International Journal of Environmental Impacts
https://www.acadlore.com/journals/IJEI

Spatial Distribution of Some Soil Characteristics in the Fallujah and Karma Regions and Evaluation of Their Suitability for Agricultural Production

Saara Hameed Mohammed*, Ahmed Flayyih Fayyadh, Muthanna. K. Al-Rawi

College of Education for Humanities, University of Anbar, 31001 Ramadi, Iraq

* Correspondence: Saara Hameed Mohammed (ed.Sal22h5010@uoanbar.edu.iq)

Received: 09-22-2025 **Revised:** 12-19-2025 **Accepted:** 12-31-2025

Citation: S. H. Mohammed, A. F. Fayyadh, and M. K. Al-Rawi, "Spatial distribution of some soil characteristics in the Fallujah and Karma regions and evaluation of their suitability for agricultural production," *Int. J. Environ. Impacts.*, vol. 9, no. 2, pp. 516–529, 2026. https://doi.org/10.56578/ijei090216.

Abstract: To determine the suitability of the soils of the Fallujah and Karma regions for agricultural purposes, a field study was conducted. Soil samples were taken to a depth of 30 cm from a number of pedunclear soils in the study area. They were characterized morphologically, physically, and chemically, and were then classified accordingly. Based on the 2015 Food and Agriculture Organization (FAO) classification system, spatial distribution maps of selected soil characteristics were generated using ArcGIS 10. The analysis relied on the SYS 1980 coordinate system to determine and visualize the spatial extent of soil suitability across the study area. The results showed that the soils of the study area are distributed between the group of advanced desert soils and desert sedimentary soils. The soil textures of the study area are distributed between medium to coarse textures within the alluvial, sandy, and sandy loam types. The study also showed that the salinity in the area is distributed into four class, and is divided into three class in the distribution of gypsum and lime ratios. The suitability results for the soils of the study area showed the presence of four types: (N) and (N1), which are unsuitable, type (S4) which is slightly suitable, and (S3) which is moderately suitable. The main determinants in the study area are soil salinity and the proportions of gypsum and lime.

Keywords: Geographical distribution; Soil classification; Soil suitability; Soil texture; Soil salinity

1 Introduction

Soil is an important economic resource and an inexhaustible resource for all human activities throughout life. Agriculture is one of these activities, without which agriculture cannot thrive and fulfill its role properly to ensure high productivity [1]. Most soil studies have focused on the geographical distribution of soils and their spatial heterogeneity. Spatial variation of characteristics on the ground, as successful management of land suitability is based on optimal selection and appropriate strategy [2] and because this resource has its spatial distribution and is affected by its characteristics and properties, therefore it will be reflected in its performance according to suitability for different purposes, including agricultural purposes. Therefore, this suitability must be studied by identifying the important characteristics and properties of it and identifying the problems and obstacles it suffers from [3]. The suitability assessment is one of the objectives of land classification and its causes. Its objectives are to obtain the highest production while protecting the soil from degradation, and to determine the type of land use after determining its productive capacity for different uses by knowing the effect of climate factors and soil characteristics on the basis of which crops can be divided into soils. The causes of these problems are largely related to the improper use and exploitation of soil resources, which results in soil degradation and a reduction in its productive capacity. Consequently, soil evaluation is used to determine the efficiency, capability, and suitability of soils for different land uses, especially for agricultural and livestock production, through the application of various evaluation methods and classification systems [4]. The evaluation process is an important and sensitive function that expresses the requirements of crops and the characteristics of the soil and land [5]. The process of agricultural suitability requires many factors, the most important of which are climatic factors, in addition to the physical and chemical properties of the soil and fertility [6], While the role of humans is considered an influential and effective factor in the interconnected ecosystem that represents the relationship between (climate, soil, and plants) [7], and understanding the nature of preserving this relationship helps us preserve lands and meet future needs in a sustainable manner to improve production capacity at the lowest costs [8]. Also because agricultural activity is one of the largest and most extensive human activities, as it occupies large areas of arable land [9] the need has emerged at the present time to study and analyze the suitability of soils for agriculture and to state the problems and obstacles and the necessity of setting limits for them in order to meet current needs and preserve lands for future generations within the concept of sustainable development due to the increasing population growth [10]. Suitability is considered one of the main planning processes for the real and optimal use of land to achieve spatial stability [11]. For this purpose, this research was conducted to achieve the objectives, including describing and classifying the soils of the Fallujah and Karma regions, adopting the 2015 FAO global reference system, studying the spatial distribution of characteristics using geographic information systems, and evaluating the suitability of the region's soils for agricultural purposes, adopting the SYS 1980 system.

2 Materials and Methods

2.1 Study Area

The study area is located astronomically between latitudes 33.12° N and 33.44° N and longitudes 43.40° E and 44.00° E Spatially, it is located in western Iraq, surrounded to the north by Salah al-Din Governorate, to the northwest and west by Tharthar Lake, the Euphrates River, and Ramadi District, to the south by Al-Amiriya District, and to the east and southeast by Baghdad Governorate, as shown in Figure 1.

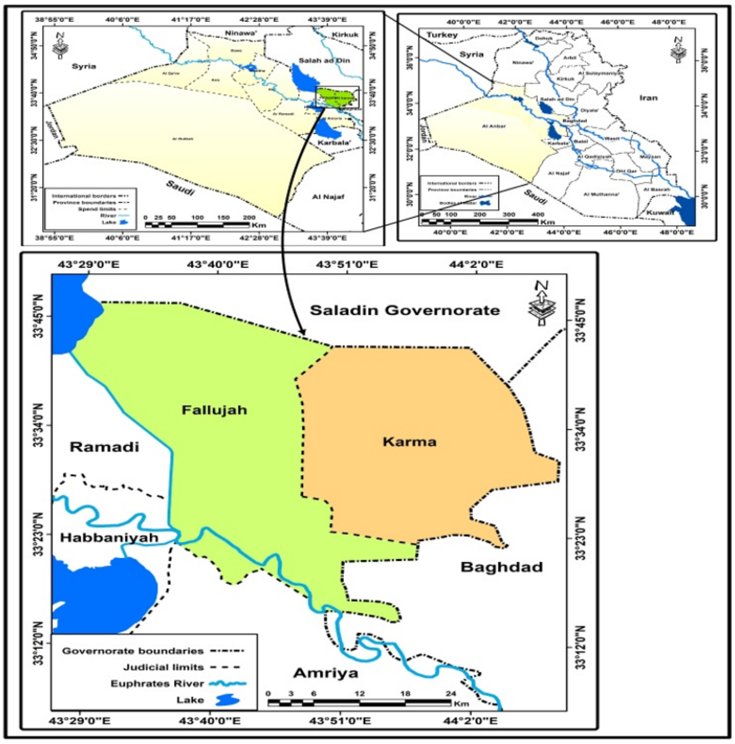

Figure 1. Study area location

2.2 Field Work

A Field Survey was conducted using the free method to investigate the impact of soil formation factors and processes and their repercussion on the formation and origin of the soils in the study area.

Several soil boreholes were drilled using augers at different locations within the boundaries of each district in the study area.

Three major soil subgroups were identified in the area, and one pedon was. Selected to represent each subgroup the Flu alluvium soil, desert alluvium soil and the developed gypsum subgroups, as shown in Figure 1.

Depending on the nature and type of agriculture exploitation, soil samples were taken from the surface horizon to a depth of 0–30 cm. Considered the effective depth of the root zone for most important agricultural crops.

The soil samples transported to the Laboratory were air-dried. Then ground and prepared for laboratory analysis.

2.3 Laboratory Work

Physical measurements. Particle size distribution of the soil samples was conducted using the suction method by pipet as described by Mohammed et al. [12].

2.4 Soil Formation Factors and Processes

The most important and effective soil formation factors in the study area are the parent material and topography. The parent material's influence is evident in the soil properties, as well as the influence of topography in terms of slope and its role in differential and anthropogenic sedimentation processes. The most important prevalent processes are gypsihcation (gypsum formation) and salinization processes. In addition to the calcination process, climatic conditions are a basic factor that determines the nature of the land's production process and its suitability for agriculture [13]. The effect of climatic conditions is determined by the direct effect on soil temperature and moisture, as soils are affected by the factors of rain and temperature, as climate is considered a major influence. On the productivity of the main food crops [14]. The climate of the region is characterized by the climate of Iraq in general, as the nature of the climate in the region is characterized by extremism and great variation in temperatures, as it rises greatly in the summer at a monthly average of 45 °C in the month of July and decreases during the winter to reach 15 °C in the month of December. Due to the extremism in temperatures between the summer and winter months, which reaches more than 22 °C, so the soil temperature is characterized within the Hyperthermic class, and dry moisture within the Aridic (Toric) class according to the United States Department of Agriculture (USDA) soil temperature and moisture classifications, and the region's rainfall is characterized by being little and falling in the winter, with an annual average value ranging between (148.1–87 mm).

3 Results and Discussion

3.1 Soil Classification of the Study Area

3.1.1 Calcareous Fluvisols

The soils in this group are symbolized by (3a/2-JC30), where the symbol JC refers to the symbol of the main soil unit in the symbol, meaning Calcareous Fluvisols [15]. These are sedimentary soils containing calcareous materials between 20–50 cm from the soil surface. The parent material for these soils is derived from river sediments. The number (30) represents the soil units associated with it and within the soil map unit, while the number (2) represents the medium texture class and number (3) represents the soft texture class, while the letter (a) represents the simple slope class flat to slightly wavy with a slope degree of 0.8%. This group is characterized by stratification patterns that reflect the history of irregular sedimentation processes.

This group corresponds to the newly formed Entisols soils in the modern American soil classification system and under the group Typic Torri fiavent. The soils of this group are distributed in the Saqlawiyah region (P10) and in the districts of (Al-Nasaf, Al-Bushjil, Al-Naimiyah and Al-Dafar) within the districts of (Al-Tawil, La'id, Al-Hitawin, Jamila, Al-Za'ana, Al-Shabni and Al-Musallamah) and are represented by the soil sections (P1, P2, P3, P4, P5). These soils are distributed on both sides of the Euphrates River basin and form an area estimated at 189 km^2 [16], as shown in Table 1.

Table 1. Classification of exposed soils in the study area

Map Unit Symbol	Description	%	Area (km^2)
JC38/2-3a	Calcareous alluvial soils	8.8	189
JC40/2-3a	Desert sedimentary soils	12.7	274
Yy10-2ab	Developed desert sedimentary soil group	35.9	774
Yy12 & 13-a	Developed gypsum soils	42.6	913
	Total	100.0	3634

Source: Laboratory analysis results of breeding samples.

3.1.2 The group of desert sedimentary soils (Eutric Fluvisol)

The soils in this group are symbolized by (2/3a-Jc40). In the soil map unit, this symbol refers to the course, gravelly desert sedimentary soils, called Eutric Fluvisols. The number (40) indicates that the soil contains 40% rocky soils, while the number (2) represents the coarse texture, represented by sandy and sandy mixed textures. Number (3) refers to the medium texture such as sandy mixture, silty mixture, and clay mixture, and the letter (a) represents the degree of slope that is classified within the level (flat). The soils of this group are characterized by being undeveloped soils: they were formed by the action of ancient river sediments followed by a gravelly gypsum layer [17]. These soils are distributed within the districts of Al-Kaifa and towards the district of Al-Karma and up to the Al-Haswa area, and they are represented by the pedons (P6, P7, P8). This group forms an area estimated at an area estimated at 274 km^2, representing 12.7%, is represented by Figure 2. Table 2 shows a typical section of Bidun in the Al-Kaifa Distrac.

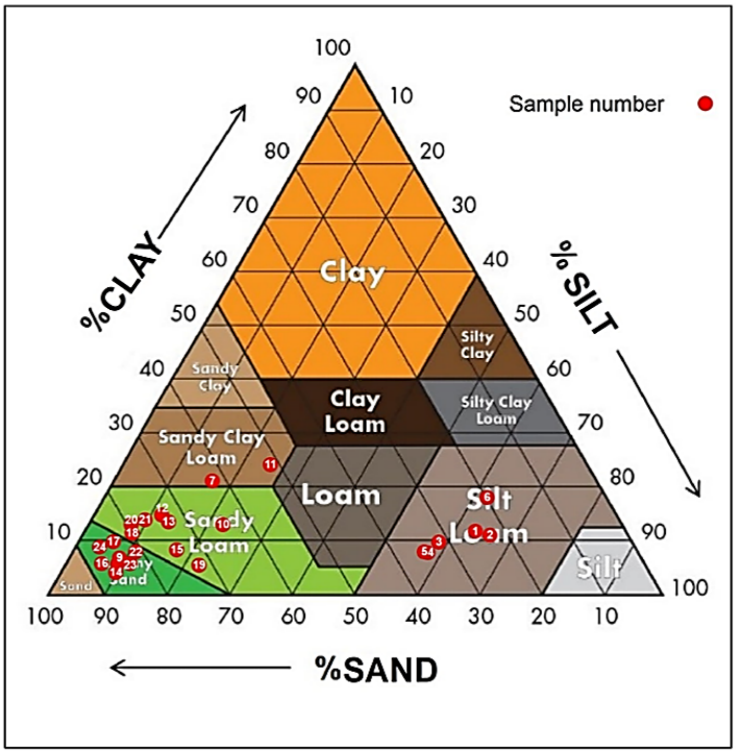

Figure 2. Soil texture triangle for samples of the study area

Table 2. Characteristics of desert sedimentary soils from the Al-Kaifa region

SAR	ESP (‰)	Texture Type	Volume Distribution of the Separated (g/kg)			Exchangeable Capacitance (centimoles/charge)	Organic Matter (g/kg)	Lime (g/kg)	Gypsum (g/kg)	Degree of Soil Interaction	Soil Salinity (dS/m)	Depth (cm)	Horizons
			Clay	Silt	Sand								
5.12	5.92	LS	75	368	557	10.10	4.40	210.0	14.0	7.98	15.20	0–20	Ap
4.01	4.45	L	75	489	436	11.00	1.29	230.0	12.0	8.01	7.80	20–40	Cy1
7.31	8.70	SL	99	284	617	12.60	0.09	250.0	12.0	7.76	34.80	40–50	Cy2
6.18	7.28	Sil	74	782	144	11.20	0.02	250.0	8.0	7.74	24.80	50–70	Cy3
5.66	6.59	L	80.8	480.8	438.5	11.23	1.45	275.0	11.5	7.87	20.63	Average	X-

Note: SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage. Source: Laboratory analysis results of breeding samples.

3.1.3 The advanced desert gypsum soil group (Gypsic Yermosols)

The soils in this group are symbolized by (Yy10-2ab), (Yy12-a), and (Yy13-a), and are represented by the pedons (P10, P11, P12). This group is represented by dry desert gypsic soils containing a gypsum horizon, corresponding to the American classification system for dry desert gypsies, typic gypsums. These soils extend from the city of Fallujah towards Al-Karma Island in the east and up to Al-Khalidiya Island in the west. These soils extend over flat to slightly undulating areas and their surface is covered with fine gravel that was formed after the withdrawal of the waters that covered the surface of Iraq and represents the remains of fossils [18]. These soils were affected by the floods of the Euphrates River in ancient times, and these soils are topped by a gypsum layer that sometimes reaches a thickness of more than a meter, and it is accompanied by other soils at a rate of up to 20,000. Table 3 shows a typical section of a pedun soil on the Al-Boushjel District [19].

Table 3. Characteristics of the alluvial calcareous soil of Al-Boushjel District

SAR	ESP (‰)	Texture Type	Volume Distribution of the Separated (g/kg)			Exchangeable Capacitance (centimoles/charge)	Organic Matter (g/kg)	Lime (g/kg)	Gypsum (g/kg)	Degree of Soil Interaction	Soil Salinity (dS/m)	Depth (cm)	Horizons
			Clay	Silt	Sand								
3.56	3.84	L	135.0	370	495	14.20	2.43	200.0	50.00	7.69	10.20	0–30	Apy
3.20	3.35	Sil	110.0	620	270	13.40	2.32	205.0	67.00	7.70	7.40	30–55	Cy1
4.39	4.95	Sil	95.0	660	245	12.20	0.00	210.0	38.00	7.71	12.20	55–100	C2
4.90	5.63	Sil	95.0	760	145	12.50	0.00	225.0	50.00	7.72	13.40	100–160	Cyk
4.01	4.44	Sil	108.8	602.5	288.8	13.08	1.19	210.0	51.3	7.71	10.80	Average	X-

Note: SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage. Source: Laboratory analysis results of breeding samples.

3.2 Physical Properties

3.2.1 Soil texture class

Based on the proportions of the three classes of sand, silt, and clay shown in Table 4, this study found that the soil texture class was mapped onto the American soil texture triangle to extract the soil texture class. This class is important in soil management processes such as tillage, weeding, fertilization, and irrigation. The texture class indicates the softness and roughness of the soil. In addition to its importance in soil classification processes, the texture type is considered one of the fixed characteristics upon which classification is based and its relationship to engineering characteristics such as expansion and contraction. Table 4 shows the physical and chemical characteristics of the soils in the study area at a depth of 0–30 cm [20]. The names and types of soil texture in the study area are shown in Table 5. Figure 2 shows its location on the soil texture triangle the soils of the study area were divided into two groups: medium textured soils, most of which represent river basin areas, in addition to being affected by slow sedimentation processes: long time dimension, and coarse textured soils, which are often close to sedimentation sources and are affected by rapid differential sedimentation processes of short time dimension. Table 6 represents the distribution of texture types and their percentages, and Figure 3 shows the nature of that distribution [21].

Table 4. The characteristics of the soils in the study area at a depth of (0–30) cm

Average Adjective Suburb	pH Degree of Reaction	ECe Desmans Soil Salinity	$CaCO_3$ Calcium Carbonate	$CaSO_4$ Gypsum Calcium Sulphate	Organic Matters (%)	Sand (%)	Silt (%)	Clay (%)	ESP (%)	SAR (%)
Nassaf	7.50	32.46	30.32	3.53	1.03	26.60	60.22	13.17	8.03	6.89
Boshijel	7.73	23.27	24.38	10.31	0.09	25.84	62.02	12.13	6.96	6.07
Naaimeah	7.19	14.28	24.28	0.72	0.03	32.05	55.86	11.08	4.82	4.41
Daffar	8.20	9.50	20.00	3.90	0.03	34.36	53.18	12.46	4.24	3.98
Kefeah	7.39	31.57	22.75	14.00	0.14	34.89	52.77	12.33	7.95	6.78
Saqlawiah	8.10	15.00	23.60	9.30	0.20	19.00	63.00	18.00	7.40	6.30
Aeb Jafal 1	7.60	7.30	26.00	1.00	1.20	60.80	17.79	21.41	4.90	5.30
Aeb Jafal 2	7.30	3.80	24.30	8.00	0.90	84.80	11.70	3.60	4.80	4.30
Nezezah	7.60	10.50	29.30	15.00	9.00	86.10	9.70	4.20	5.60	6.90
Matrood and Sammad	7.90	6.90	26.20	4.00	1.20	60.30	21.90	15.80	13.90	8.20
Aysawiah	7.60	8.80	27.00	12.00	1.10	52.20	25.50	24.30	13.20	8.90
Hamrah	8.20	7.00	32.80	6.00	1.20	70.60	14.23	14.87	18.30	12.20
Kshash	7.90	10.00	29.60	7.00	1.20	69.80	14.53	15.67	14.80	12.60
Thapeteah	7.20	2.50	23.80	5.00	1.20	88.27	5.73	6.00	17.30	13.30
Sheha and Bofahed	7.30	3.10	26.30	2.00	1.10	63.70	24.30	12.00	12.90	8.60
Bezaiez Aysawiah	7.50	6.50	24.60	1.50	1.10	82.10	12.00	5.90	19.70	12.30
Bezaez Bnat Hasan	8.10	16.00	30.90	6.00	1.20	84.24	11.03	4.73	19.30	11.89
Mohsen East	7.20	2.00	23.50	3.00	1.20	70.40	26.40	3.20	18.60	12.40
Mohsen West	7.50	3.30	26.20	13.00	1.20	77.20	18.00	4.80	13.40	10.60
Gusawi	7.40	5.80	26.80	4.00	1.00	69.20	14.00	16.80	15.80	12.70
Majaha and Um kafer	7.30	7.30	25.90	11.00	1.10	58.80	24.40	16.80	5.70	4.30
Lahyab	7.20	6.80	24.70	14.00	1.10	81.00	14.00	5.00	16.80	14.30
Jazera 1	7.60	5.70	27.60	13.00	1.10	85.80	10.50	3.70	4.60	3.80
Jazera 2	7.70	5.20	28.80	10.00	0.90	84.24	11.03	4.73	4.90	3.60

Note: SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage.

Table 5. The name of the texture, its symbol and its classification within the study area

Suburb	Symbol	Soil Texture
Nassaf	SIL	Silty loame
Boshijel	SIL	SIL
Naaimeah	SIL	SIL
Daffar	SIL	SIL
Kefeah	SIL	SIL
Saqlawiah	SIL	SIL
Aeb Jafal 1	SCL	Sand clay laom
Aeb Jafal 2	LS	Loamy Sand
Nezezah	LS	LS
Matrood and Sammad	SL	Sandy loam
Aysawiah	SCL	Sandy Clay Loam
Hamrah	SL	Sandy Loam
Kshash	SL	SL
Thapeteah	LS	Loam Sandy
Sheha and Bofahed	SL	Sandy Loam
Bezaiez Aysawiah	LS	Loam Sandy
Bezaez Bnat Hasan	LS	LS
Mohsen East	SL	Sandy Loam
Mohsen west	SL	SL
Gusawi	SL	SL
Majaha and Um kafer	SL	SL
Lahyab	LS	Loam Sandy
Jazera 1	LS	LS
Jazera 2	LS	LS

Source: Laboratory analysis results of breeding samples.

Table 6. Characteristics of the developed desert gypsum soils on the Karma Island

SAR	ESP (%)	Texture Type	Volume Distribution of the Separated (g/kg)			Exchangeable Capacitance (centimoles/charge)	Organic Matter (g/kg)	Lime (g/kg)	Gypsum (g/kg)	Degree of Soil Interaction	Soil Salinity (dS/m)	Depth (cm)	Horizons
			Clay	Silt	Sand								
4.90	5.30	LS	48	180	772	16.20	4.70	61	153	7.20	2.70	0–22	Ap
3.45	3.85	LS	4	132	864	11.40	2	228.75	273	7.20	2.70	22–38	By
2.49	3.71	S	1.20	114	884	12.40	0.60	1988.25	300	7.23	2.60	38–115	Cy
3.61	4.28	S	17.70	142.30	840	13.33	2.43	162.66	242	7.26	2.66	Average	X-

Note: SAR, sodium adsorption ratio; ESP, exchangeable sodium percentage. Source: Laboratory analysis results of breeding samples.

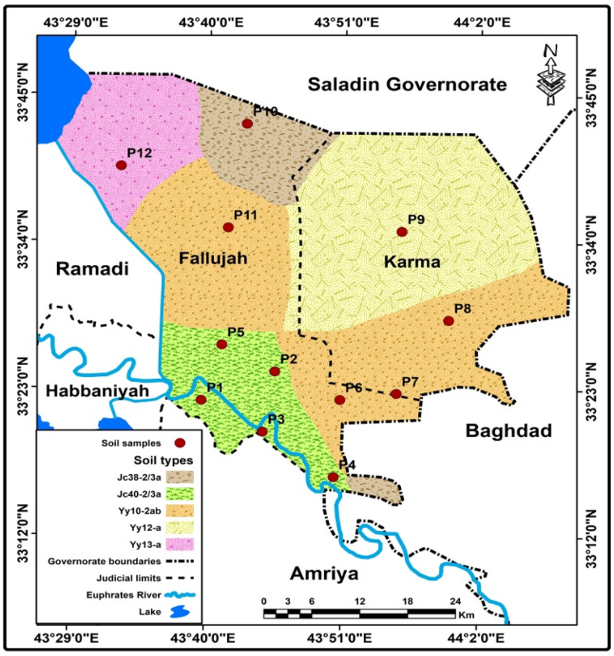

Figure 3. The geographical distribution of soil types and locations in the study area

Source: Landsat 8 satellite imagery with a spatial resolution of 30 × 30 meters, analyzed using ArcGIS 10 software for land use and land cover classification.

3.3 Soil Properties

Based on a field study of the region, it was possible to analyze the characteristics and properties of the soils in the region. The following describes and distributes these characteristics.

3.3.1 Soil salinity

Soil salinity represents an important factor contributing to soil degradation, as it negatively affects the soil's biological functions [22]. In addition, it reduces the soil's productive capacity because elevated salinity levels increase the electrical conductivity of the soil.

Soil salinity is one of the important chemical properties in the soil and is usually expressed by the amount of electrical conductivity and is measured in deciSiemens/m. The soil is classified as saline based on the American Salinity Classification (SOLAR) as the soils of the study area varied in the value of electrical conductivity by more than (4 deciSiemens/m) [23]. Based on that, the soils of the study area's districts were classified as shown in Table 7, and the Figure 4 shows the nature of the spatial distribution of this characteristic.

Table 7. Classification of soil salinity in the study area

Soil Salinity	Symbol	Electrical Conductivity (deciSiemens)	Districts Name	Area (km^2)	% from Area
Low salinity	S0–S1	0–4	Abb Jafal, Al-Dabatiyya, Al-Shiha and Al-Bufahd, Muhaisin Al-Gharbi, Muhaisin Al-Sharqi	154	7.14
Moderate	S2	4–8	Abb Jafal, Al-Matroud and Al-Masmad Al-Hamra, Bazaiz Al-Issawiya, Al-Qaysawi, Majah and Umm Kabir, Al-Lahib, Al-Jazeera District,	714	33.11
High salinity,	S3	8–16	Al-Naimiyah, Al-Dafar, Al-Saqlawiyah, Al-Jazeera, Al-Issawiyah, Al-Kashash, Bzayez Banat Al-Hassan	916	42.48
Very high salinity	S4	More than 16	Nassaf, bushijel	372	17.25

Source: Laboratory analysis results of breeding samples.

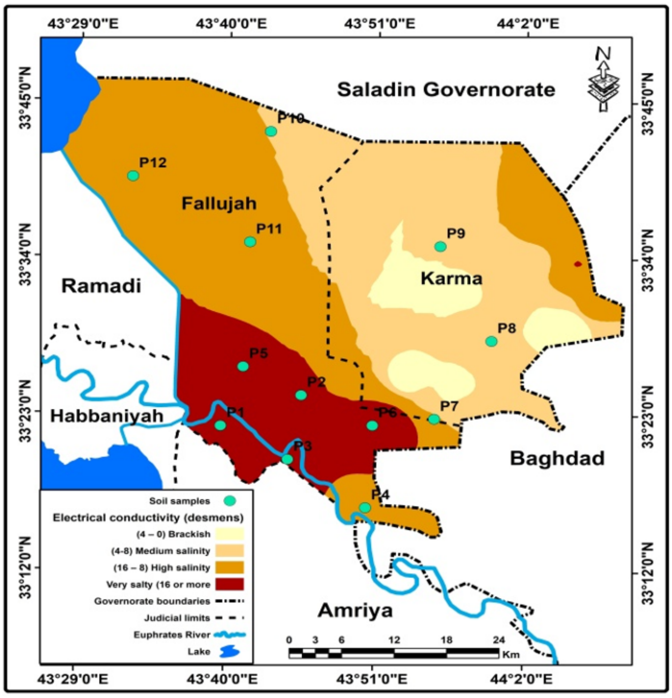

Figure 4. Soil salinity of the soils in the study area

Source: Landsat 8 satellite imagery with a spatial resolution of 30 × 30 meters, analyzed using ArcGIS 10 software for land use and land cover classification.

Table 7 shows that the study area to cited with in(S0–S1) Class are Agriculturally exploited have low salinity, do not affect most plant, and often represent alluvial soils located within the river basin and river levee.

In region with moderate salinity, most vegetable crops are affected, as well as some groin crops, this effect is evident in the reduction of land Productivity by at least 30%.

The districts falling within salinity S3–S4 class characterized by low Productivity of vegetable crops and most grain crops and only some salt- tolerant tree shrubs grow there.

The high salinity is attributed to blocked drains and rising ground water level, which leads to salt acumination on the surface.

3.3.2 Calcium carbonate ($CaCO_3$)

Calcium carbonate is a common salt found in most soils in arid and semi-arid regions. The source of carbonate in soil is the limestone parent material from which the soil originated, which was transported by river water, as well as by wind. Calcium carbonate affects soil properties, contributing to the filling of porosity between soil particles. In addition to its work on collecting soil materials, it also contributes to reducing the cation exchange capacity in the soil, and it also helps to raise the pH values in the soil and thus reduces the availability of trace elements in the soil and also contributes to the retention and precipitation of some other elements [24]. Its percentage in Iraqi soils generally ranges between (15%–35%). The soils of the study area are characterized by being very calcareous because the percentage of carbonates is more than (15%). Calcium carbonates are distributed in the districts of the study area, with a range of (20%–32.8%), as in Table 8 and Figure 5, it shows the nature of the geographical distribution of the calcium carbonate category in the study area.

Table 8. Classification of soils in the study area according to the percentage of calcium carbonate

Class	Calcium Carbonate (%)	Category	District Name Area (km^2)	Area (km^2)	% of Area
First	17–23	Lightly calcareous	Nassaf, Daffar, Kefeah	85	3.90
Second	23–24	Moderately calcareous	Abb Al-Bushjal, Al-Naimiyah, Al-Saqlawiyah, Aab Jafal 1, Aab Jafal 2, Al-Jazeera, Al-Eisawiyah, Buzayez Al-Eisawiyah, Muhaisin Al-Sharqi, Muhaisin Al-Gharbi, Al-Dabatiyyah, Al-Shiha and Al-Bu Fahad, Buzayez, Al-Jazeera, Al-Qaysawi, Al-Laheeb	1913	88.70
Third	29–35	Highly calcareous	Jazzera, Hamra, Nasaf, Buzayez, Banat-Alhassan	158	7.30

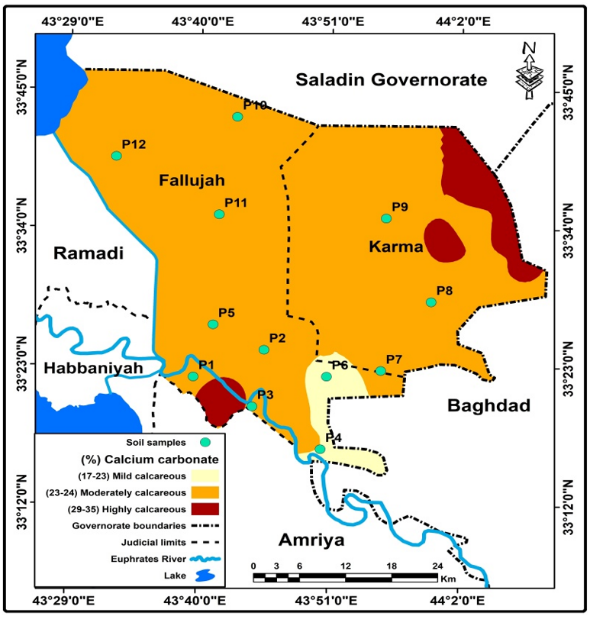

Figure 5. Calcium carbonate percentage of soils in the study area

Source: Landsat 8 satellite imagery with a spatial resolution of 30 × 30 meters, analyzed using ArcGIS 10 software for land use and land cover classification.

3.3.3 Calcium sulfate (gypsum) $CaSO_4$, H_2O

These sulfate salts are among the salts that are widespread in the soils of arid and semi-arid regions, including the districts of the study area. Gypsum is either primary, resulting from the origin of gypsum, or secondary, which is deposited from irrigation water and groundwater [25]. The percentage of gypsum in the study area varies depending on the physiographic location [26]. Gypsum is distributed in the study area according to the following class, as shown in Table 9, and Figure 6 shows the distribution of gypsum in the study area.

Table 9. Calcium sulfate ratios in the soils of the study area

Class	Calcium Sulfate (%)	Classification	Districr Name	Area (km^2)	% from Area
First	0–5	Non-gypsum	Al-Naimiyah, Al-Dafar, Al-Matrood and Al-Samad, Al-Dabtiyah, Al-Shiha Al-Bufahd, Buzayez Al-Issawiyah, Muhaisin Al-Gharbi, Al-Kasawi, Al-Nassaf	226	10.48
Second	5–10	Medium gypsum	Al-Saqlawiyah, Abb Jafal, Al-Hamra, Al-Hamra, Al-Kashash, Buzayez Banat Al-Hassan, Al-Jazeera 2	1446	67.60
Third	10–15	High gypsum	Bushjal, Kefeah, Abb Jafal, Al-Jazeera, Muhaisin Al-Sharqi, Majah Umm Kabir, Al-hube	483	22.40

Source: Results of analysis of chemical properties of soil.

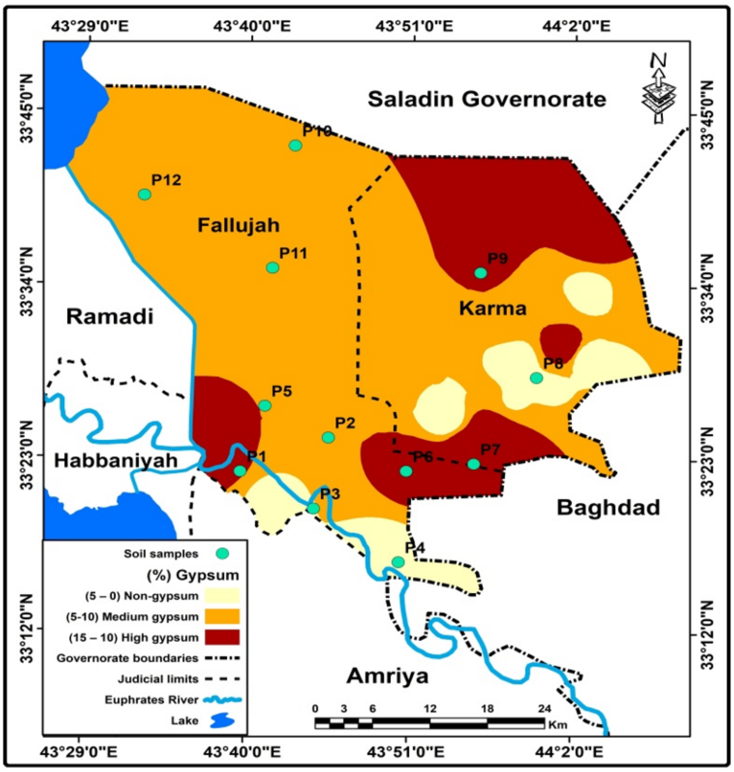

Figure 6. Distribution of gypsum percentage in the soils of the study area

Source: Landsat 8 satellite imagery with a spatial resolution of 30 × 30 meters, analyzed using ArcGIS 10 software for land use and land cover classification.

3.4 Classification of Soil Suitability for Agricultural Production

Based on the characteristics and properties of the provinces' soils known in Table 10, and based on the 1980 SyS classification, and based on the following equation [27]:

Table 10. Classification of soil suitability for agricultural production

District Name	Traits and Their Values According to the Standard Tables (Sys 1980)									Index value		
	A	B	C	D	E	F (%)	G	H	I	Index Value	Symbol	Description
Al-Nasaf	95	0.90	1	0.20	1	0.90	1	1	1	15.39	N	Non suitable
Al-Bushail	95	1	0.70	0.20	1	0.95	1	1	1	12.63	N	Non suitable
Al-Naimiyah	95	1	1	0.80	1	0.50	1	1	1	38.00	S4	Low suitable
Al-Dafar	95	1	1	0.80	1	0.50	1	1	1	38.00	S4	Low suitable
Al-Kaifah	95	1	0.70	0.20	1	0.95	1	1	1	9.05	N	Non suitable
Al-Saqlawiyah	95	1	1	0.80	0.50	0.95	1	1	1	36.10	S4	Low suitable
Abb Jafal 1	75	0.90	0.70	0.80	0.50	0.50	1	1	0.95	8.97	N	Non suitable
Abb Jafal 2	55	0.90	1	0.95	1	0.50	1	1	0.95	24.81	N	Low suitable
Al-Jazeera	55	1	0.70	0.80	1	0.95	1	1	1	26.33	S4	Moderate suitable
Al-Matroud and Al-Samad	85	0.90	1	0.80	1	0.90	1	1	1	55.08	S3	Low suitable
Al-Eisawiyah	75	0.90	0.70	0.80	1	0.90	1	1	1	34.02	S4	Low suitable
Al-Hamra	85	0.90	1	0.80	1	0.60	1	1	1	36.72	S4	Moderate suitable
Al-Kashash	85	0.90	1	0.80	1	0.90	1	1	1	55.08	S3	Low suitable
Al-Dabtiyah	55	1	1	0.95	0.50	0.60	1	1	1	15.67	S4	Moderate suitable
Al-Shiha and Al-Bafahd	85	0.90	1	0.95	1	0.90	1	1	1	65.40	S3	Low suitable
Bzayez Al-Eisawiyah	55	1	1	0.80	0.50	0.60	1	1	1	13.20	N1	Moderate suitable
Bzayez Banat Al-Hassan	55	0.90	1	0.80	0.50	0.60	1	1	1	11.88	N	Low suitable
Muhaisin Al-Gharbi	85	1	1	0.95	1	0.60	1	1	1	48.45	S4	Moderate suitable
Muhaisin Al-Sharqi	85	0.90	0.90	0.95	1	0.90	1	1	1	45.78	S4	Low suitable
Al-Kasawi	85	0.90	1	0.80	1	0.90	1	1	1	55.08	S3	Moderate suitable
Haijiah and Umm Al-Kabir	85	0.90	0.70	0.80	1	0.95	1	1	1	40.96	S4	Non suitable
Al-Laheeb	55	1	0.70	0.80	0.50	0.60	1	1	1	9.24	N	Moderate suitable
Al-Jazeera District 1	55	0.90	0.70	0.80	0.50	0.50	1	1	1	6.58	N	Low suitable
Al-Jazeera District 2	55	0.90	0.70	0.80	0.50	0.50	1	1	1	6.58	N	Low suitable

Note: A = texture, B = carbonates, C = gypsum, D = salinity, E = drainage, F = exchangeable sodium percentage (ESP), G = depth, H = chlorides, I = withering. Source: Laboratory analysis results of breeding samples.

$$Cs = A * B * C * D * E * F * G * H * I \tag{1}$$

where,

Cs = capability suitable

A = texture index
B = lime index
C = gypsum index
D = salinity index
E = drainage index
F = ESP index
G = depth index
H = pedon development
I = withering index

The standard multiplication method was adopted for the above attributes after taking their weighted value according to the work method. It was possible to obtain the results known in Table 10.

Based on the SYS 1980 designations for the suitability classes as shown in Table 11. According to Figure 7, it was possible to divide the districts of the study area into the following classes [28].

Table 11. The types of suitability with their evidence

Class	Description	Symbols	Validity Index District	District Name	Area (km^2)	% from Area
First class	Very suitable	S1	90	–	–	–
Second class	Suitable	S2	90–75	–	–	–
Third class	Moderate suitable	S3	75–50	Matrud, Samad, KaShash Sheha.bufahad, kessawi	1346	62.43
Fourth class	Few suitable	S4	50–25	Al-Naimiyah, Al-Dafar, Al-Saqlawiyah, Al-Jazeera, Al-Issawiyah, Al-Hamra, Al-Dabtiyah, Mohsen Al-Gharbi, Mohsen Al-Sharqi, Hijama and Umm Al-Kabir	82	3.80
Fifth class	Lowly suitable	N	25	Al-Nasaf, Al-Bushjal, Al-Kaifah, Aab Jafal 1, Aab Jafal 2, Bazaiz Al-Issawiyah, Al-Lahib, Al-Jazeera District 1, Al-Jazeera District 2	727	33.7

Source: Laboratory analysis results of breeding samples.

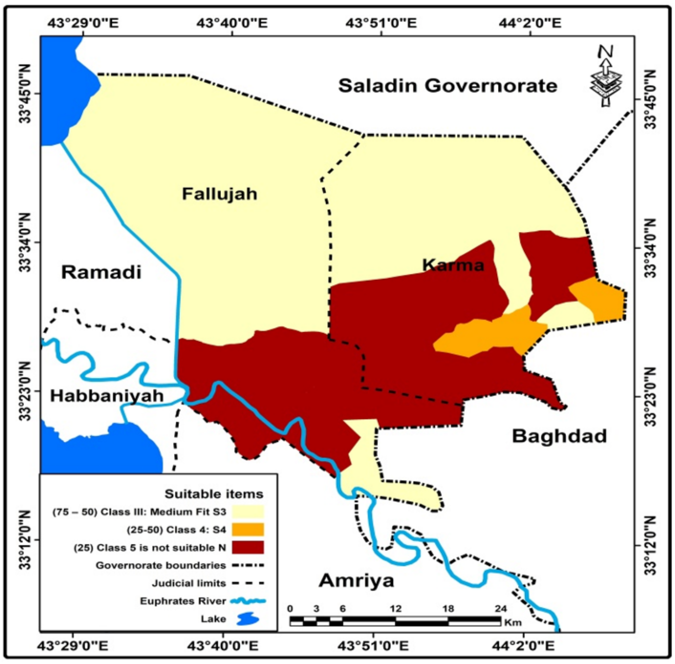

Figure 7. The types of soil suitability for agricultural production in the region’s soils

1. Class(S3): this class occupied 62.43% from study area and is considered moderately Suita for agricultural production, as the limitation are simple and can be improved to increase the lands productivity to second class.

2. Class(S4): this class occupied 3.80% from the study area and is considered few suitable for agricultural production as the limitation are moderate as salinity, high calcareous and gypsum content and low fertility.

3. Class (N): this class occupied 33.7% from the study area and is considered non suitable for agricultural production as the limitation are high as salinity Texture, high calcareous and gypsum content.

4 Conclusion and Recommendations

Natural processes, including climatic, topographical, and parent material factors, have significantly influenced the classification of the region's soils through the presence of gypsum and calcareous horizons. Geomorphological and pedogenic processes have also influenced the formation of sedimentary soils through the diversity of secondary geomorphological units, including river basins, river shoulders, river levees, point bars, and river crevasses.

The areas and types of soils varied according to their physical and chemical properties, and this is what was shown by their geographical distribution within the perspective of the land in the study area, and the equation (SYS 1980) succeeded in evaluating the suitability of the lands in the study area. After studying the results, it became clear that the study aims to identify the lands most suitable for agricultural production. After analyzing these results, it became clear that expanding the horizons of evaluation studies for land suitability by adopting evaluations and their preferences, and attention to aspects of soil management for the purpose of reducing its salinity by opening closed drains and attention to irrigation operations using modern methods such as sprinkler and drip irrigation. These recommendations are important as they provide a complete vision for decision makers to move towards integrated management of these lands and reach effective solutions that will develop and find solutions to the problems that the region's soils suffer from.

Author Contributions

Conceptualization, S.H.M. and A.F.F.; methodology, S.H.M.; software, S.H.M.; validation, S.H.M., A.F.F., and M.K.A.-R.; formal analysis, S.H.M.; investigation, S.H.M.; resources, A.F.F.; data curation, S.H.M.; writing—original draft preparation, S.H.M.; writing—review and editing, A.F.F. and M.K.A.-R.; visualization, S.H.M.; supervision, A.F.F.; project administration, A.F.F.; funding acquisition, A.F.F. All authors have read and agreed to the published version of the manuscript.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] K. Ezimand, A. A. Kakroodi, and M. Kiavarz, "The development of spectral indices for detecting built-up land areas and their relationship with land-surface temperature," *Int. J. Remote Sens.*, vol. 39, no. 23, pp. 8428–8449, 2018. https://doi.org/10.1080/01431161.2018.1488282

[2] K. S. Mohammed, S. A. Ouda, A. F. Al-Lahaibi, M. I. Mohammed, and O. H. Jasim, "Assessing the efficiency of injana clay for cadmium sorption: Implications for environmental sustainability," *Iraqi Geol. J.*, vol. 57, no. 2, pp. 13–25, 2024. https://doi.org/10.46717/igj.57.2F.2ms-2024-12-12

[3] T. V. Tran, D. Bruce, C. Y. Huang, D. X. Tran, S. W. Myint, and D. B. Nguyen, "Decadal assessment of agricultural drought in the context of land use land cover change using MODIS multivariate spectral index time-series data," *GIScience Remote Sens.*, vol. 60, no. 1, p. 2163070, 2023. https://doi.org/10.1080/15481603.2022.2163070

[4] S. Jin, L. Yang, P. Danielson, C. Homer, J. Fry, and G. Xian, "A comprehensive change detection method for updating the National Land Cover Database to circa 2011," *Remote Sens. Environ.*, vol. 132, pp. 159–175, 2013. https://doi.org/10.1016/j.rse.2013.01.012

[5] H. M. F. Shalal, K. S. Mohammed, M. H. Al-Kubaisi, I. Yusoff, M. T. Anees, and A. F. B. Abu Bakar, "Analysis and assessment of surface water quality in Al-Habbaniyah, Iraq," *J. Univ. Anbar Pure Sci.*, vol. 20, no. 1, pp. 345–357, 2026. https://doi.org/10.37652/juaps.2025.162815.1529

[6] E. F. Lambin and D. Ehrlich, "Land-cover changes in sub-Saharan Africa (1982–1991): Application of a change index based on remotely sensed surface temperature and vegetation indices at a continental scale," *Remote Sens. Environ.*, vol. 61, no. 2, pp. 181–200, 1997. https://doi.org/10.1016/S0034-4257(97)00001-1

[7] C. M. Viana, S. Oliveira, S. C. Oliveira, and J. Rocha, "Land use/land cover change detection and urban sprawl analysis," in *Spatial Modeling in GIS and R for Earth and Environmental Sciences*. Elsevier, 2019, pp. 621–651. https://doi.org/10.1016/B978-0-12-815226-3.00029-6

[8] K. S. Mohammed, N. Samat, and H. N. Khalid, "Using remote sensing and GIS for observation land use land cover changes and quantifying arable land loss in Penang Island—A case study of Balik Pulau," in *32nd Asian Conference on Remote Sensing*, Taipei, Taiwan, 2011, pp. 1697–1715.

[9] D. Lu, P. Mausel, E. Brondizio, and E. Moran, "Change detection techniques," *Int. J. Remote Sens.*, vol. 25, no. 12, pp. 2365–2401, 2004. https://doi.org/10.1080/0143116031000139863

[10] A. Madasa, I. R. Orimoloye, and O. O. Ololade, "Application of geospatial indices for mapping land cover/use change detection in a mining area," *J. Afr. Earth Sci.*, vol. 175, p. 104108, 2021. https://doi.org/10.1016/j.jafrearsci.2021.104108

[11] C. Polykretis, M. G. Grillakis, and D. D. Alexakis, "Exploring the impact of various spectral indices on land cover change detection using change vector analysis: A case study of Crete Island, Greece," *Remote Sens.*, vol. 12, no. 2, pp. 1–19, 2020. https://doi.org/10.3390/rs12020319

[12] K. S. Mohammed, A. F. F. Al-Lahaibi, and K. A. Abdullah, "Evaluating temporal variations in soil deterioration in Iraq's Karma District using spectral indicators," *Anbar J. Agric. Sci.*, vol. 22, no. 2, pp. 1397–1410, 2024. https://doi.org/10.32649/ajas.2024.184878

[13] R. C. Estoque and Y. Murayama, "Classification and change detection of built-up lands from Landsat-7 ETM+ and Landsat-8 OLI/TIRS imageries: A comparative assessment of various spectral indices," *Ecol. Indic.*, vol. 56, pp. 205–217, 2015. https://doi.org/10.1016/j.ecolind.2015.03.037

[14] N. Q. Omar, S. A. M. Sanusi, W. M. W. Hussin, N. Samat, and K. S. Mohammed, "Markov-CA model using analytical hierarchy process and multiregression technique," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 20, no. 1, p. 012008, 2014. https://doi.org/10.1088/1755-1315/20/1/012008

[15] X. Yang and C. P. Lo, "Using a time series of satellite imagery to detect land use and land cover changes in the Atlanta, Georgia metropolitan area," *Int. J. Remote Sens.*, vol. 23, no. 9, pp. 1775–1798, 2002. https://doi.org/10.1080/01431160110075802

[16] J. Chen, M. Lu, X. Chen, J. Chen, and L. Chen, "A spectral gradient difference-based approach for land cover change detection," *ISPRS J. Photogramm. Remote Sens.*, vol. 85, pp. 1–12, 2013. https://doi.org/10.1016/j.isprsjprs.2013.07.003

[17] J. Wang, M. Bretz, M. A. A. Dewan, and M. A. Delavar, "Machine learning in modelling land-use and land cover-change (LULCC): Current status, challenges and prospects," *Sci. Total Environ.*, vol. 822, p. 153559, 2022. https://doi.org/10.1016/j.scitotenv.2022.153559

[18] D. Renza, E. Martinez, and I. Molina, "Unsupervised change detection in a particular vegetation land cover type using spectral angle mapper," *Adv. Space Res.*, vol. 59, no. 8, pp. 2019–2031, 2017. https://doi.org/10.1016/j.asr.2017.01.027

[19] J. Rogan and D. Chen, "Remote sensing technology for mapping and monitoring land-cover and land-use change," *Prog. Plan.*, vol. 61, no. 4, pp. 301–325, 2004. https://doi.org/10.1016/S0305-9006(03)00066-7

[20] D. Espinoza-Molina, R. Bahmanyar, R. Díaz-Delgado, J. Bustamante, and M. Datcu, "Land-cover change detection using local feature descriptors extracted from spectral indices," in *2017 IEEE International Geoscience and Remote Sensing Symposium (IGARSS)*, Fort Worth, TX, USA, 2017, pp. 1938–1941. https://doi.org/10.1109/IGARSS.2017.8127358

[21] M. E. Chaves, M. C. A. Picoli, and I. D. Sanches, "Recent applications of Landsat 8/OLI and Sentinel-2/MSI for land use and land cover mapping: A systematic review," *Remote Sens.*, vol. 12, no. 18, p. 3062, 2020. https://doi.org/10.3390/rs12183062

[22] M. Mathan and M. Krishnaveni, "Monitoring spatio-temporal dynamics of urban and peri-urban land transitions using ensemble of remote sensing spectral indices: A case study of Chennai Metropolitan Area, India," *Environ. Monit. Assess.*, vol. 192, no. 1, p. 15, 2020. https://doi.org/10.1007/s10661-019-7986-y

[23] D. Akyürek, Ö. Koç, E. M. Akbaba, and F. Sunar, "Land use/land cover change detection using multi-temporal satellite dataset: A case study in Istanbul New Airport," *ISPRS Arch. Photogramm. Remote Sens. Spat. Inf. Sci.*, vol. 42, pp. 17–22, 2018. https://doi.org/10.5194/isprs-archives-XLII-3-W4-17-2018

[24] H. Xing, L. Zhu, D. Hou, and T. Zhang, "Integrating change magnitude maps of spectrally enhanced multi-features for land cover change detection," *Int. J. Remote Sens.*, vol. 42, no. 11, pp. 4284–4308, 2021. https://doi.org/10.1080/01431161.2021.1892860

[25] A. N. French, T. J. Schmugge, J. C. Ritchie, A. Hsu, F. Jacob, and K. Ogawa, "Detecting land cover change at the Jornada Experimental Range, New Mexico with ASTER emissivities," *Remote Sens. Environ.*, vol. 112, no. 4, pp. 1730–1748, 2008. https://doi.org/10.1016/j.rse.2007.08.020

[26] N. Mozaffaree Pour, O. Karasov, I. Burdun, and T. Oja, "Simulation of land use/land cover changes and urban expansion in Estonia by a hybrid ANN-CA-MCA model and utilizing spectral-textural indices," *Environ. Monit. Assess.*, vol. 194, no. 8, p. 584, 2022. https://doi.org/10.1007/s10661-022-10266-7

[27] J. K. Bentum, D. K. Dodoo, P. K. Kwakye, D. K. Essumang, and G. A. Adjei, "Spatial and temporal distribution

of polychlorinated biphenyl residues in tropical soils," *Open J. Appl. Sci.*, vol. 6, no. 4, pp. 234–247, 2016. http://doi.org/10.4236/ojapps.2016.64024

[28] J. Pichtel, H. T. Sawyerr, and K. Czarnowska, "Spatial and temporal distribution of metals in soils in Warsaw, Poland," *Environ. Pollut.*, vol. 98, no. 2, pp. 169–174, 1997. https://doi.org/10.1016/S0269-7491(97)00131-0