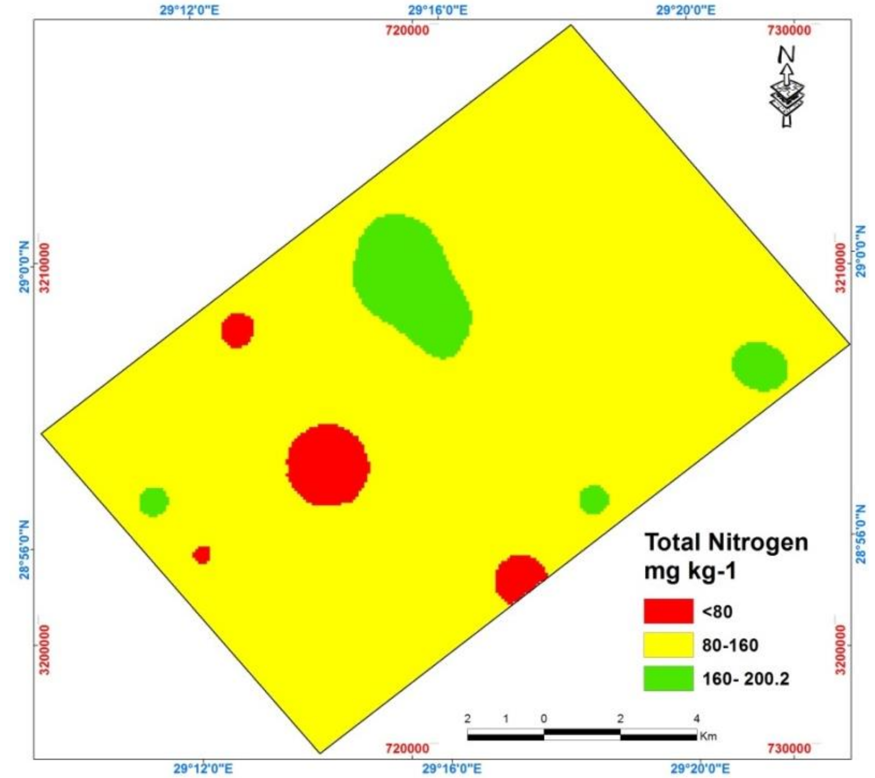

Fig. 16. Spatial distribution of total nitrogen content of the studied area.

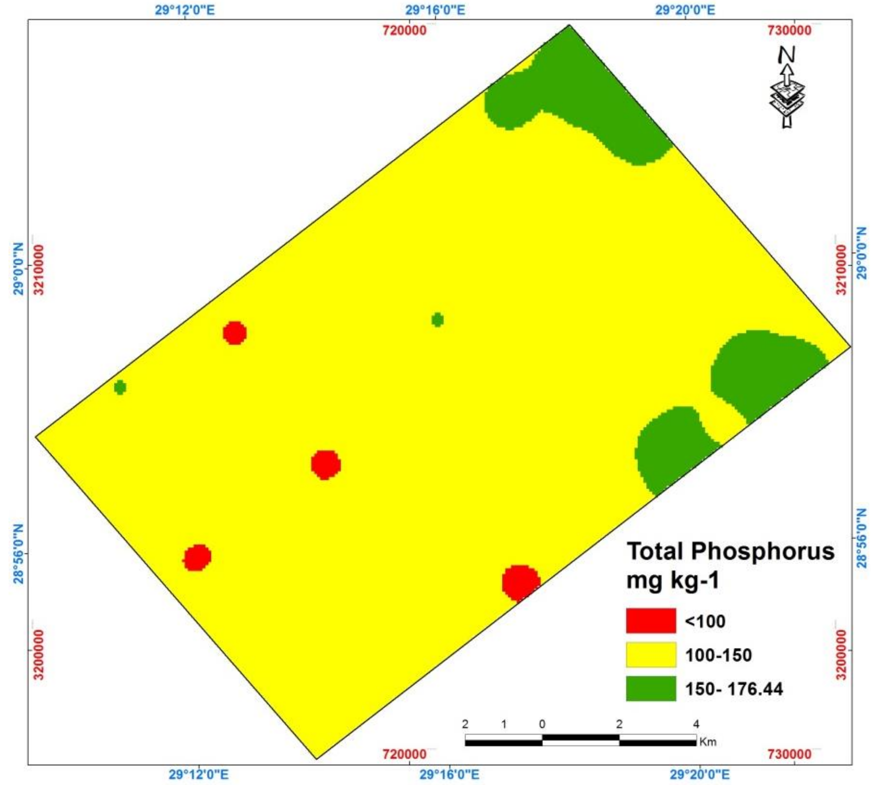

Fig. 17. Spatial distribution of total phosphorus content of the studied area.

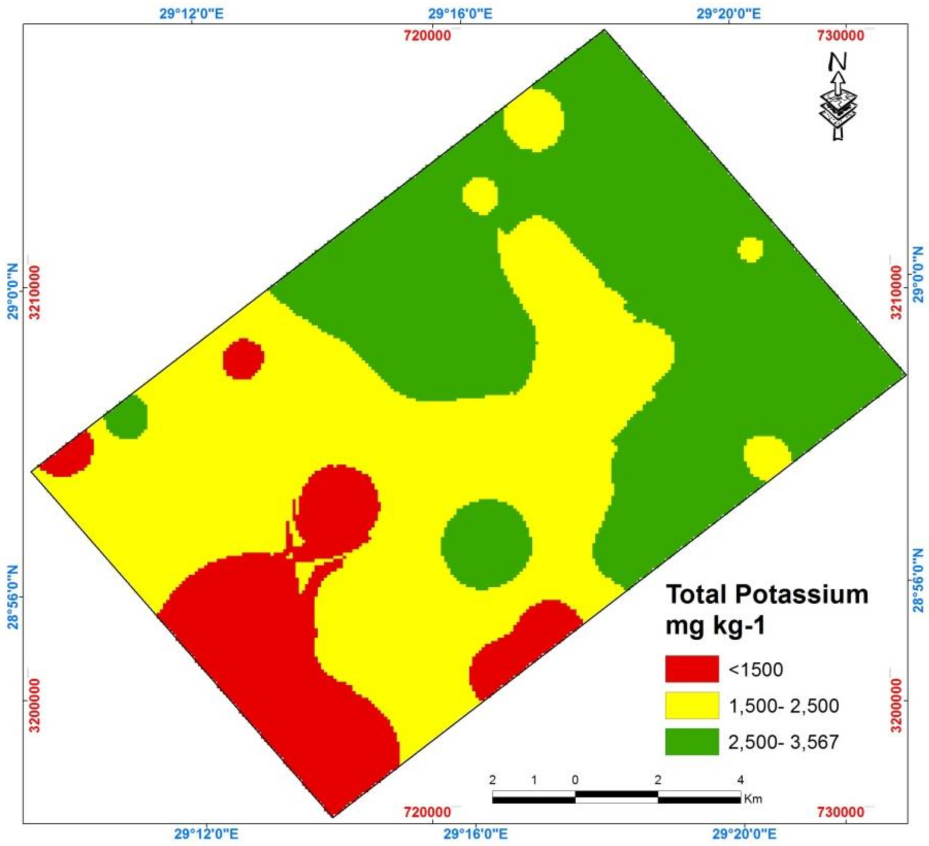

Fig. 18. Spatial distribution of total potassium content of the studied area.

3.6. Water quality for irrigation purposes

Crop production and the quality are significantly influenced by irrigation water quality. The type and quantity of dissolved salts in water determine its suitability for irrigation. Salinity (TDS) and sodium adsorption ratio (SAR) are the primary factors considered when evaluating groundwater for irrigation purposes (FAO, 1985). The obtained analytical groundwater samples data are displayed in Table 6.

Table 6. Chemical analyses of water samples from the studied area.

Sample	Cations (m mol/L)				Anions (m mol/L)				pH	TDS (ppm)	EC dSm^{-1}	SAR
No.	Na$^+$	K$^+$	Ca^{++}	Mg^{++}	Cl$^-$	HCO$_3^-$	SO$_4^=$	CO$_3^=$				
1	0.81	0.86	0.95	1.11	2.00	0.4	1.33	-	7.45	435.2	0.68	1.02
2	1.04	0.49	1.17	0.89	1.25	1.24	1.10	-	7.00	230.4	0.36	1.03
3	3.66	0.77	3.59	1.20	5.00	2.9	1.32	-	7.45	486.4	0.76	2.39
4	1.31	0.42	1.46	0.59	2.15	0.63	1.00	-	7.50	224.0	0.35	1.36
5	0.65	0.01	1.60	0.99	1.87	0.38	1.00	-	7.25	198.4	0.31	0.57

3.7. Land capability assessment

Using the Arc GIS 10.8 program (database), a land capability model was created. The capability map was then created by importing the generated tables into Arc GIS. Land capability grades varied from grade 2 to class 4 (Figure 19). The land capability grade 2 covered an area of 30701 Fed.(66.41% of the total area under study). The coarse texture of the soil is the primary limiting factor for this grade. An area of approximately 11831 Fed. (25.59% of the entire examined area), belonged to grade 3, with limitations of salinity and texture. The grade 4 soils were roughly of 3695 Fed. (7.99% of the entire region under study), with moderate to severe limiting factors of salinity and depth.

3.8. Land suitability assessment for crops

The soil properties of various mapping units were matched with the crop requirements of four distinct crops; wheat, barley, pepper, and alfalfa (FAO, 1976). Applying the parametric technique and land index as indicated by Sys et al. (1993), current and potential suitability for each crop were obtained. The digital maps were created in Arc GIS environment.

3.8.1. Current suitability

The current suitability classes for the selected crops are shown in Table 7 and Figures 20, 22, and 24. The obtained results revealed that 66.41% of the study region was marginally suitable (S3) for wheat and barley while, 92.01% was moderately suitable (S2) for alfalfa.

3.8.2. Potential suitability

By improving the soil salinity status, and applying adequate agricultural practices to overcome texture roughness, potential suitability could be achieved. Figures 21, 23, and 25 as well as Table 7 demonstrated that approximately 92.01% of the area under study belonged to highly suitable (S1) for alfalfa. However, 32.44% of the total area was moderately suitable (S2) for pepper. About 66.41% of the studied region was classified as moderately suitable (S2) for barley and wheat.

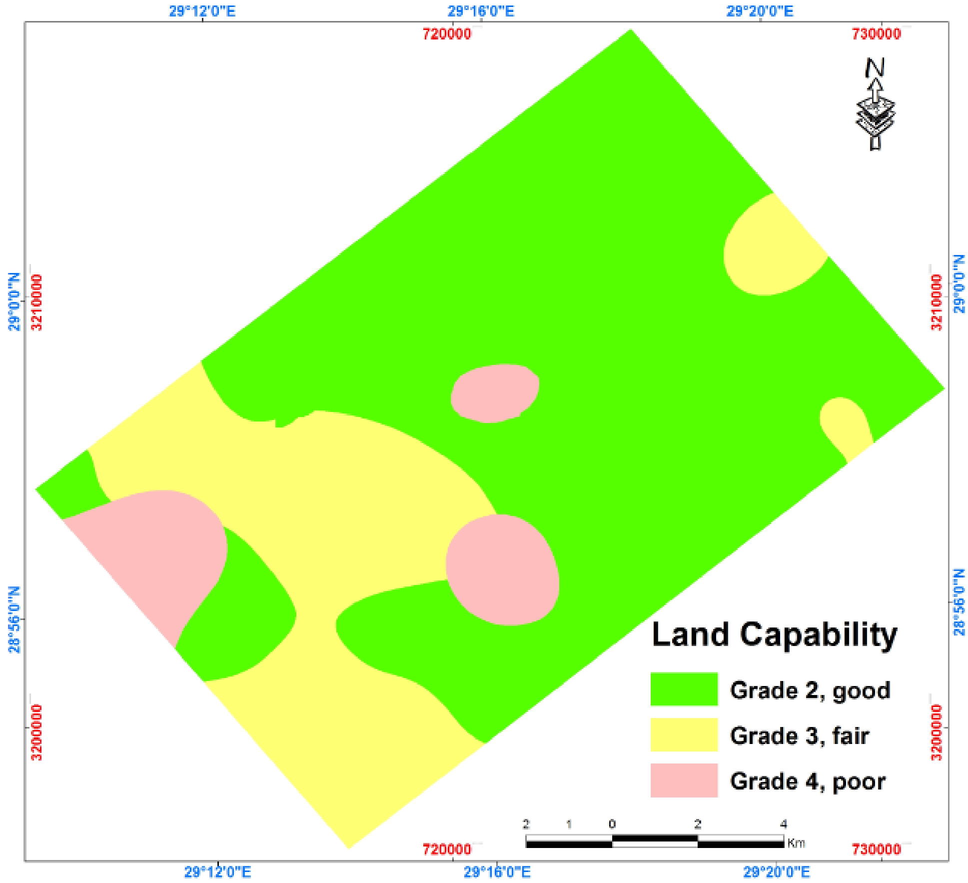

Fig. 19. Spatial distribution of land capability classes of the studied area.

Table 7. Current and potential land suitability classes for selected crops in the studied area.

Suitability Class	Wheat & Barley		Pepper		Alfalfa	
	Current	Potential	Current	Potential	Current	Potential
S1	---	---	---	---	---	92.01 %
S 2	---	66.41%	---	67.56 %	92.01 %	---
S 3	66.41 %	26.74 %	93.15 %	32.44 %	1.14 %	1.14 %
N1	33.59 %	6.85 %	6. 85 %	---	---	---
N2	---	---	---	---	6. 85 %	6.85 %
Total	100%	100%	100%	100%	100%	100%

S1= highly suitable, S2= moderately suitable, S3= marginally suitable, N1= currently not suitable and N2 = permanent not suitable.

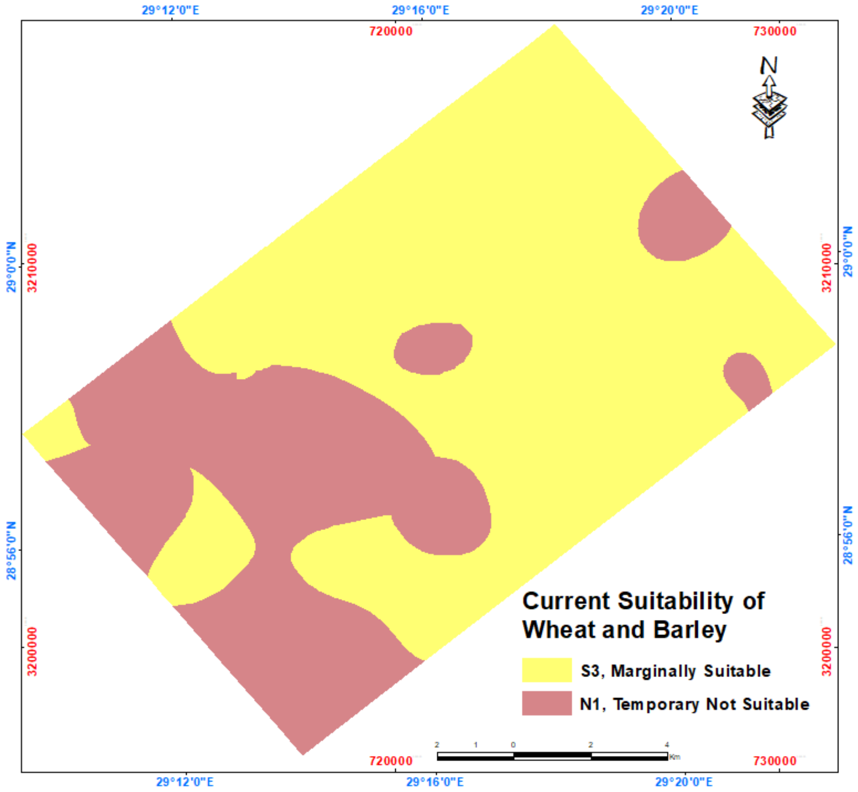

Fig. 20. Spatial distribution of current land suitability classes for Wheat and Barley.

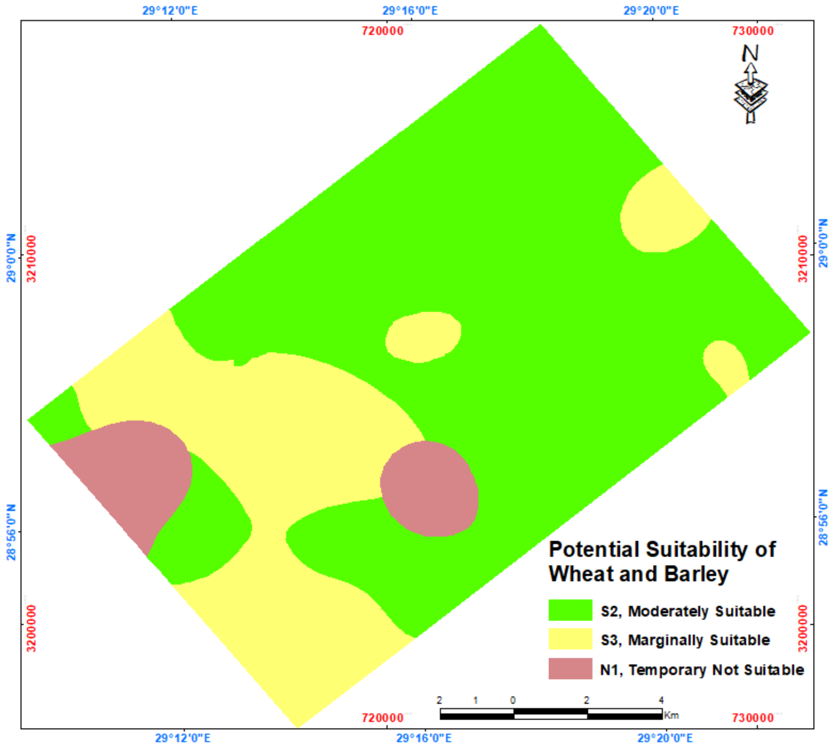

Fig. 21. Spatial distribution of potential land suitability classes for Wheat and Barley.

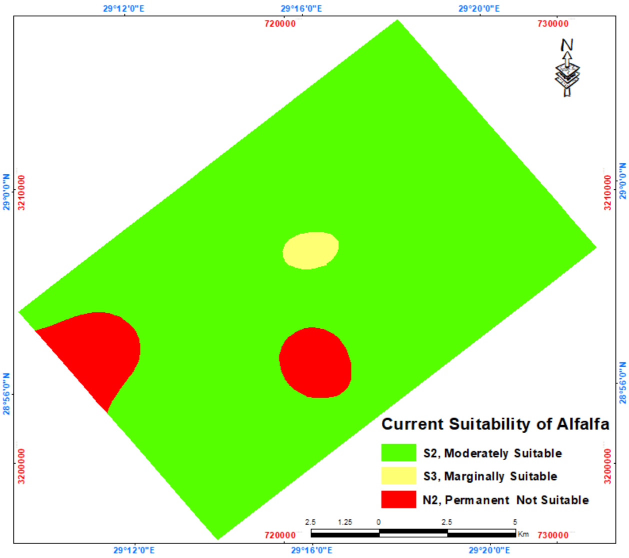

Fig. 22. Spatial distribution of current land suitability classes for Alfalfa.

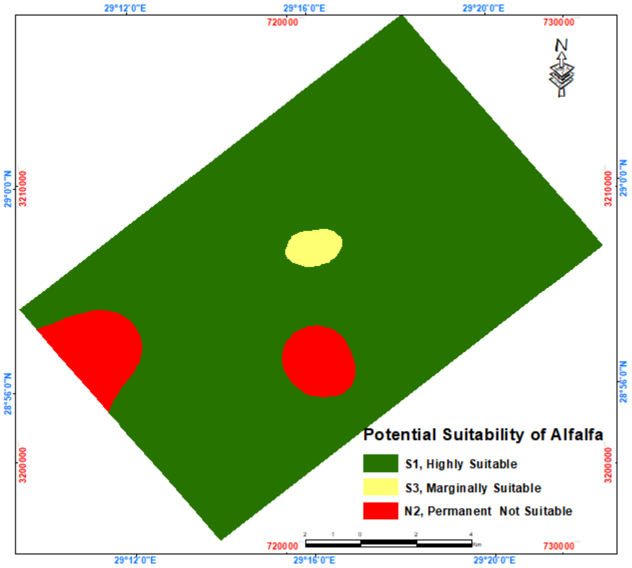

Fig. 23. Spatial distribution of potential land suitability classes for Alfalfa.

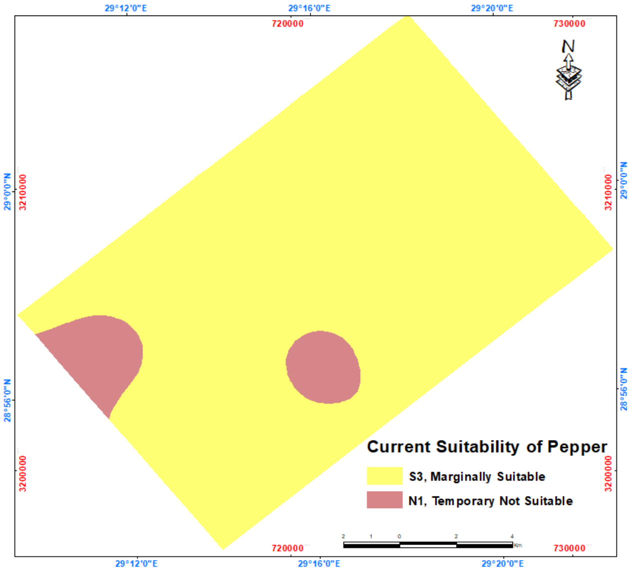

Fig. 24. Spatial distribution of current land suitability classes for Pepper.

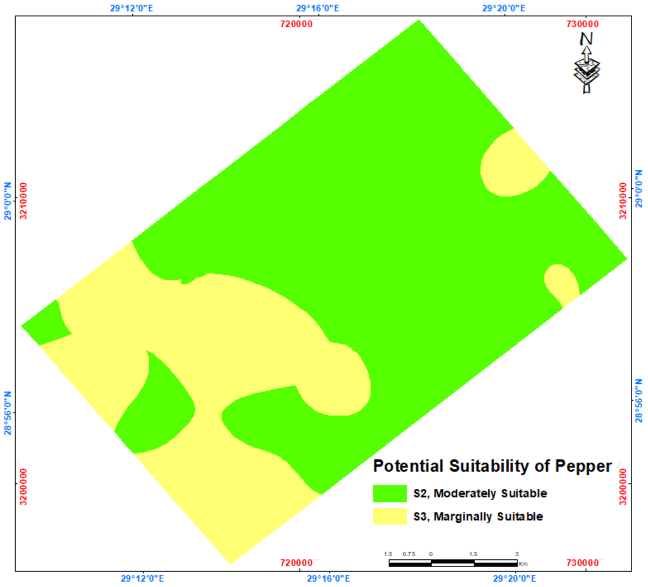

Fig. 25. Spatial distribution of potential land suitability classes for Pepper.

4. Discussion

4.1. Soil Physicochemical Properties

Figures 5–11 and Table 3 in the acquired data demonstrate that the majority of the study area, of about 92% of the area, had deep to very deep soil profiles, and the soil was coarse-textured; varied between sand and sandy loam. Generally, the Moghra and Gable Qatrani formations, which influenced the formation of this landscape and led to the dominance of sand fractions in all the studied soils. Moreover, more than 65% of the study area suffered from high salinity derived from the dominant Eocene limestone and it may be the primary cause of the extremely salinization rate. In addition, 5.6% of the study area is sodic-affected where, sodium certainly has a detrimental effect on the soil. Accordingly, high ESP may accelerate soil chemical dispersion, resulting in crust development and a reduction in infiltration rate (Borena and Hassen, 2022). Also, more than half of the area was classified as strongly calcareous soil. Commonly, soils with a coarse to moderately coarse texture are typically related to $CaCO_3$ (Wassif and Wassif, 2021). The author suggested that there is a potential correlation between the amount of calcium carbonate and the parent material of the soil in the area under study. On the other hand, the study area did not show a high concentration of gypsum, as it was classified as slightly to moderately gypsiric. According to Confirm Susan et al. (2014), the presence of gypsum imparts qualities to soils and influences the development of soil properties such as, soil morphology, water holding capacity, available nutrients, root growth, rapture resistance, and the standard concepts of soil texture. Further, most of the study area had low CEC, which is quite important to the soil capacity to hold onto cations. Key factors that significantly affect CEC values include soil texture, organic matter concentration, and particle mineralogy (Meimaroglou and Mouzakis, 2019).

4.2. Soil nutrients contents

The results, presented in Tables 4, 5, and Figures 12–18, revealed that most of the soil in the study area were poor in available nutrients despite its high total nutrients content. Might be due to fixation process and losses because of inadequate land management practices. The majority of the investigated area (75% of the total area) had a low content of available N as compared with total N. Their poor organic matter content, low CEC, higher pH, and greater temperature could cause the low N content (Ganzour, 2015; and Li, et al., 2020).

Available P in the area did not exceed 3% of the total content. This could be due to either precipitation through a reaction with soluble Ca or adsorption on the surface of $CaCO_3$ particles (Hamed and Khalafallh, 2017). P availability in the examined region may also be decreased by P adsorption on Mn and Fe oxides.

Almost all of the studied area had low and medium available K content, and had a small percentage of total content compared to clayey soils. According to Kepka (1992) and Venkatesh and Satyanarayana (1994), the added potassium to the soil is fixed by the tiniest fraction of the solid phase. It is worth to mention that the obtained results of the current study are in agreement with those studies.

The same results were hit for micronutrients, as all or most of the study area is poor in its content of available micronutrients, due to the soil coarse texture, low OM, and moderately to severely calcareous conditions (Hamed and Khalafallh, 2017; Ganzour et al., 2020; and FAO, 2022). Generally, soil micronutrient deficiencies have negative impacts on the growing crops and consequently their yield, as well as soil health. Therefore, it is essential to keep the balance of micronutrients in the soil to guarantee the ecological processes and sustainable use of natural resources that sustain life on Earth (Dewangan et al., 2023).

4.3. Interpreting Irrigation Water Analysis

Four out of five water samples from the distributed wells in the studied region were found to be suitable for irrigation as they had an EC of < 0.75 dSm^{-1}. However, sample No. 3 had an EC of 0.76 dSm^{-1} and Na^+ 3.66 mmol/L; which might detrimentally affect the crops, especially the salt-sensitive crops according to FAO (1985) and Bauder et al. (2011). The elicitation of salt-resistant varieties of crops and adopting an adequate modern irrigation system this water well can be used.

4.4. Land assessment

The land capability evaluation showed that most of the studied area could be considered as arable land covering 92% of the total area, where 66.41% belonged to class 2 (good for farming), and 25.59% was classified as class 3 (fair for farming). These capability classes were characterized by soil coarse texture only or/and salinity limiting factors. In this regard, Ayars, et al. (2012) and ANR (2015) confirmed that it is very easy to leach the salts, especially soil with coarse texture and an open profile before planting so that salts move away from the root zone. They also calculated the leaching requirements. On the other hand, 8% of the investigated area was preferably exploited in other activities such as animal and poultry production farms.

The land suitability for four distinct crops (wheat, barley, pepper, and alfalfa) was tested (Table 7 and

Figures 20–25). The obtained results demonstrated that most of the studied area was suitable for agriculture with some limitations. However, the current study showed that the limiting variables were salinity and texture which could be lessened by employing excellent management methods, which include establishing drainage system, leaching salt, adding organic matter, and applying adequate agricultural practices. The potential suitability would be realized.

5. Conclusions

The study area is one of the most promising reclamation areas, as the study confirmed that about 92% of the area is completely suitable for agricultural with texture and salinity limiting factors. Thus, it is recommended to reclaim the land by leaching the salts and as the profile is open and the texture is light, salt would be easy to be leached. Also, organic fertilization and the addition of materials that have the ability to retain water and nutrients are necessary, and mineral fertilization must be added in batches with the modern irrigation systems. The current study confirmed that after carrying out reclamation operations, barley, wheat, alfalfa, and pepper can be cultivated on such lands. It is also necessary to emphasize that acceleration of reclamation of these areas, as they belong to dry climate lands and are therefore vulnerable to desertification.

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