



ISSN: 0067-2904

Soil Spatial Distribution Analysis as a Method for Optimal Land Management

Mujtaba Saad Jamal¹, Ahmed Assad Zaeen²

¹Remote Sensing and Geographic Information System Department, College of Science, Baghdad, Iraq

²Remote Sensing Unit, College of Science, Baghdad, Iraq

Received: 17/6/2025

Accepted: 20/ 11/2025

Published: 30/9/2026

Abstract

To effectively manage agricultural fields and select suitable methods for field operations, it is essential to have a basic understanding or access to a database specific to that area. A field study was conducted in the Abu Ghraib area, west of Baghdad, Iraq, to map the spatial distribution of soil properties. Forty-seven soil samples were randomly collected from the area based on land use diversity. The samples were analyzed in the laboratories of the College of Agricultural Engineering Sciences at the University of Baghdad. ArcMap 10.8 software was used to map the spatial distribution of soil properties using the inverse distance weighting method. The results showed that the soil texture is loamy-silty mixed, followed by silty clay and clay. There was variation in the distribution of both salinity and pH along the river channel, ranged 125-136 ds/m and 7.10-9.5 ds/m, respectively. Organic matter and nitrogen content exhibited the same spatial distribution, based on the nature of land use, ranging from 5.5 to 11.9 g/kg and from 6.10 to 14.5 mg/kg, respectively. The abandoned lands exhibited high salinity and alkalinity, along with low organic matter and nitrogen content. As a recommendation, the soil should be managed scientifically to overcome its salinity first. Then, it should be planted with salt-tolerant crops until the land is fully reclaimed and suitable for other crops. Drains are an effective method for draining groundwater and salts to the main drains if the problem is related to the nature of the soil and not due to leaving it uncultivated.

Keywords: IDW, soil properties, soil management, spatial analysis,

تحليل التوزيع المكاني للتربة كطريقة للإدارة المثلى للأراضي

مجتبی سعد جمال¹، احمد اسعد زعین²

¹قسم التحسس النائي ونظم المعلومات الجغرافية، كلية العلوم، جامعة بغداد، بغداد، العراق

²وحدة الاستشعار عن بعد، كلية العلوم، جامعة بغداد، بغداد، العراق

الخلاصة

من أجل إدارة الحقول الزراعية واختيار الأساليب المناسبة للعمليات الحقلية، توجد معرفة أولية أو قاعدة بيانات لتلك المنطقة. أجريت دراسة حقلية في منطقة أبي غريب، غرب بغداد، العراق من أجل رسم خرائط التوزيع المكاني لصفات التربة. جمعت 47 عينة تربة من المنطقة عشوائياً اعتماداً على تنوع استخدام

*Email : ahmed.asaad@sc.uobaghdad.edu.iq



الارض. حلت عينات التربة كيميائيا وفيزيائيا في مختبرات كلية علوم الهندسة الزراعية في جامعة بغداد. استخدم برنامج ArcMap لرسم خرائط التوزيع المكاني لصفات التربة باستخدام طريقة IDW. اشارت النتائج الى ان نسجة التربة مزيجية عربنية طينية هي الشائعة، تليها الطينية غربنية والطينية. هناك تباين في توزيع كل من الملوحة ودرجة الحموضة وبنفس الاتجاه نحو القناة النهرية وتراوحت بين (123-136 ds/m) و (7.10-9.5 ds/m) على التوالي. المادة العضوية ومحتوى التربة من النتروجين ايضا اظهرتا نفس التوزيع المكاني بناء على طبيعي استغلال الارض حيث تراوحت بين (5.5-11.9 g/kg) و (6.10-14.5 mg/kg). اظهرت الاراضي المتروكة ملوحة وقلوية عالية وانخفاض في المادة العضوية ومحتوى النتروجين. كتوصية. يتوجب ادارة التربة بطريقة علمية من اجل التغلب على ملوحتها اولا. من ثم زراعتها بالمحاصيل المتحملة للملوحة الى ان يتم استصلاحها كليا حيث تصبح ملائمة لباقي المحاصيل الزراعية. المبالز طريقة جيدة لسحب الماء الارضي مع الاملاح نحو المبالز الرئيسية حال كون المشكلة متعلقة بطبيعي التربة و ليس بسبب تركها من دون زراعة.

1. Introduction

Understanding the soil's physical and chemical properties is crucial for minimizing soil erosion, maximizing crop productivity, and maintaining environmental quality [1]. Because they affect nutrient availability and crop productivity, soil chemical and physical characteristics, including pH, electrical conductivity (EC), Nitrogen, soil organic matter (SOM), and texture, are essential for comprehending soil fertility and health [2]. Soil pH is regarded as the 'master variable' of soil chemistry because of its significant influence on numerous chemical reactions involving essential plant nutrients [3]. Since they dictate the ideal nutrient availability and soil chemistry, EC and PH are master variables in agricultural productivity [4].

Soil pH is a crucial indicator, as it can be used to predict various levels of chemical activity in the soil likewise it is a helpful instrument for making decisions on the types of plants suitable for a given area, if soil pH requires to be changed, and the quantity of nutrients that plants can obtain from the soil [5]. The pH of the soil is one of the primary variables that affect the availability of readily accessible nutrients [6], indicating the soil's alkalinity or acidity. The acidity increases as the pH decreases from 7 to 0, and between pH 7 and 14, it becomes more basic or alkaline [7], [8]. EC of soil affects salinity, which in turn significantly impacts the soil's EC, ultimately affecting crop development and growth. While ions, or salts, appear, the mixture's EC improves. In the absence of salts, the low EC indicates that the soil mixture had weak electrical conductivity. Salts become impacted by various factors, including irrigation methods, internal soil water drainage, and the amount and timing of rainfall. The salts. Evaporation extracts water from the soil, and dry conditions effectively concentrate salts.

As an indicator of the quality and management of farmlands and water resources, EC in soil and water is highly beneficial [9]. A key element of the ecosystem's nitrogen pool is soil total nitrogen (STN), and determining the precise amount of STN is crucial for understanding the mechanisms involved in the global nitrogen cycle [10]. However, due to the economy's rapid growth, land use patterns have undergone significant changes, particularly the conversion of natural ecosystems to artificial ones [11,12]. This has a major impact on the soil's physical and chemical characteristics, including nitrogen [13]. Thus, a thorough understanding of the distribution of STN content serves as the foundation for measuring soil nutrients and is crucial for sustainable land-use management. STN content is unevenly distributed throughout the soil and depends on several variables, such as the parent soil composition, land use type, and surface vegetation cover. It is challenging to forecast the distribution of STN content across wide areas, as the conventional method of measuring STN

content relies on labor-intensive and time-consuming laboratory analysis of soil samples from the field [14]. The SOM can enhance physical, chemical, and biological soil processes, encourage the development of soil aggregates, and improve soil absorption and buffering [15].

Furthermore, the global carbon balance relies on the carbon stored in SOM, a crucial component of the global carbon cycle [16]. The absence of high-precision geographical distribution maps of SOM content also affects the accuracy of assessments of soil quality and the regional carbon cycle [17]. For sustainable agricultural development and the high-quality management of farmland, accurate and timely mapping of regional SOM content is crucial. One of the primary elements influencing the spectral features of soil is the amount of SOM present [18]. Although considerable research has attempted to forecast SOM, creating high-precision and high-resolution SOM maps remains challenging due to the difficulty in selecting reliable satellite data sources and prediction algorithms [19].

Soil texture is a crucial physical characteristic of soil that reveals the distribution of the fundamental soil constituents, including sand, clay, and silt, and can help shed light on how well it contributes to our understanding of soil characteristics and their spatial variability. The Inverse Distance Weighting (IDW) is frequently used in soil mapping, particularly in areas with limited data. The soil, which contains particles of varying sizes, reflects these ratios. The IDW method was utilized to examine soil texture. This method was used to estimate the spatial values of soil texture using known sample locations. When evaluating the value, the closer points will have a greater impact than the farther points [20, 21]. The study's primary objective is to provide guidance for improved soil management that is compatible with its current chemical and physical properties, ensuring continued sustainability.

2. Materials and methods

2.1. Study area

The study was conducted in the Abu Ghraib area, situated west of the Iraqi capital, Baghdad, at a latitude of 33.301143° N to longitude of 44.161589° E and a latitude of 33.285424° N to longitude of 44.130039° E. It has an area of approximately 5 km², Figure 1.

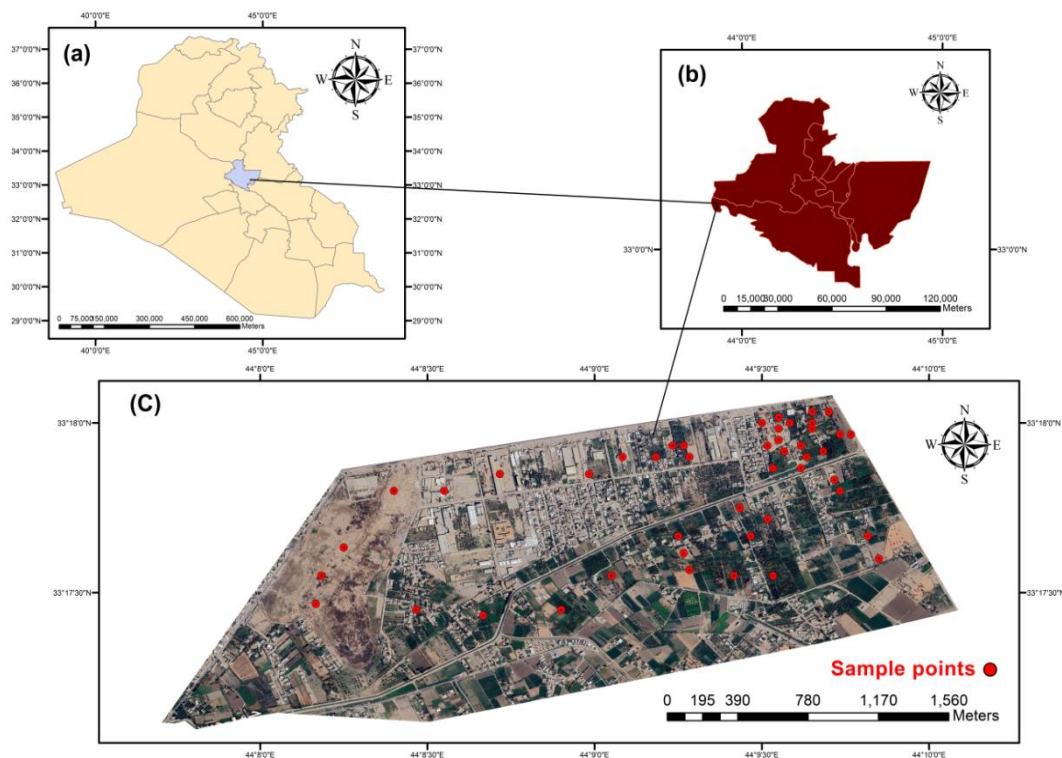


Figure1: a) Iraq's map, b) Baghdad City, c) study area showing sampling locations.

2.2. Climate

Iraq is known for its extremely hot summers and mild winters, with maximum temperatures occurring in June, July, and August of 43-50°C and in January between 1-8°C [22]. The summers in Baghdad can be extremely hot, with temperatures reaching 45°C. In contrast, the annual average rainfall of Baghdad is about 154 mm during the winter; summertime rarely sees rain [23].

2.3. Sampling procedure

Forty-seven samples were taken randomly from the study area based on agricultural activity and land cover type. A global positioning system was used to locate each sampling point accurately. Samples were collected at depths of 30 cm (Rootzone that reflects the soil content of nutrients), then bagged in plastic bags and sent to the Central Laboratory for Soil, Water, and Plant Analysis at the College of Agriculture, University of Baghdad, for physical and chemical analysis (Figure 1(C)).

2.4. Laboratory analysis

For laboratory analysis, 2 kg of composite soil samples were collected. The soil samples were then crushed and sieved through a 2 mm sieve. For the estimated soil pH, 10 g of dry soil is weighed into a clean glass beaker. 25 mL of distilled water was added in a 1:1.5 ratio; the mixture was stirred well and left to stand for 30 minutes. The soil pH was measured using a pH meter [24], and soil samples were classified according to Table (1)[25]. EC was measured using the 1:5 soil water suspension method and then filtered. The electrodes of the EC device were immersed in a solution to record the reading [26]. Soil samples were classified according to [27] Table (2). The soil nitrogen content was estimated using the Kjeldahl method [28]. Soil organic matter content was calculated using the loss on ignition method, which measures the loss in mass resulting from the burning of organic matter at high temperatures [29]. The soil texture was estimated using the Bouyoucos Hydrometer method [30].

Table 1: Classification of Soil pH[25].

Soil pH	Classification
<3,5	Ultra acid
3,5-4,4	Extremely acid
4,5-5,0	Very Strongly acid
5,1-5,5	Strongly acid
5,6-6,0	Moderately acid
6,1-6,5	Slightly acid
6,6-7,3	Neutral
7,4-7,8	Slightly alkaline
7,9-8,4	Moderately alkaline
>9,0	Strongly alkaline

Table 2. Classes of salinity and EC (1 dS/m ; adapted from NRCS Soil Survey Handbook) [27].

EC (dS/m)	Salinity Class
$0 < 2$	Non-saline
$2 < 4$	Very slightly saline
$4 < 8$	Slightly saline
$8 < 16$	Moderately saline
≥ 16	Strongly saline

2.6. Data Interpolation using inverse distance weighted (IDW)

The IDW is one of the most popular interpolation methods for spatial distribution analysis and interpolation [31]. The IDW approach was used to create the spatial distribution of soil characteristics. The value is calculated as a weighted average of known values in a given neighborhood. According to the statement, things that are closer together are more connected than those that are farther apart, even though everything is connected to everything else. The IDW approach assigns values to unknown points [32] using values from a distributed collection of known points. The value at the unknown location equals the weighted sum of the values of the N known points. This method can estimate specific soil characteristics in the context of soil property investigation.

IDW equation (1):

$$Z(X,Y) = \frac{\sum_{i=1}^n \frac{z_i}{d_i^p}}{\sum_{i=1}^n \frac{1}{d_i^p}} \quad (1)$$

Where i is the number of measured sample points within the neighborhood defined; Z_i is the observed value at location i; d_i is the distance between the measured location i and the predicted location X, Y; λ_i is the distance-dependent weight associated with each sample point; and p is the power parameter that defines the rate of weight reduction as distance increases. In this case, $Z(X, Y)$ represents the predicted value at the sample location (X, Y).

2.6.1. Verification of the spatial distribution

The cross-validation method is employed to gauge the accuracy of interpolation methods by testing them at known sample sites, where the real sample values are compared with the estimated values to calculate the error difference, thereby evaluating the accuracy of each interpolation method. This validation process is iterated for each available sample [33]. To verify the accuracy of the IDW-based maps illustrating the Chemical and physical characteristics of the soil in Abu Ghraib City, the objective was to compare the field values with the values predicted by the IDW approach. To assess the discrepancy between the observed values and IDW-determined values, metrics such as the root mean square error (RMSE) and R^2 were computed [34]. The choice of interpolation method depends on the amount of data available in a research region. To identify the most effective interpolation technique, various methods were employed to generate maps that depict the chemical and physical properties of the soil. RMSE, as the primary cross-validation criterion, accounts for extrema and stationary points, aiding in the evaluation of interpolation accuracy [34]; it could be computed as follows (2):

$$RMSE = \sqrt{\frac{1}{n} \sum_{i=1}^n (z_i - \hat{z}_i)^2} \quad (2)$$

Where n is the number of values utilized for the estimation, m: is the number of selected parameters in the empirical equation, $\hat{Z}$ is the estimated value, and Z_i is the measured value at the sampling.

3. Results and Discussion

3.1. Physical soil properties

The study area exhibited varying soil particle distributions corresponding to distinct soil texture classes. The maximum, minimum, and average percentages of sand were (46.6%, 6.1%, and 15%), silt (77.2%, 36.1%, and 49%), and clay (53.9%, 2%, and 36%), respectively, Table (3). This indicates that the silty clay loam class is the most dominant texture, while the sandy class is the least dominant. Clayey, silty clay, and silty classes were the most common, with averages of about 19%, 2%, and 17%, respectively. Figures (2, 3, and 4) showed the spatial distribution of sand, silt, and clay, respectively.

Table 3: Some chemical and physical soil properties of the studied site.

Sample No.	Easting m	Northing m	pH	EC (ds/m)	N mg/kg	OM g/kg	Sand %	Silt %	Clay %	Soil Texture
1	421873.768	3684859.899	8.8	80.2	8	9.2	10.25	56.31	33.44	SiCL
2	421951.91	3684920.918	8.1	77.2	8.5	9.2	10.19	56.09	33.72	SiCL
3	421874.263	3684921.542	7.9	20.1	8.6	9.3	9.95	56.91	33.14	SiCL
4	421873.52	3684829.077	7.6	25.6	6.1	7.5	15.19	45.09	39.72	SiCL
5	421770.331	3684860.731	7.5	8.5	10.5	10.2	12.95	47.88	39.17	SiCL
6	421718.907	3684891.969	7.1	6.9	14.2	11.3	13.1	38.1	48.8	C
7	421718.411	3684830.325	8	10.2	8.1	9.2	13.9	45	41.1	SIC
8	421717.915	3684768.792	8.6	35	7.9	8.5	15	55	30	SiCL
9	421641.012	3684861.773	8.4	50.2	6.2	7.5	19.25	50.73	30.02	SiCL
10	421665.901	3684738.388	8.3	40.8	6.2	7.3	18.89	51.99	29.12	SiCL
11	422054.357	3684796.8	8.6	45.3	7.3	8.1	19.25	50.73	30.02	SiCL
12	422002.592	3684797.216	8.5	44.5	8.1	9.2	18.89	49.1	32.01	SiCL
13	421924.295	3684705.484	7.4	10	11.3	11.6	13.01	38.19	48.8	C
14	421924.295	3684705.484	7.5	5.5	11.4	11.5	13.3	38.2	48.5	C
15	421821.105	3684737.137	7.6	4.6	12.3	11.9	13.9	37.5	48.6	C
16	421846.492	3684675.285	7.5	2.5	12.2	11.7	6.89	43.05	50.06	SiC
17	421743.208	3684706.941	8.5	8.9	6.2	7.5	19.25	50.75	30	SiCL
18	421820.114	3684613.961	8.6	9.1	10.2	10.8	46.62	47.42	5.96	SL
19	421690.791	3684615.002	7.4	3.5	11.9	11.4	12.17	49.01	38.82	SiCL
20	421277.938	3684741.523	7.9	2.1	10.2	10.5	13.39	38.91	47.7	C
21	421303.322	3684679.67	7.7	2.9	7.3	8	15.99	37.02	46.99	C
22	421226.266	3684741.942	7.5	2.1	8.1	8.9	17.09	36.1	46.81	C
23	421148.21	3684680.927	7.3	2.2	11.3	10.9	10.25	56.31	33.44	SiCL
24	420993.005	3684682.188	8.2	1.9	7.3	6.9	15.25	51.31	33.44	SiCL
25	420837.048	3684591.097	8.8	8.9	9.1	9.4	15.25	58.31	26.44	SiL

26	420423.288	3684594.477	8.8	33.2	6.7	5.8	19.2	74.9	5.9	SiL
27	420163.883	3684504.244	8.9	40.2	6.6	5.9	46.6	51.4	2	SiL
28	419931.118	3684506.159	9.1	130	6.5	6.1	20.4	56.5	23.1	SiL
29	419695.807	3684200.082	9.3	133	7.3	6.7	15.16	65.74	19.1	SiL
30	419591.089	3684046.938	9.5	136	6.1	5.5	6.1	77.2	16.7	SiL
31	419563.929	3683893.154	9.1	125	7.2	6.5	15.06	65.84	19.1	SiL
32	420029.236	3683858.49	8	2.5	7.7	6.9	6.99	40.01	53	SiC
33	420339.328	3683825.23	7.6	1.9	12.1	10.4	7.09	39.02	53.8 9	C
34	420701.693	3683852.979	7.4	2.1	14.5	11.5	8.8	38.9	52.3	C
35	420935.977	3684035.903	7.5	3.9	11.9	10.7	9	39	52	C
36	421248.154	3684248.914	7.5	1.9	10.9	10.14	10.25	56.35	33.4	SiCL
37	421273.197	3684156.35	7.9	9.9	6.5	7.4	10.09	56.4	33.5 1	SiCL
38	421298.333	3684063.786	7.3	4.6	12.3	11.9	10.05	53.29	36.6 6	SiCL
39	421504.975	3684031.291	7.2	4.2	13.1	11.1	9.98	50	40.0 2	SiC
40	421533.844	3684400.612	7.5	6.5	11.8	10.7	7.75	43.13	49.1 2	SiC
41	421584.369	3684246.195	7.7	2.9	11.1	10.9	7.99	44.1	47.9 1	SiC
42	421686.075	3684029.83	7.6	3	11.9	11.2	8.8	44.2	47	SiC
43	421662.673	3684338.035	7.5	4.5	9.5	9.7	9	44.1	46.9	SiC
44	421974.731	3684551.07	8.1	2.1	7.7	6.9	19.2	47	33.8	SiCL
45	422000.12	3684489.329	7.1	2.3	6.6	7.8	19.6	46.2	34.2	SiCL
46	422127.469	3684241.828	7.5	6.5	12.5	11.7	7.79	45.91	46.3	SiC
47	422178.251	3684118.236	7.9	15	6.1	7	19.21	56.02	24.7 7	SiL

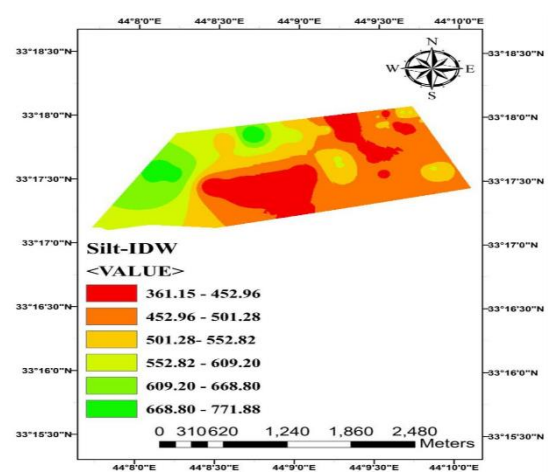
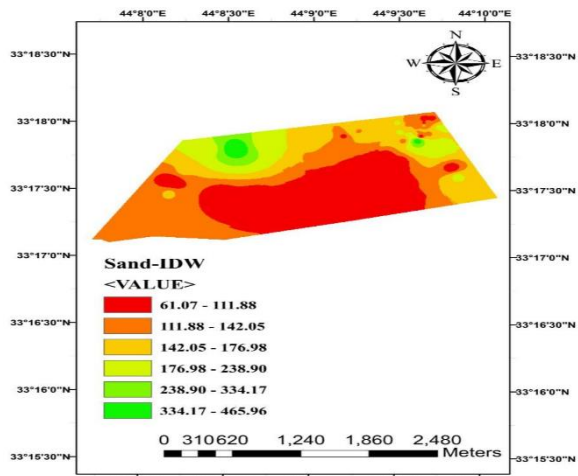


Figure 2: Spatial distribution of sand particles. **Figure 3:** Spatial distribution of silt particles.

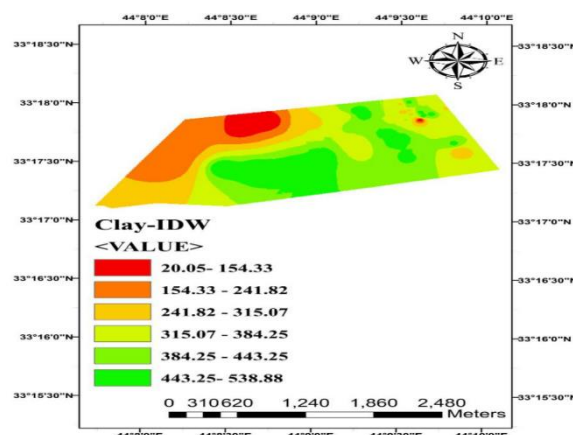


Figure 4: Spatial distribution of clay particles.

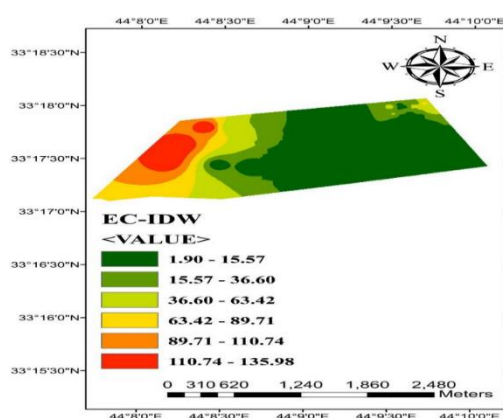


Figure 5: Spatial distribution of pH.

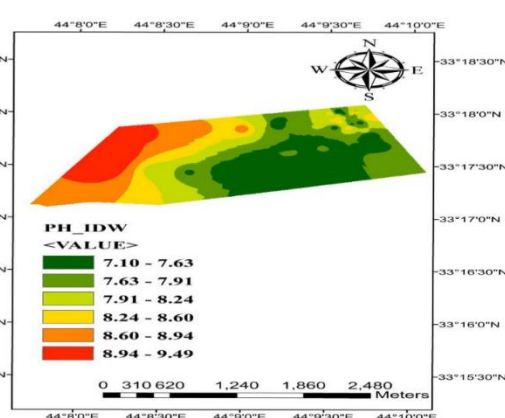


Figure 6: Spatial distribution of soil EC.

The pH value of the soil under different land-use systems ranged from 7.10-9.5, with an average value of 8.0. Based on the [USDA Natural Resources (2011)][25], Table (1), the study area was classified as natural-slightly alkaline to strongly alkaline. The higher values were found on the western side of the study area (bare soil that has not been agriculturally exploited), while the lower values were found on the eastern side. The uneven distribution or trend is due to capillary action in arid and semi-arid climates, where salts are raised to the top of the soil surface with the evaporated water, along with the soil solution that contains various compounds (CaCO_3 and NaHCO_3). The rest of the study area is cultivated entirely, which involves breaking the capillary action, while the plants reduce the effect of high temperature. Being close to the river leads to more frequent groundwater discharge. Rainfall or flooding washes soluble salts (Na^+ and CO_3^{2-}) from the soil into the river, which diminishes alkalinity [37]. The electrical conductivity value ranged from 1.90 to 136 dS/m, with an average value of 25 dS/m. Based on [27] Table (2), the study area was classified as non-saline to strongly saline. The higher values were found on the western side of the study area (bare soil that has not been agriculturally exploited), while the lower values were found on the eastern side. This is due to the movement of rainfall or irrigation water via groundwater toward the drainage area, which is the river. This movement can take the soluble salts from the soil to the river, so the closer to the river, the more drained the area, and vice versa [38].

The nitrogen content varied between 6.10 and 14.5 mg/kg, with an average of 9 mg/kg. The southeastern zone has the highest nitrogen levels, while the northwestern zone has the lowest values Figure (7). The spatial variation in organic matter content was similar to that of

nitrogen, where the organic matter content varied between 5.5 and 11.9 g/kg, with an average of 9 g/kg. The southeastern zone has the highest nitrogen levels, while the northwestern zone has the lowest values (Figure 8). Noticing that the cultivated areas with any plant cover showed a higher amount of nitrogen and organic matter than bare or saline areas. This is attributed to the biological, physical, and chemical processes driven by the vegetation cover [39]. Plant cover continuously adds organic material to the root zone, providing a continuous source of nutrients. Plant root exudates comprise sugars, amino acids, and other compounds, which serve as a rich source of food for soil microorganisms. The dead plant's fine roots and leaves decompose frequently, which in turn adds organic material directly to the soil. In contrast, bare or saline soils lack plant cover due to osmotic stress, drastically reducing the input of plant debris materials [40].

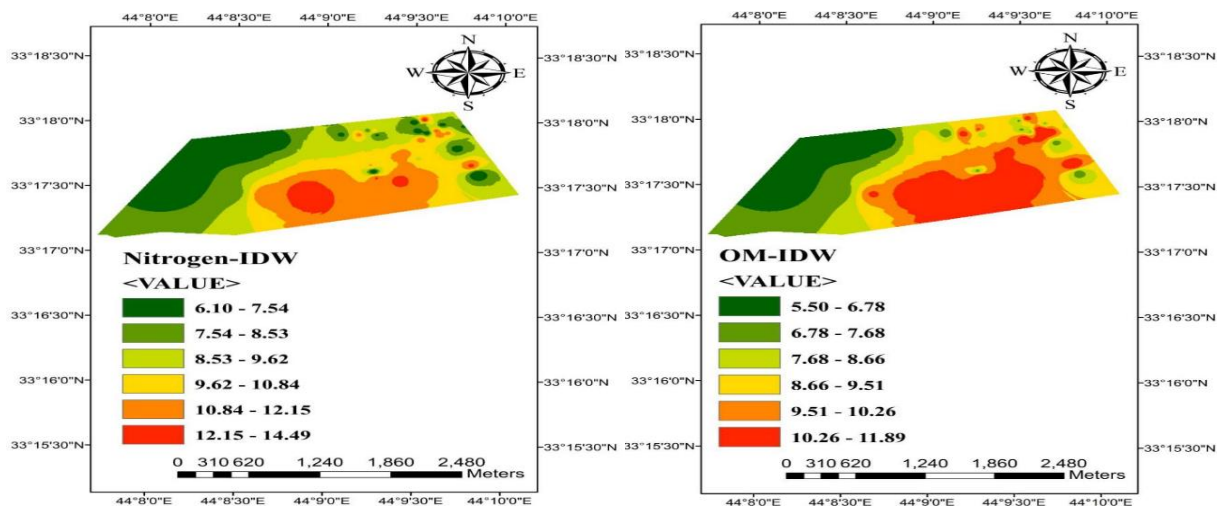


Figure 7: Spatial distribution of soil nitrogen . **Figure 8:** Spatial distribution of soil organic matter.

4. Conclusion

Based on soil test results, the majority of the study area is composed of silty clay loam (SiCL), followed by clay (C) and Silty Clay (SiC). Silty clay loam is optimal for holding water content, while the other requires systematic irrigation. Soil organic matter level between 5.5 and 11.9 g/kg with higher nitrogen content. A plant cover and rotation system are the most effective strategies for enriching the soil with organic matter [41]. Soil salinity was at 125-136 ds/m at high soil reaction ($\text{pH} > 9.0$), indicating potential sodicity risks. Recommending a sodium absorption ratio (SAR) test, where diagnosing the salt type can support using the optimal method for agricultural land reclamation. Also, installing subsurface drainage (tile drains) is essential to prevent waterlogging [42]. Deep tillage (subsoiling) is required once every 2 or 3 years in cases where compacted layers are present; breaking this hard layer can enhance the plant's root penetration [43]. Some crops are tolerant of heavy soils (Silty Clay or Clay), such as wheat, oats, sorghum, or rice. Additionally, shallow-rooted crops should not be planted in compacted soils; instead, it is recommended to plant deep-rooted types, such as alfalfa, to enhance the soil biology zone [44]. Continuous soil cultivation can reduce soil nutrient content after a few years, so a crop rotation procedure is recommended to replenish the soil with nutrients, organic matter, and soil microorganisms. Including legumes in the crop rotation will increase the soil's nitrogen levels. Barley crop in the crop rotation can overcome soil salinity issues, where barley is a tolerant crop for hard salinity and salty soils.

References

- [1] S. Snapp, "Embracing variability in soils on smallholder farms: New tools and better science," *Agricultural Systems*, vol. 195, p. 103310.2022.
- [2] R. R. Weil, N. C. Brady, and R. R. Weil, *The nature and properties of soils*. Pearson London, UK, 2017.
- [3] N. Barrow and A. E. Hartemink, "The effects of pH on nutrient availability depend on both soils and plants," *Plant and Soil*, vol. 487, no. 1, pp. 21-37.2023.
- [4] G. J. Udo, E. J. Uwanta, J. J. Awaka-ama, U. U. Ubong, and R. Igwe, "Implications of Crude Oil Exploration and Exploitation on Seasonal Variability of pH and Electrical Conductivity of Arable Soil, Water and Sediment of Ibeno Coastal Area, Niger Delta, Nigeria," *Researchers Journal of Science and Technology*, vol. 4, no. 3, pp. 26-43.2024.
- [5] R. Mylavarapu, J. Bergeron, N. Wilkinson, and E. Hanlon, "Soil pH and electrical conductivity: a county extension soil laboratory manual: CIR1081/SS118, rev. 1/2020," *Edis*, vol. 2020, no. 1.2020.
- [6] A. H. Gondal, I. Hussain, A. B. Ijaz, A. Zafar, B. I. Ch, H. Zafar, M. D. Sohail, H. Niazi, M. Touseef, and A. A. Khan, "Influence of soil pH and microbes on mineral solubility and plant nutrition: A review," *International Journal of Agriculture and Biological Sciences*, vol. 5, no. 1, pp. 71-81.2021.
- [7] W. Larcher, *Physiological plant ecology: ecophysiology and stress physiology of functional groups*. Springer Science & Business Media, 2003.
- [8] H. Marschner, "Mineral nutrition of higher plants."1995.
- [9] N. Patni, L. Masse, and P. Jui, "Groundwater quality under conventional and no tillage: I. Nitrate, electrical conductivity, and pH," Wiley Online Library0047-2425, 1998.
- [10] Q. Zhang, M. Liu, Y. Zhang, D. Mao, F. Li, F. Wu, J. Song, X. Li, C. Kou, and C. Li, "Comparison of machine learning methods for predicting soil total nitrogen content using Landsat-8, sentinel-1, and sentinel-2 images," *Remote Sensing*, vol. 15, no. 11, p. 2907.2023.
- [11] D. Mao, L. Luo, Z. Wang, M. C. Wilson, Y. Zeng, B. Wu, and J. Wu, "Conversions between natural wetlands and farmland in China: A multiscale geospatial analysis," *Science of the Total Environment*, vol. 634, pp. 550-560.2018.
- [12] Y. Gao, S. Sarker, T. Sarker, and O. T. Leta, "Analyzing the critical locations in response of constructed and planned dams on the Mekong River Basin for environmental integrity," *Environmental Research Communications*, vol. 4, no. 10, p. 101001.2022.
- [13] L. Yang, P. Luo, L. Wen, and D. Li, "Soil organic carbon accumulation during post-agricultural succession in a karst area, southwest China," *Scientific Reports*, vol. 6, no. 1, p. 37118.2016.
- [14] R.M. Yang, G.-L. Zhang, F. Liu, Y.-Y. Lu, F. Yang, F. Yang, M. Yang, Y.-G. Zhao, and D.-C. Li, "Comparison of boosted regression tree and random forest models for mapping topsoil organic carbon concentration in an alpine ecosystem," *Ecological indicators*, vol. 60, pp. 870-878.2016.
- [15] K. Usharani, K. Roopashree, and D. Naik, "Role of soil physical, chemical and biological properties for soil health improvement and sustainable agriculture," *Journal of Pharmacognosy and Phytochemistry*, vol. 8, no. 5, pp. 1256-1267.2019.
- [16] A. I. Coppola, S. Wagner, S. T. Lennartz, M. Seidel, N. D. Ward, T. Dittmar, C. Santín, and M. W. Jones, "The black carbon cycle and its role in the Earth system," *Nature Reviews Earth & Environment*, vol. 3, no. 8, pp. 516-532.2022.
- [17] X. Meng, Y. Bao, Y. Wang, X. Zhang, and H. Liu, "An advanced soil organic carbon content prediction model via fused temporal-spatial-spectral (TSS) information based on machine learning and deep learning algorithms," *Remote Sensing of Environment*, vol. 280, p. 113166.2022.
- [18] T. Angelopoulou, N. Tziolas, A. Balafoutis, G. Zalidis, and D. Bochtis, "Remote sensing techniques for soil organic carbon estimation: A review," *Remote Sensing*, vol. 11, no. 6, p. 676.2019.
- [19] A. F. Al-ysari, M. F. Majeed, and Y. Y. Khudair, "The effect of natural factors on changing soil uses in the marshes: An experimental study using Landsat satellite data," *World Water Policy*, vol. 10, no. 3, pp. 698-710.2024.

- [20] J. Barrena-González, J. F. Lavado Contador, and M. Pulido Fernández, "Mapping soil properties at a regional scale: assessing deterministic vs. geostatistical interpolation methods at different soil depths," *Sustainability*, vol. 14, no. 16, p. 10049.2022.
- [21] I. Khouni, G. Louhichi, and A. Ghrabi, "Use of GIS based Inverse Distance Weighted interpolation to assess surface water quality: Case of Wadi El Bey, Tunisia," *Environmental Technology & Innovation*, vol. 24, p. 101892.2021/11/01/ 2021.
- [22] K. Cooke, "Iraq's climate stresses are set to worsen," *PreventionWeb*, Geneva, Switzerland. Available online: <https://www.preventionweb.net/news/iraqs-climate-stresses-are-set-worsen> (accessed on November 2024).2018.
- [23] G. W. Thomas, "Soil pH and soil acidity," *Methods of soil analysis: part 3 chemical methods*, vol. 5, pp. 475-490.1996.
- [24] R. Awale, S. Machado, R. Ghimire, and P. Bista, "Soil health," *Advances in dryland farming in the inland Pacific Northwest*, pp. 47-97.2017.
- [25] M. M. Tahat, K. M. Alananbeh, Y. A. Othman, and D. I. Leskovar, "Soil health and sustainable agriculture," *Sustainability*, vol. 12, no. 12, p. 4859.2020.
- [26] D. L. Corwin and K. Yemoto, "Salinity: Electrical conductivity and total dissolved solids," *Soil Science Society of America Journal*, vol. 84, no. 5, pp. 1442-1461.2020.
- [27] D. L. Corwin and E. Scudiero, "Field-scale apparent soil electrical conductivity," *Soil Science Society of America Journal*, vol. 84, no. 5, pp. 1405-1441.2020.
- [28] J. Kjeldahl, "Neue methode zur bestimmung des stickstoffs in organischen körpern," *Zeitschrift für analytische Chemie*, vol. 22, no. 1, pp. 366-382.1883.
- [29] A. Walkley and I. A. Black, "An examination of the Degtjareff method for determining soil organic matter, and a proposed modification of the chromic acid titration method," *Soil Science*, vol. 37, no. 1, pp. 29-38.1934.
- [30] G. W. Gee and D. Or, "2.4 Particle-size analysis," *Methods of soil analysis: Part 4 physical methods*, vol. 5, pp. 255-293.2002.
- [31] G. Achilleos, "The Inverse Distance Weighted interpolation method and error propagation mechanism—creating a DEM from an analogue topographical map," *Journal of Spatial Science*, vol. 56, no. 2, pp. 283-304.2011.
- [32] H. Moussa and M. Abboud, "The Methodology of Applying Inverse Distance Weighting Interpolation Method in Determining Normal Heights," *Resourceedings*, vol. 4, no. 1, pp. 01-06.2024.
- [33] X. Yao, B. Fu, Y. Lü, F. Sun, S. Wang, and M. Liu, "Comparison of four spatial interpolation methods for estimating soil moisture in a complex terrain catchment," *PloS one*, vol. 8, no. 1, p. e54660.2013.
- [34] A. C. Cameron and F. A. Windmeijer, "An R-squared measure of goodness of fit for some common nonlinear regression models," *Journal of Econometrics*, vol. 77, no. 2, pp. 329-342.1997.
- [35] Y. Ding, Y. Wang, and Q. Miao, "Research on the spatial interpolation methods of soil moisture based on GIS," in *International Conference on Information Science and Technology*, 2011, pp. 709-711: IEEE.
- [36] J. F. Veyan, E. de Obaldia, J. J. Alcantar-Peña, J. Montes-Gutierrez, M. J. Arellano-Jimenez, M. J. Yacaman, and O. Auciello, "Argon atoms insertion in diamond: New insights in the identification of carbon C 1s peak in X-ray photoelectron spectroscopy analysis," *Carbon*, vol. 134, pp. 29-36.2018.
- [37] I. C. Fitzpatrick, N. Millner, and F. Ginn, "Governing the soil: natural farming and bionationalism in India," *Agriculture and Human Values*, vol. 39, no. 4, pp. 1391-1406.2022.
- [38] J. Yu, Y. Li, G. Han, D. Zhou, Y. Fu, B. Guan, G. Wang, K. Ning, H. Wu, and J. Wang, "The spatial distribution characteristics of soil salinity in coastal zone of the Yellow River Delta," *Environmental Earth Sciences*, vol. 72, pp. 589-599.2014.
- [39] L. Sharma, S. Bali, A. Zaeen, P. Baldwin, and D. Franzen, "Use of rainfall data to improve ground-based active optical sensors yield estimates," *Agronomy Journal*, vol. 110, no. 4, pp. 1561-1571.2018.

- [40] W. Li, Z. Yang, J. Jiang, and G. Sun, "Spatial Variation and Stock Estimation of Soil Organic Carbon in Cropland in the Black Soil Region of Northeast China," *Agronomy*, vol. 14, no. 11, p. 2744.2024.
- [41] A. K. Saha, J. T. McMaine, T. Trooien, P. Sexton, and C. Graham, "Impact of no-till, crop rotation, cover crop, and drainage on soil physical and hydraulic properties," *Soil Science Society of America Journal*, vol. 88, no. 2, pp. 239-257.2024.
- [42] J. Frankenberger, S. K. McMillan, M. Williams, K. Mazer, J. Ross, and B. Sohngen, "Drainage water management: A review of nutrient load reductions and cost effectiveness," *Journal of the ASABE*, p. 0.2023.
- [43] M. Sadiq, N. Rahim, M. M. Tahir, A. Alasmari, M. M. Alqahtani, A. Albogami, K. Z. Ghanem, M. A. Abdein, M. Ali, and N. Mehmood, "Conservation tillage: a way to improve yield and soil properties and decrease global warming potential in spring wheat agroecosystems," *Frontiers in Microbiology*, vol. 15, p. 1356426.2024.
- [44] J. Rane, A. K. Singh, M. Kumar, K. M. Boraiah, K. K. Meena, A. Pradhan, and P. V. Prasad, "The adaptation and tolerance of major cereals and legumes to important abiotic stresses," *International Journal of Molecular Sciences*, vol. 22, no. 23, p. 12970.2021.