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Soil fertility assessment in the North of Nasiriyah City (Iraq) using geographic information system technology

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Abstract Evaluating agricultural land for its suitability for cultivation is essential to achieve optimal benefit. Geographic Information Systems (GIS) is one of the most important technologies used in evaluating agricultural lands by collecting and analyzing spatial data, which allows for sustainable soil management. The results showed that the application of spatial analysis tools of the GIS and the distribution of soil fertility in the study area had a low soil organic matter content and moderate levels of available nitrogen, phosphorus and potassium, but they were not evenly distributed in the study area, in addition to a high soil pH value. The results showed that the soil fertility assessment classifications was only two categories in the study area. The non-fertile soil category constituted over 86% of the total area. In contrast, the low fertility soil category accounted for 14% of the total area. The other fertility categories- very fertile, fertile, and moderately fertile- were not presented in the study area as they did not exhibit the ideal condition for certain properties used in soil fertility evaluation, due to high salinity and calcium carbonate minerals, as well as low organic matter content.

Keywords: GIS, Soil fertility map, Soil characteristics, Soil fertility categories, Salinity

Introduction

Soil plays an important role in supporting terrestrial ecosystems, and is an essential medium for plant growth by providing essential water and nutrients. Soil fertility is defined as the ability of the soil to supply essential nutrients in adequate and balanced amount of soil, enabling high yields under specific soil and cropping conditions (Ali *et al*., 2014). Agricultural crop production requires a comprehensive understanding of soil fertility, which varies spatially and with different land management practices (Khadka *et al*., 2018). Soil fertility is affected by various factors, such as environmental, conditions, geological, and soil chemical physical and biological properties, such as

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texture, pH, electrical conductivity, soil structure, organic matter content, nutrients availability.

These parameters play an important role in determining the productivity of the soil fertility (Singh *et al*., 2023). In the context of ongoing climate change, agricultural lands are subject to salinity, water scarcity, and environmental degradation, leading to change in agricultural production conditions and crop decreased in continuous agricultural land surveys are essential to achieve better use of natural resources (Moursy *et al*., 2022). Soil fertility assessment is an important step in the proper utilization, protection and management of soil resources. The purpose of soil fertility analysis is to provide land users with comprehensive and useful information that helps improve soil management, reduce waste, and make informed decision about soil a their use has been weakened (Binh *et al*., 2024).

Continuing farmland surveys using traditional methods is challenging, time-consuming, effort-intensive and clostly which may be incorrect in some cases so it is important to use modern methods and models to incorporate spatial data and soil properties together for comprehensive geographic analysis it provides a comprehensive solution to collect, store, analyze, and visualize spatially connected data related (Lanki and Onwu, 2024). Given the limited number of studies conducted in Al-Nasiriyah using GIS, this present study aimed to analyze soil fertility status and large-scale maps of soil fertility in north Thi-Qar district.

Materials and methods

Study area

The study area is located between 3504600N to 3511000N latitude and 614000E to 623250E longitude north of Nasiriyah and east of Al-Rifai district. The selected study area covers an area of 4.509 hectares (see Figure 1). The climate in the study area is features hot summers and cold winters, and its cultivated with various cereal and vegetable crops.

Soil sampling and laboratory analysis

Soil samples were collected from a depth of 0 – 30 cm during the 2024-2025 agricultural season at twelve locations within the research region (Figure 2). The sampling points were determined using a Garmin GPS 60 CSX global positioning system. The samples were dried, ground, and subsequently sifted with a 2 mm opening. Subsequently, the soil sample were analyzed in the soil laboratory of the National Center for Water Resources Management, employing established analytical methods to estimate various physical and chemical characteristics of the soil.

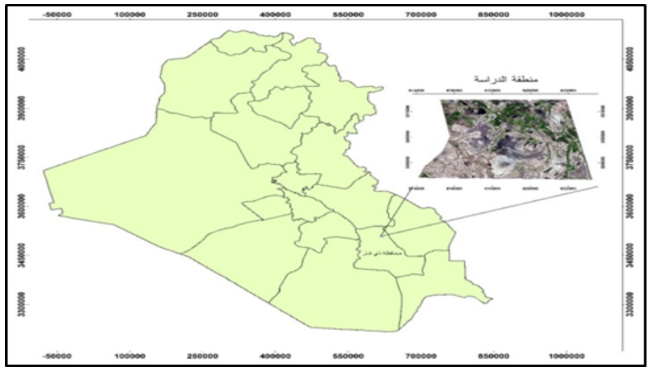

Figure 1. Location map of study area

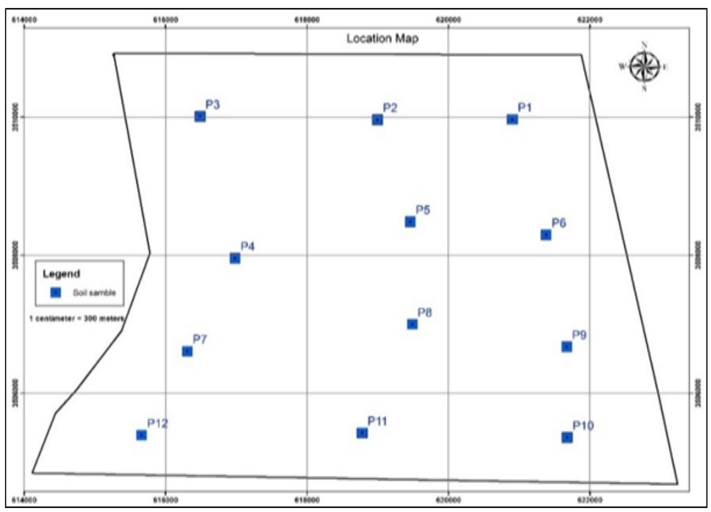

Figure 2. Soil sample points on the study area map

Soil fertility mapping

The coordinates of soil sample locations in the study area were recorded using a Garmin GPS and spatially projected onto the base map in ArcGIS 10.8.A database for the study area was created, linking spatial data to the descriptive data obtained from the analysis of the samples in the laboratory, which were also projected on to the base map in ArcGIS. The kriging method was employed to produce a soil fertility map for the study region, utilizing fertility evaluate criteria and the Inverse Distance Weight (IDW) method. Soil characteristics influencing fertility for crop cultivation were identified, including texture, organic matter, cation exchange capacity, calcium carbonate, nitrogen, phosphors, potassium, soil pH, electrical conductivity, and percentage of exchangeable sodium. Estimate of the various soil properties were multiplied together to obtain a final assessment of soil fertility, which was used to determine soil suitability classification, following the equation provided by Sys *et al.* (1991).

$$\mathbf{F = T*OM*CEC*CaCO_3*N*P*K*pH*EC*ESP}$$

Where, F = Fertility, T= Texture, OM= Organic Matter, CEC= Cation Exchangeable Capacity, $CaCO_3$= Calcium Carbonate, N= Nitrogen, P= Phosphorous, K= Potassium, pH= Soil Reaction, EC= Electric Conductivity, ESP= Exchangeable Sodium Percentage. The values of the evidence are determined using special tables.

Table 1. Soil fertility varieties with evidence of their validity

Degree Class	Class	Symbol	Validity guide value
First Class	Very Fertility	F1	Greater than 80
Class Second	Fertility	F2	80-60
Third Class	Moderately Fertility	F3	60-40
Class Fourth	Low Fertility	F4	40-20
Fifth Class	Non Fertility	N	Less than 20

Results

The status of soil fertility and percent distribution of soil properties obtained from collected soil samples as shown in the Table 2.

Texture

The results of the analysis soil texture distribution in the study area indicated that the sand content ranged from 0.4% to 11.2%, the silt content from 40.4% to 68.5% and the clay content from 21.0% to 52.0%(Table 2). Three types of soil texture were absorved as silty clay with 71%, silty clay loam with 20%, and silty loam with 9% throughout the study area (Figure 3).

Table 2. Soil fertility status of study area

S. NO.	Sand	Silt	Clay	Soil Texture	OM gm Kg^{-1}	CEC Cmol kg^{-1}	$CaCO_3$ (%)	N (ppm)	P (ppm)	K (ppm)	pH	EC (ds m^{-1})	ESP (%)
		(%)											
1	6.3	48.7	45.0	SiC	12	31.3	40	34.03	19.2	218	7.0	27.1	26
2	9.1	58.9	32.0	SiCL	18	27.5	34	44.60	17.5	108	7.8	6.4	5
3	4.4	60.6	35.0	SiCL	13	29.2	37	35.00	20.3	221	7.1	31.8	35
4	5.3	44.7	50.0	SiC	16	31.7	29	40.10	15.7	267	7.1	29.6	27
5	7.6	40.4	52.0	SiC	11	31.9	47	33.00	19.5	250	7.5	17.1	15
6	11.2	66.8	22.0	SiL	15	23.4	43	38.20	22.4	186	7.6	3.9	4
7	0.6	52.4	47.0	SiC	13	30.6	31	37.73	20.9	212	7.4	20.9	19
8	6.0	57.0	37.0	SiCL	15	28.6	37	38.50	16.8	120	7.2	51.3	45
9	0.4	50.6	49.0	SiC	17	29.8	40	41.40	19.3	202	7.2	22.8	24
10	1.2	57.8	41.0	SiC	13	29.1	37	36.60	22.7	237	7.2	18.4	16
11	10.4	68.5	21.0	SiL	15	22.7	38	37.23	20.2	248	7.3	54.2	38
12	8.2	43.8	48.0	SiC	19	29.5	24	45.34	16.9	243	7.1	60.1	48
Mean	**5.89**	**54.18**	**39.91**		**14.75**	**28.77**	**36.41**	**38.47**	**19.28**	**209.33**	**7.29**	**28.63**	**25.16**

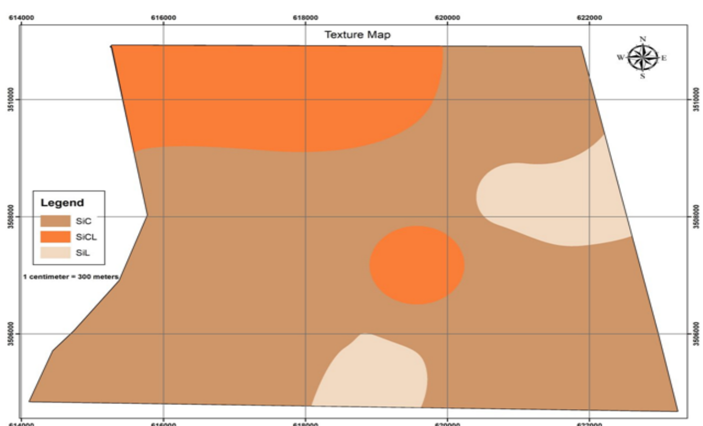

Figure 3. Texture distribution in the study area

Organic matter

The results showed that the amount of organic matter in the study area ranged from 11 to 19 g kg^{-1}, with an average of 14.75 g kg^{-1} (Table 2). Distribution of organic matter size in the study area from 13 to 16 g kg^{-1}, accounting for 68% of the total area occurs (Figure 4).

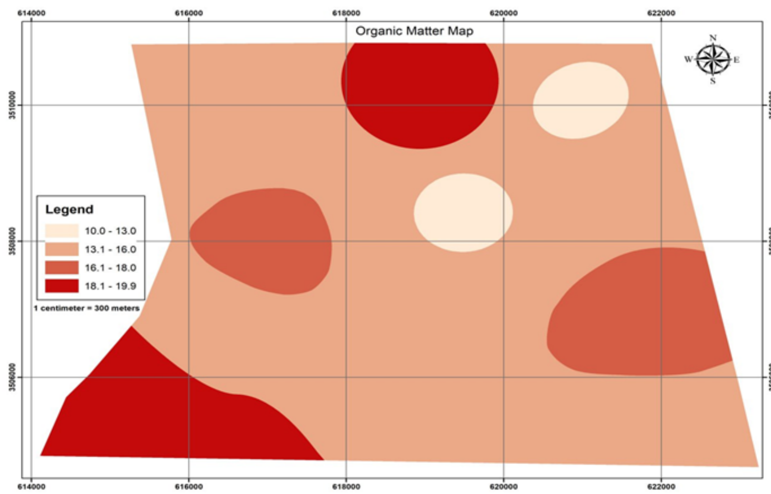

Figure 4. Distribution of organic matter in the study area

Cation exchangeable capacity

Results showed that the CEC from 22.7 to 31.9 cmol kg^{-1}, with an average 28.77 cmol kg^{-1} (Table 2). The spatial distribution of CEC which was categorized into four level within the study area as the first category ranged from 22 to 24 cmol kg^{-1}, the second from 24.1 to 28 cmol kg^{-1}, the third from 28.1 to 30 cmol kg^{-1}, and the fourth from 30.1 to 32 cmol kg^{-1}, comprising 12%, 5%, 25%, and 58% respectively, of the total area, respectively (Figure 5).

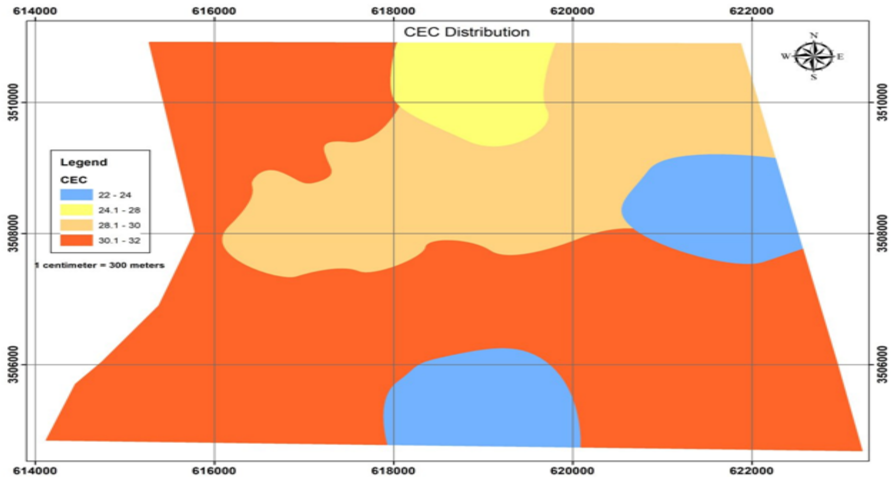

Figure 5. Cation exchangeable capacity distribution in the study area

Calcium carbonate

The percentage of calcium carbonate ranged 24% to 47% within an average 36.41% (Table 2). The highest distribution of calcium carbonate in the study area ranged of 36.1% to 40%, representing 68% of the total area studies. A significant increase in calcium carbonate content was observed in the range of 40.1% to 47%, accounting for 8% of the total area (Figure 6).

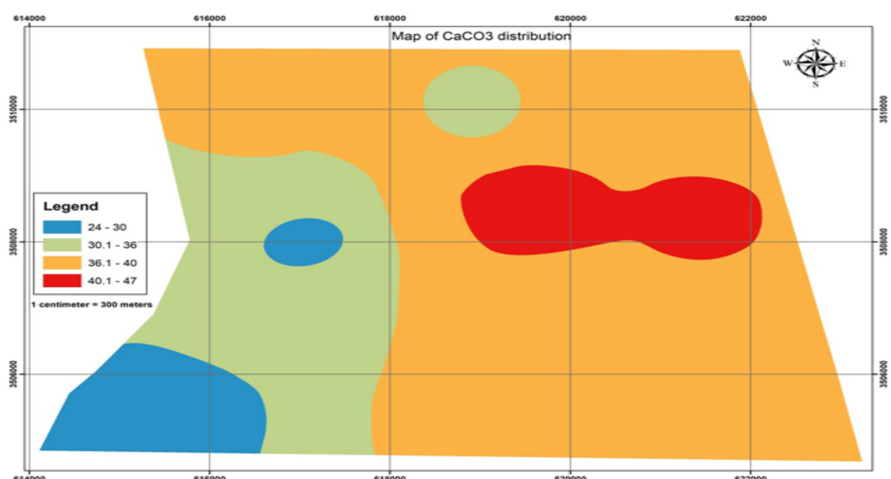

Figure 6. Calcium carbonate distribution in the study area

Available nitrogen

The soil nitrogen content ranged from 33 to 45.34 mg kg^{-1}, with an average of 38.47 mg kg^{-1} (Table 2). The spatial distribution of available nitrogen in the soil fertility map, indicating that the nitrogen content was low to moderate (Figure 7).

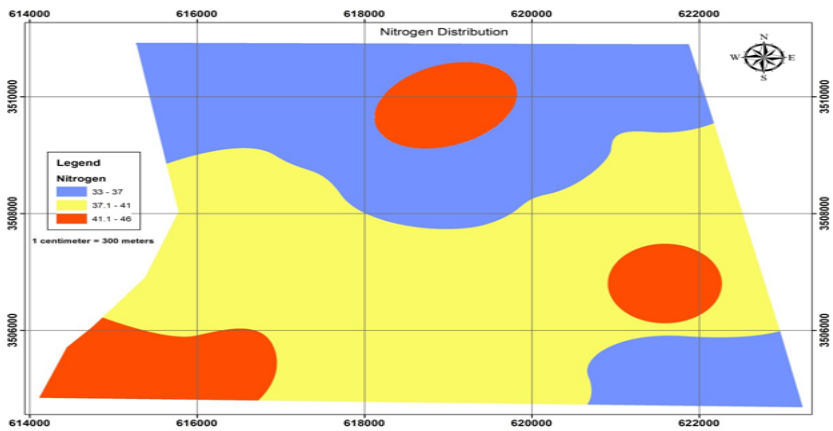

Figure 7. Distribution of available nitrogen (kg ha^{-1}) in the study area

Available phosphorous

The phosphors content of the soil ranged from 15.7 to 22.7 mg kg^{-1}, with an average of 19.28 mg kg^{-1} (Table 2). The soil fertility map indicated that approximately 39% and 61% of the study area's soil within low and medium phosphorous content categories, respectively (Figure 8).

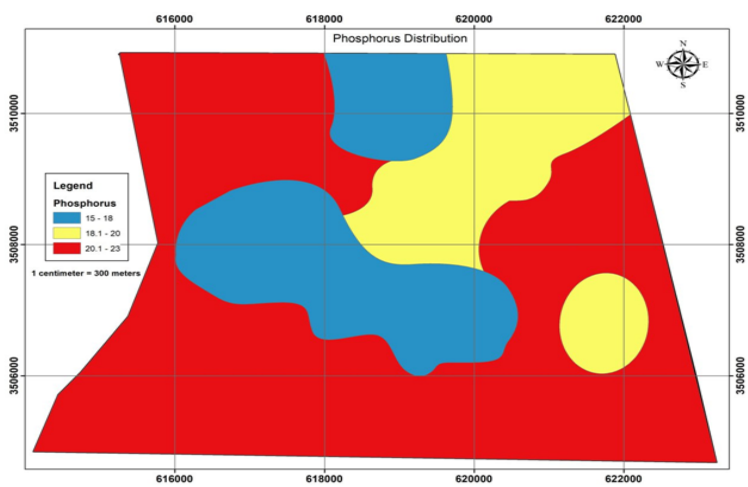

Figure 8. Available phosphor (kg ha^{-1}) distribution in the study area

Available potassium

The soil potassium content ranged from 108 to 267 mg kg^{-1}, with an average of 209.33 mg kg^{-1} (Table 2). Approximately10% and 21% of the study area's soil showed low and medium potassium content categories, respectively. In contrast, the majority of the study area exhibited available potassium levels exceeding 235 mg kg^{-1}, accounting for about 69% (Figure 9).

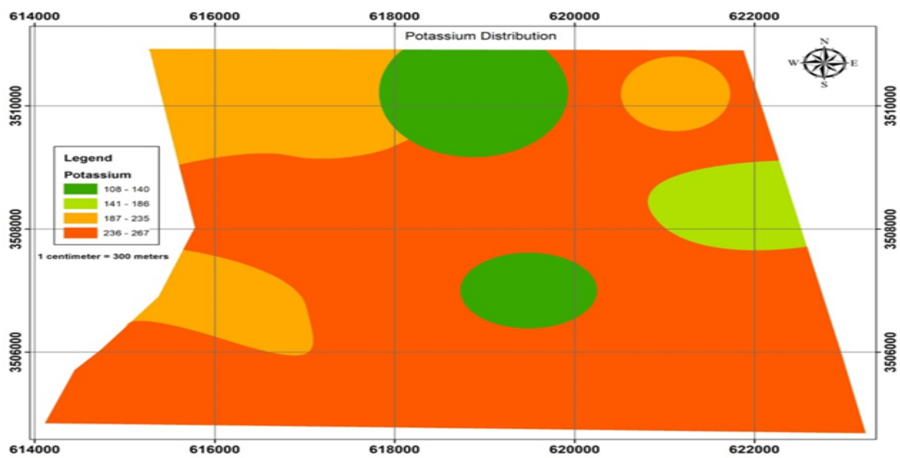

Figure 9. Available potassium (kg ha^{-1}) distribution in the study area

Soil pH

The results of the current study indicate that the soil pH values in the study region varied from 7.0 to 7.6. with an average of 7.29, as shown in Table 2. The findings revealed that the soil pH within the range of mildly alkaline soils, with the lower pH values (7.0-7.2) covering 77% of the total area studies, while the higher pH values are found in the other area (Figure 10).

Electric conductivity

The results showed that the electrical conductivity values in the study region ranged from 3.9 to 60.1 dS m^{-1}, with an average of 28.63 dS m^{-1} (Table 2). The high salinity levels, classified under categories S_3, S_4, and S_5 were, 7.8%, 61.2%, and 26.4%, respectively, totaling 95.4% of the entire study area (Figure 11).

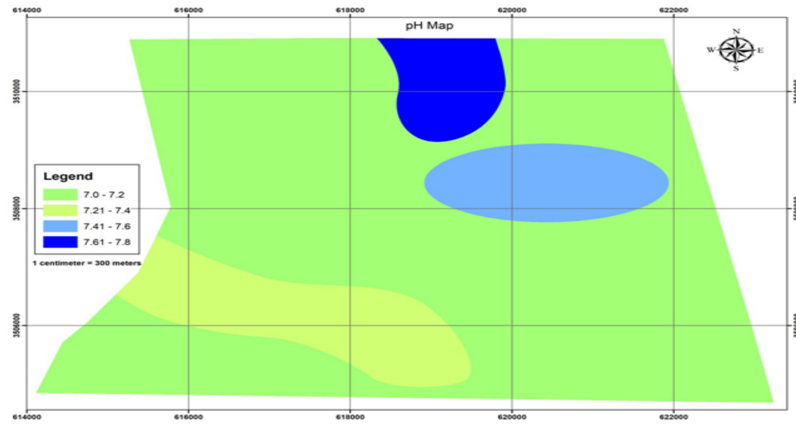

Figure 10. Soil pH distribution in the study area

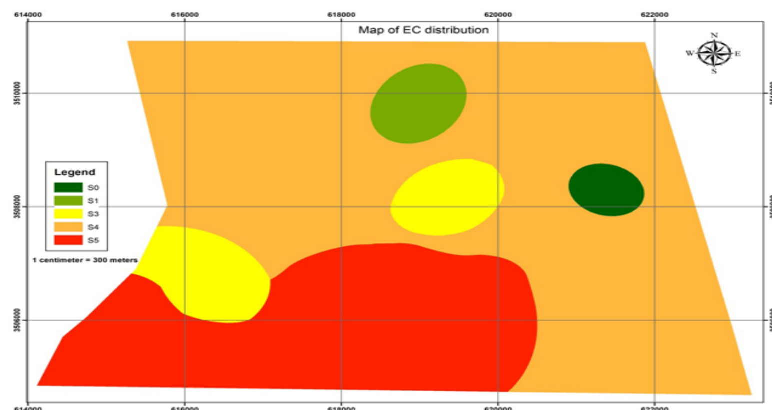

Figure 11. Electric conductivity distribution in the study area

Exchangeable sodium percentage

The findings indicated that the percentage of exchangeable sodium in the study area ranged from 4.0% to 48%, with an average of 25.16% (Table 2). The spatial distribution on the percentage of sodium was identified to be five distinct levels within the study area (Figure 12). Class 1 exhibited the lowest percentage of exchangeable sodium at 6%, followed by class 2 at 29%, class 3 at 37%, class 4 at 23%, and class 5% of the total area.

Soil fertility assessment

Results in Figure 13 showed the soil fertility classification analysis according to the standard multiplication method was only two categories in the study area. The non-fertile soil category constituted over 86% of the total area.

In contrast, the low fertility soil category accounted for 14% of the total area. The other fertility categories- very fertile, fertile, and moderately fertile- were not presented in the study area.

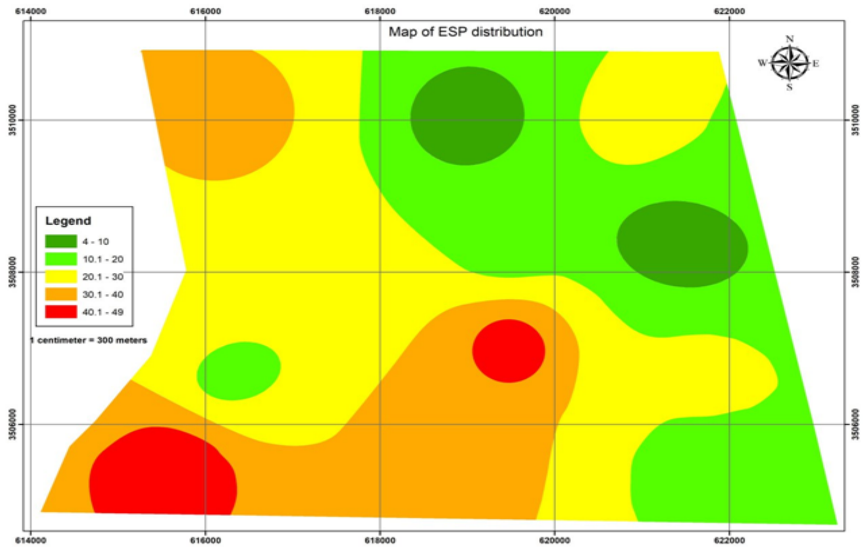

Figure 12. Exchangeable sodium percentage distribution in the study area

Non-fertile N

The results of the soil fertility analysis showed that the poor soil class was more than 86% of the total land area, which covered 3.898 hectares, representing the largest area within the study region. The soil in this group consisted of silty clay and silty clay loam texture, higher levels of calcium carbonate minerals, moderate cation exchange capacity (CEC), better levels of nitrogen, phosphorus, and potassium (NPK), slightly alkaline pH, low organic matter, and higher salinity and exchangeable sodium percentage (ESP). That high salinity and high ESP, in addition to high temperatures and low rainfall, might be negatively affected soil fertility in this area.

Low fertility

The area classified as low fertile land comprises approximately 14% of the total study area, which covered to 0.610 hectares. The soil in this category were composed of silty loamy and silty clay loamy texture, alkaline pH, low organic matter, high content of calcium carbonate minerals, medium CEC, good NPK, high salinity, and relatively low ESP. The classification of this area was a low fertile soil due to high salinity, low organic matter content, and increased of soil pH. No other soil groups were identified in the study area due to the lack of quality required to assess soil fertility. This is a primary attributed to the high salt concentrations present in these regions.

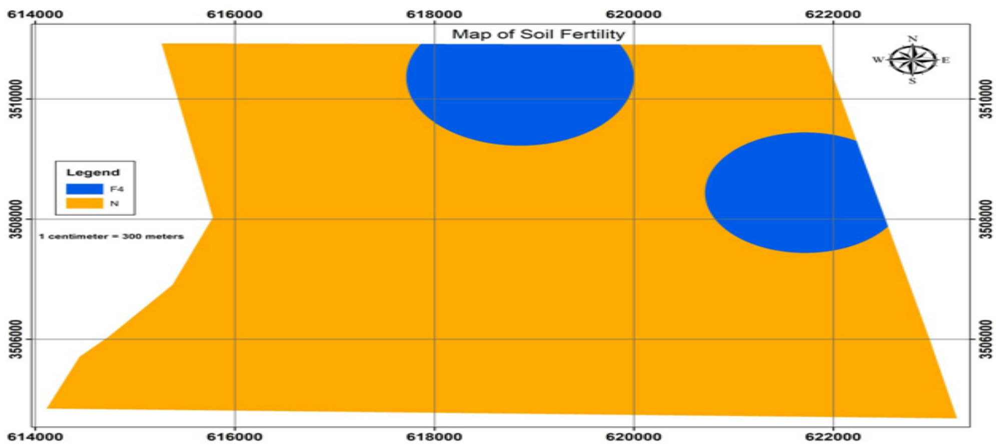

Figure 13. Distribution of soil fertility in study region

Discussion

Soil texture is essential for many chemical, physical, and biological properties of soil. It influences soil aeration, the movement and absorption of water and nutrients, as well as the ability of the soil to hold water, in addition to supporting biological activities (Khadka *et al*., 2016).

Organic matter is considered to be one of the major components of soil due to its important role in influencing soil properties. It helps to increase soil water holding capacity, increase biological activity, and reduce soil pH as it decomposes, releasing organic acid in addition to being a source of many nutrients such as nitrogen, phosphors, and sulfur in particular (Shanmukha *et al*., 2024). The decreased organic matter in southern Iraq can be attributed to the high temperature and drought conditions, which have reduced natural vegetation cover in this region (Al-Bayati *et al*., 2023).

Cation exchange capacity (CEC) is a neuter feature of soil, as it indicates the ability of the soil to hold and produce nutrients, which affects soil structural stability and soil pH (Eldiabani and Elsbia, 2022). The levels of CEC in the soil of the study area were favorable due to the high clay content-given that most soils exhibited fine to medium texture- the fertility of the soil is not solely influenced by clay content. Organic matter plays significant role in stabilizing soil aggregates, thereby reducing nutrient loss from the soil (Sasongko *et al*., 2022).

The proportion of carbonate minerals increase in region with lower rainfall, especially in dry and semi-dry regions of the world. An increase in the amount of calcium carbonate in the soil leads to elevated soil pH levels, which affects the availability of nutrients, specially micronutrients. This, in turn, leads to decreased of soil productivity (Al-Budeiri and Al-Aloosy, 2019). The relatively high presence of calcium carbonate can be attributed to the composition of the soil's parent material, surface topography, and soil formation processes, which have led to an increase in calcium carbonate in the upper horizons of the soil (Saleh, 2023).

This reduced nitrogen content in the study area could be due to insufficient organic matter levels in the soil and elevated temperature, which accelerate the decomposition of organic matter and its subsequent loss, leading to nitrogen deficiency. In addition, nitrogen losses and leaching rates in soils are high due to increased soil pH and use of irrigation water (Shanmukha *et al*., 2024). The deficiency of phosphors in the soil is considered a significant factor affecting soil fertility. The reduced concentration of phosphors in the study area may be attributed to the high levels of calcium carbonate present, which subject the added phosphor to various precipitation and adsorption processes, thereby diminishing its availability to plant (Al-Budeiri and Al-Aloosy, 2019). Results in (Table 2, Figure 9) indicates a favorable condition of available potassium in the soil. This situation may be attributed to the predominance of fine-textured soil in the study area. Which contained a significant proportion of clay. Fine-textured soils tend to have a greater capacity for potassium adsorption and retention due to their higher cation exchange capacity, thereby enhancing the availability of potassium in the soil (Gurav *et al*., 2024).

Soil pH is crucial for soil fertility by influencing various soil properties and the availability of nutrients for plants. The elevated soil pH is attributable to the nature of soil minerals composing, including an increased content of carbonate minerals, prevailing climatic conditions in the region, and poor management practices, such as excessive use of chemical fertilizers, among other factors (Tagung *et al*., 2022).

Saline soil is defined as soil in which the electrical conductivity (EC) of the saturation extract (ECe) exceeds 4 dS m^{-1} at temperature of 25 °C. An increase in electrical conductivity beyond this threshold leads to soil degradation and decrease in productivity of most agricultural crops (Shrivastava and Kumar, 2015). Results in (Table 2, Figure 11) represents a significant concentration of soluble salts in the soil solution, which negatively impacts plant physiological traits directly and alters various soil characteristics, such as structure and porosity, thereby increasing salt accumulation and reducing agricultural yields (Saleh *et al*., 2020). The high salt concentration in the study area can be attributed to the nature of land use, the application of traditional irrigation methods, poor quality irrigation water, variation in soil texture, and infrequent rainfall (Saleh *et al*., 2019).

The soil in which percentage of exchangeable sodium is low is not considered a limiting factor for agricultural crop growth. However, when the percentage exceeds 16% it becomes a limiting factor for soil fertility and plant growth due to the degradation of physical soil processes. This degradation results in the separation of clay aggregates, leading to their expansion, the clogging of soil pores, difficulty in water movement, low permeability, poor drainage, and the hardening of the soil. Additionally, the formation of surface crust upon wetting and drying occurs due to high concentration of sodium (Warrence, *et al*., 2002). Results in (Table 2, Figure 12) indicate that the proportion of (ESP) is a determining factor for soil fertility in most of the study region. This could be due to the soil's low organic matter content, which can lead to poor drainage and reduced permeability and water movement, consequently resulting in elevated levels of exchangeable sodium (Win *et al*., 2024).

Fertility status of the soil in the study region was a significantly low. Soil salinity can be considered the primary cause of the reduced fertility, compounded by improper soil management practices, the lack of modern irrigation technologies, and prevailing environmental conditions particularly elevated temperatures. These factors are contributed significantly to increase concentration of salts in the soil, along with a reduction in organic matter and an increase in calcium carbonate levels.

Finalilly, the spatial distribution maps and fertility assessments will assist in improve soil management and inform appropriate decisions for the reclamation and sustainability of salts-affected lands, ultimately enhancing their fertility and thereby increasing productivity, which would yield economic benefits for farmers.

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Conflicts of interest

The authors declare no conflict of interest.

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