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Evaluating Land Suitability for Wheat Cultivation Criteria Analysis Fuzzy-AHP and Geospatial Techniques in Northern Basrah Governorate.

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Abstract: Land suitability assessment is essential for planned land management strategies aimed at preserving soil and increasing productivity while ensuring sustainable agricultural production. Land degradation resulting from poor land management and fallowing practices typically leads to low land productivity in Iraq. To maintain agricultural productivity in the targeted area, agricultural requirements must align with available resources through land suitability analysis. In the northern region of Basrah Governorate in Iraq, the study focused on integrating GIS-based land suitability analysis with the fuzzy-analytical hierarchy process (F-AHP) approach. The analysis revealed varying suitability categories throughout the study area, with the largest proportion of unsuitable areas found in category N2, covering 31,202.36 hectares (37.76%), and category N1, currently unsuitable, covering an area of 19,956.24 hectares (24.15%). On the other hand, the moderately suitable category (S3) covered 8,297.26 hectares (10.04%), while the moderately suitable category (S2) covered 23,177.79 hectares (28.05%) of the total study area. No highly suitable lands were identified. The key determining factors for the suitability of lands for wheat cultivation were high values of electrical conductivity, carbonate minerals, bulk density, and low organic carbon content. Most agricultural lands are being used in a manner that contradicts their suitable potentials in the study area. Therefore, the pattern of agricultural land use needs to be adjusted based on their current potentials to reduce soil degradation.

Keywords: FAHP; IDW; RS; GIS.

Introduction

The fast growth of the world population as well as overfeeding of people are the main reasons for the current focod problems. Moreover, it emphasizes the necessity of focusing on agriculture; the world's population is expected to reach 9.1 billion by 2050, and global agricultural output must increase by 70 percent in order to provide sufficient food supply for all on a daily basis (FAO, 2007). One of the main reasons for low production is that the land is not suitable for agriculture. In order to grow crops where they are most suitable and increase yields through better crop adaptation to their environment, this issue calls for a thorough assessment of the suitability of the land (Tashayo *et al*., 2020). The process of assessing the state of the land under which a specific purpose will be carried out with the goal of choosing the best land use for a given unit of land is known as land suitability assessment (Van Benthem, 2013). Despite the development of numerous models that provide a numerical rating on the suitability of the parcel with the current and prospective functions, there is no universal approach to land appraisal modeling. Therefore, ensuring the sustainable production of agriculture is the main goal of recently adopted policies (Zhang *et al*., 2015). It is now essential and crucial to consider soil suitability for agriculture when evaluating, classifying, and assigning land for planning and management reasons. Using the FAHP-based GIS model to assess land suitability in relation to specific crop production is an effective strategy that will help reduce the environmental impact of agriculture (Kuzman *et al*., 2021; Kilic *et al*., 2022). The use of fuzzy logic and GIS remains critical in overcoming numerous agriculture problems, particularly the provision of quality services such as proper planning of manure application and limiting soil degradation. This will also help to achieve maximum crop yield through optimal application of Wheat cultivation occupies approximately 6.0 million hectares of irrigated cropland worldwide (FAO, 2005). Thus, regional land suitability modeling is critical for improving sustainable agriculture, development, and productivity. The use of F-AHP in conjunction with GIS is an important approach for soil management, optimal land use planning, and overall environmental protection from degradation (Romeijn *et al*., 2016). With the agricultural sector in Basrah Governorate in decline, the main aim of this study is to use the Fuzzy Analytical Hierarchy Process (FAHP) system to identify the best suitable areas for wheat cultivation in northern of Basrah Governorate.

Materials & Methods

Study Area: The northern regions of Basrah Governorate, which lie in Iraq's Basrah Governorate, are situated between 36°40′–37°50′E and 40°10′–40°20′N (Fig. 1). The study area is 82,719.5175 hectares in total. There are roughly eight months of precipitation each year, or 191.9 mm of precipitation total. This specific type of soil is classified as Hyperthermic due to the infrequent rainfall, unpredictable weather patterns, and higher annual temperature rates, annual temperatures of approximately 28.9 C and over 48℃ in July (Al-Atab *et al*., 2021).

The study area consists of flood plains and alluvial deposits that are derived from the flood plains of the Tigress and Euphrates Rivers, and is situated at an elevation of +7 meters above the seaside datum. It is made up of wide lowlands and river fillings that have developed since the riverine lands of the Tigris-Euphrates alluvial plain (Fig. 1).

These are conditioned by various geomorphic and pedogenetic agents. This zone has medium-to-fine grain texture and a deposition thickness of three to half a meter. However, the pH of the soil in this region is moderately to slightly alkaline, indicating that salinity levels affect it differently. This area is made up of a few old dry swamps, and the salinity of the ponds varies greatly, ranging from about two meters in some areas to much higher levels in others (Saleh *et al*., 2019).

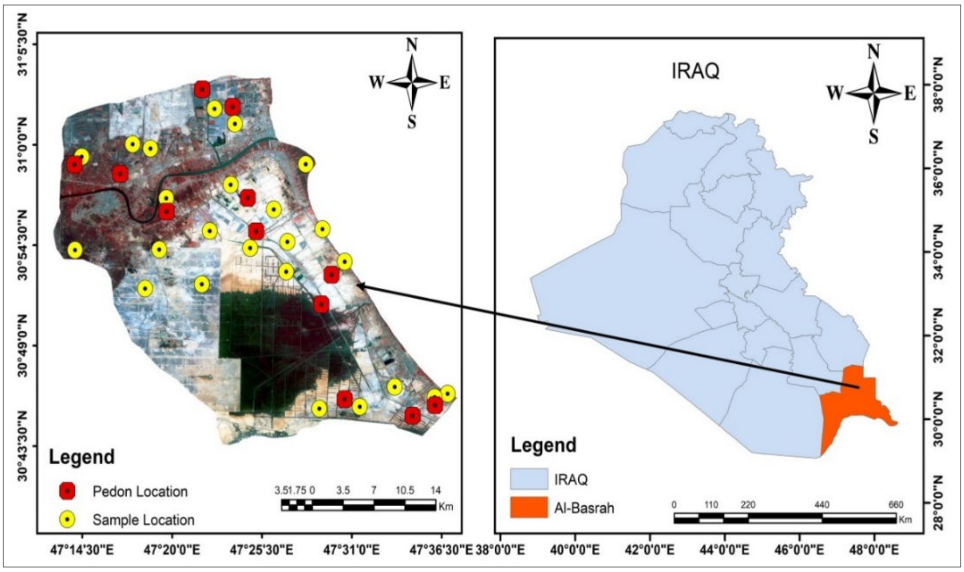

Fig (1): study area and soil sample location.

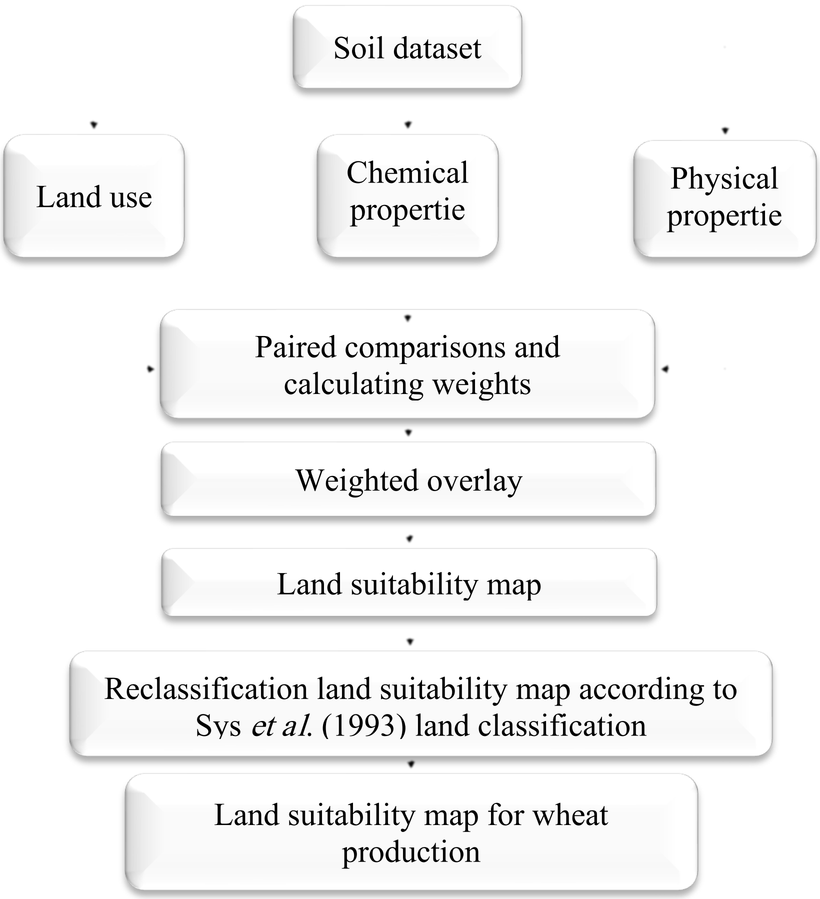

Fig. (2): The processes followed to create a suitable land map for wheat cultivation.

The work methodology applied the Fuzzy Analytic Hierarchy Process (FAHP) used by Buckley (1985) and adapted to the Analytic Hierarchy Process (AHP) system, as well as Geographic Information Systems (GIS), to determine the best suitable areas for wheat production in the northern part of Basrah province. The spatial distribution layers of different characteristics were integrated using GIS to identify the suitable areas for wheat production. The work methodology diagram is illustrated in fig (2).

Eight different criteria were used, consisting soil physical properties (soil texture, bulk density, and soil depth), and the chemical properties (electrical conductivity, pH, organic carbon, and calcium carbonate), as well as land use mapping, to determine the suitability of the land for wheat cultivation. The weights of the criteria were determined based on prevailing conditions in the study area. Each property was reclassified according to table (1), which represents the importance of each property, ranging from 1, which represents unsuitability for wheat cultivation, to 5, which represents maximum importance in wheat cultivation.

The survey was done in the region with several field visits supported by the digital elevation model, supervised and unsupervised classification, spectral reflectance, and some spectral indicative. In light of this information, 36 soil sample (12 pedons and 24 ugar holes) from 0 to 50 cm were established in different physiographic units that represented the study area in November 2022. These samples served as sampling points for soil characteristics related to land suitability assessment while also providing spatial coordinates for each site.

Laboratory work

The soil reaction (pH), electrical conductivity in saturated soil paste, organic carbon content, and carbonate minerals were measured according to the method described in Page *et al*. (1982). As for the physical properties, the particle size distribution of the soil was estimated using the pipette method, and the bulk density was determined using the paraffin wax method, as described in Black *et al*. (1965).

Table (1): Importance of properties for wheat cultivation.

N	Criteria	Rating	category	N	Criteria	Rating	category
		0 - 4	5			< 16	1
		4- 8	4	5	CEC	16 - 24	3
1	Ec	8 - 16	3			>24	5
		16- 25	2			1 - 1.2	5
		>25	1		Bulk Density	1.2 - 1.3	4
		3-20	5	6		1.3 - 1.4	3
		20 - 30	4			1.4 - 1.6	2
2	$CaCO_3$	30 - 40	3			>1.6	1
		40 - 60	2			< 10 cm	1
		>60	1			10 - 20	2
		< 0.2	1	7	Soil depth	20 – 50	3
3	O.C	0.2 - 0.4	3			50 - 90	4
		0.4 - 0.6	4			>90	5
		> 0.6	5	8	Texture	SiC	5
		7.6- 8.0	5			SiCL	4
		8.0- 8.2	4			Urban	1
4	PH	8.2- 8.4	3	9	Land use	Water	1
		8.4 - 8.5	2			Salinity Land	3
		>8.5	1			Agricultural Land	5

Field work

Determining the weights of the criteria using the FAHP method

The study adopted a fuzzy hierarchical analysis process to form the hierarchical structure of the study, which involved several levels. The problem under consideration is the first tier; this leads to the main criteria in the second tier, and the supporting criteria represent the last tier. Two matrix comparison tests are used to determine the weight assigned to each component governing the evaluation when performing the suitability analysis. The corresponding matrices are compared in order to evaluate the criteria; integer-valued estimates, or weights, are assigned to each selected index indicating its contribution to the suitability goal on a fuzzy number scale. The basic arithmetic of fuzzy numbers has been calculated as described in Buckley (1985) and Chang (1996).

First stage: The basis of a comparison matrix created a pairwise comparison that defined the priority between the criteria

$$= \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & a_{2n} & \cdots & 1 \end{bmatrix}$$

$$\text{aij} = \begin{cases} 1,2,3,4,5,6,7,8,9 \\ 1 \\ 1^{-1}2^{-1}3^{-1}4^{-1}5^{-1}6^{-1}7^{-1}8^{-1}9^{-1} \end{cases}$$

When i is more important than j, I = j when i is less important than j.

The Second stage: Preparing the pairwise comparison matrix according to the Analytic Hierarchy Process (AHP) and using the following equations to calculate the Fuzzy Geometric Mean:

$$wi = ri * (r_1 + r_2 + \cdots + r_n)^{-1} \qquad (1)$$

$$A = (l, m, u)^{-1} = \left(\frac{1}{u}, \frac{1}{m}, \frac{1}{l}\right)^{\frac{1}{n}} \qquad (2)$$

$$A_1 \times A_2 = (L_1, M_1, U_1)^{\frac{1}{4}} \times (L_2, M_2, U_2)^{\frac{1}{4}} = (L_1 \times L_2, M_1 \times M_2, U_1 \times U_2)^{\frac{1}{4}} \qquad (3)$$

The fuzzy geometric mean is used to calculate the weights according to Buckley (1985):

$$wi = r_1 + r_2 + \cdots + r_9 \qquad (4)$$

Third: Extracting the weights according to the Fuzzy Approach (Chen *et al.*, 2008), as illustrated in table (2):

Here, 'ain' represents the fuzzy value of the i criterion in comparison to the n criterion.

The geometric mean (ri) represents the fuzzy values obtained by comparing criterion i with all other criteria.

The fuzzy weight of the i criterion is denoted as with geometric mean (ri) represents the fuzzy values obtained by comparing criterion i with all other criteria.

Table (2): Geometric mean is used to calculate the weights (Buckley, 1985).

Criteria	min	max	Fuzzy geometric mean value (ri)	Fuzzy weights(wi)
Ec	12.16	51.89	(6.16,11.09,16.85)	0.58
CaCO3	39.2	50	(1.25,1.22,16.85)	0.056
O.C	0.135	0.69	(1.85,3.29,1.29)	0.198
pH	7.75	8.34	(1.05,1.22,1.54)	0.061
soil depth	72	128	(0.7,0.72,0.68)	0.031
Bulk density	1.42	1.63	(0.34,0.3,0.24)	0.013
Texture	-	-	(0.46,0.44,0.4)	0.019
Sand	44.3	186.3		
Silt	463.1	590.6		
Clay	273.9	430.7		
land use	Urban and water	Agricultural land	(0.22,0.22,0.17)	0.042

The third stage is to extract the weights according to the fuzzy approach and according to the following equation (Chen *et al.*, 2008), shown in table (2).

Evaluation of land suitability for wheat cultivation

Using ARG-GIS 10.3, the appropriate fields for growing wheat in the study area were highlighted. Maps showing the spatial distribution of each characteristic were classified by the weight of the criterion used. Equation (4) was applied to generate the wheat-suitability map.

$$\boldsymbol{LSI\ for\ wheat} = (0.5267 * \text{Land use}) + (0.1445 * \text{texture}) + (0.1189 * \text{Ec}) + (0.0587 * \text{CaCO3}) + (0.1189 * \text{O.C}) + (0.0119 * \text{pH}) + (0.0058 * \text{CEC}) + (0.0115 * \text{Bulk density}) + (0.0031 * \text{soil depth}) \quad (5)$$

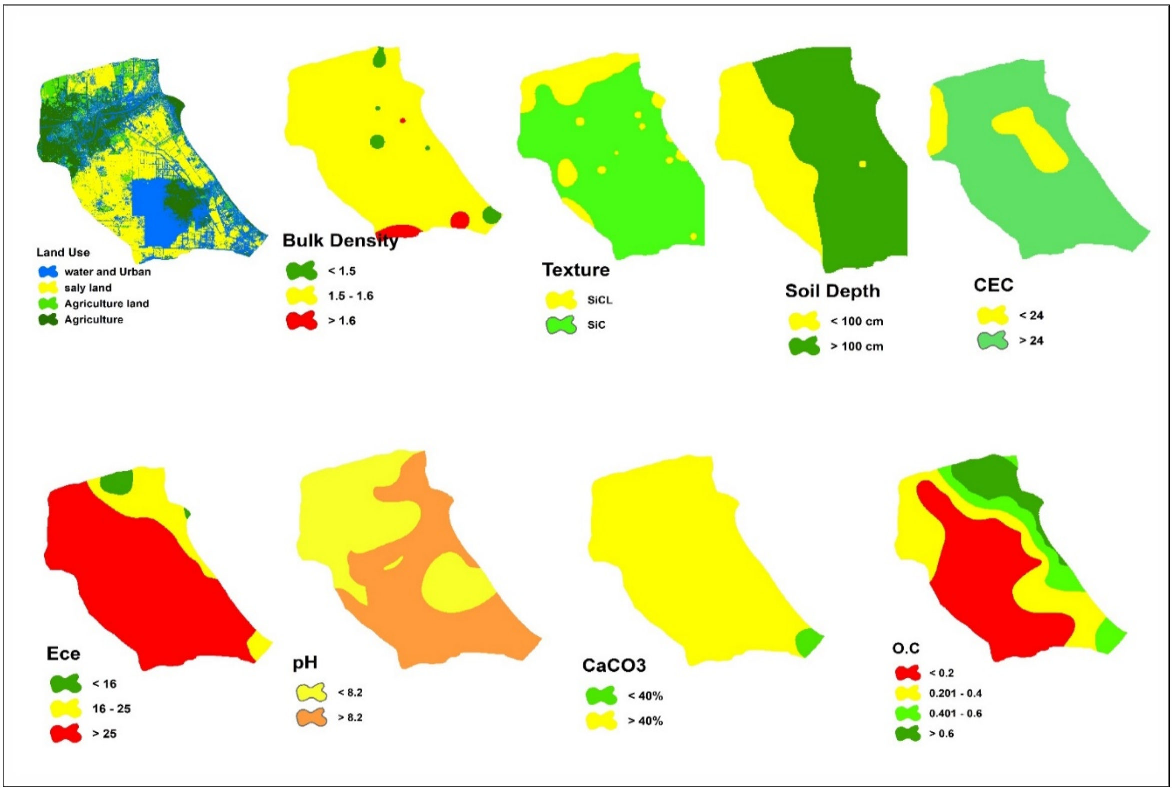

Fig. (3): Criteria used in evaluating land for wheat cultivation.

After that, this equation is applied in Geographic Information Systems (GIS), where spatial distribution maps for each criterion used in this study are generated. This is done using spatial interpolation techniques, specifically Ordinary Kriging with a Spherical model for chemical characters, and IDW for physical characters. The r-squared value and the standard error for each criterion are calculated. Then, the spatial distribution maps are converted into fuzzy maps ranging from 0 to 1 using the overlay command. This is followed by multiplying the fuzzy maps by the final weight of each criterion using the raster calculator command. Next, the overlay command is used again to produce the final map, which represents the spatial distribution of land suitability for wheat cultivation. Additionally, the area and percentage of each suitability class are calculated. Fig. (2) illustrates the workflow steps for developing an equation to assess land suitability for wheat cultivation, as well as the production of a map depicting the suitability of lands for wheat cultivation in the study area. This process allows for the visualization and analysis of the spatial patterns of land suitability, providing valuable information for decision-making and land management in the study area

Results & Discussion

Physical properties

Particle size distribution

This was evident in the results showing the particle size distribution of various soil fractions and their representative horizons of different physiographic units. The relative distribution of sand fractions was between 44.3 and 186.3 g kg^{-1}, while that of silt fractions was between 273.9 and 430.7 $g.kg^{-1}$. The domination of fine sediment particles of silt and clay can result from the condition of the depositions and the position of the Pedons with regard to the sediment's source. The factor includes the velocity of a water current, which may contain various semimetal components. (Alatab *et al*., 2021).

Bulk density

The results showed in table (3) the values of bulk density for the pedons horizons in the study area, ranging from 1.42 to 1.73 $g.cm^{-3}$. The decrease in bulk density values in the surface layers can be attributed to multiple factors, including the type of cultivated vegetation cover and agricultural practices, as well as the soil's organic matter content, which plays an important role in this context. The increase in bulk density values with depth can be attributed to the compression of these horizons due to mechanical forces and the impact of agricultural machinery, as well as the pressure exerted by soil components on each other internally (Al Jaberi and Alatab, 2020).

Chemical properties

Electrical conductivity

The results in table (2) show the values of electrical conductivity, which generally ranged from12.16- 51.89 dsm^{-1}. This increase in values can be attributed to the activity of the root system, which leads to the accumulation of salts in the upper horizons due to the proximity of groundwater to the soil surface, high temperatures, and evaporation of water from the soil surface, resulting in the accumulation of salts in the surface horizon (Saleh *et al*., 2020).

Soil pH

The results showed that the soil pH values for the studied pedons horizons ranged from 7.96 to 8.45. The variation between sites and the vertical distribution of soil pH values is due to the differences in soil content of carbonates, calcium sulfates, salt concentration, sodium ion concentration, and soil texture, especially its content of clay particles (Saleh *et al*., 2019).

Calcium carbonate

The results showed that the calcium carbonate content in the studied pedons was high, with a homogeneous and vertically distributed pattern. The values of calcium carbonate ranged from 375 to 460 $gk.g^{-1}$. This can be attributed to the low rainfall, which leads to a weak redistribution of carbonates (Kadhim *et al*., 2020)

Organic carbon

The results showed significant variation in the organic carbon content of the studied pedons, ranging from 0.015 to 0.73%. The low percentage of organic carbon in most sites can be attributed to the prevailing climatic conditions in southern Iraq, including high temperatures and low rainfall, resulting in a decrease in vegetation cover, as well as the prevailing dryness and salinity in the region, which leads to the oxidation of organic matter (Saleh *et al*., 2020).

Table (3): Results of physical and chemical properties.

Properties		Min Value	Max Value	Interpolation method	Type	Model
Soil Depth (cm)		72	145	IDW	Smoothing	-
Texture	% Sand	5.31	18.26	IDW	Smoothing	-
	% Silt	42.47	54.44			
	% Clay	29.15	50.11			
Ec dsm^{-1}		12.16	105.1	kriking	Ordinary	Spherical
% $CaCO_3$		39.2	50	kriking	Ordinary	Spherical
pH		7.75	8.34	kriking	Ordinary	Spherical
% O.C		0.135	0.69	kriking	Ordinary	Spherical
CEC cmol kg^{-1}		22.72	32.16	kriking	Ordinary	Spherical
Bulk Density g cm^{-3}		1.47	1.69	IDW	Smoothing	-

Evaluation of land for wheat crop

The results of the study, as shown in fig. (4) and table (4), indicate the presence of four distinct categories of lands suitable for wheat cultivation in the studied units. These differences in categories can be described as follows:

Moderately suitable (S2)

Moderate suitability

Lands belonging to this category are moderately suitable for wheat cultivation due to the presence of certain determining factors with a moderate impact, particularly soil salinity and carbonate minerals. Some of these factors, such as carbonate mineral content, cannot be easily overcome in the near future. This category includes some lands located within river basins and wetlands, as well as a significant portion of riverbanks. The total area covered by this category is approximately 23,177.79 hectares, accounting for approximately 28.05% of the total study area (Romeijn *et al*., 2016).

Marginally suitable (S3)

Lands belonging to this category are considered limited in their use for wheat cultivation due to strong limiting factors, including high soil salinity and high bulk density. Additionally, there are moderate limiting factors such as carbonate minerals, low organic carbon content, and soil pH. This indicates that these lands have limited suitability for wheat cultivation. This category covers an area of approximately 8,297.26 hectares, representing approximately 10.04% of the total area. These values classify this category as having low suitability for wheat cultivation (Kilic *et al*., 2022).

Table (4): Land suitability categories and their areas in the study area.

L.S.I	Area hectares	Percentage
Unsuitable N2	31202.36	37.76
Unsuitable N1	19956.24	24.15
Marginality Suitable S3	8297.26	10.04
Moderately Suitable S2	23177.79	28.05

Unsuitable (1N)

This category includes lands characterized by high electrical conductivity values, high lime content, high bulk density, high soil pH, and deep soil depth. These factors have led to a decrease in the productivity potential of these lands. By implementing an appropriate soil management system to address these limiting factors, these lands can gradually become less suitable or moderately suitable. This category covers an area of approximately 19,956.24 hectares, accounting for 24.15% of the total study area. These lands are primarily located in the southern part of the study area, particularly in the wetland unit and some river basins. These lands were characterized by high electrical conductivity values, along with high levels of calcium, bulk density, and pH, as well as soil depth. Consequently, the productivity potential of these lands has decreased (Al-Atab *et al*., 2021).

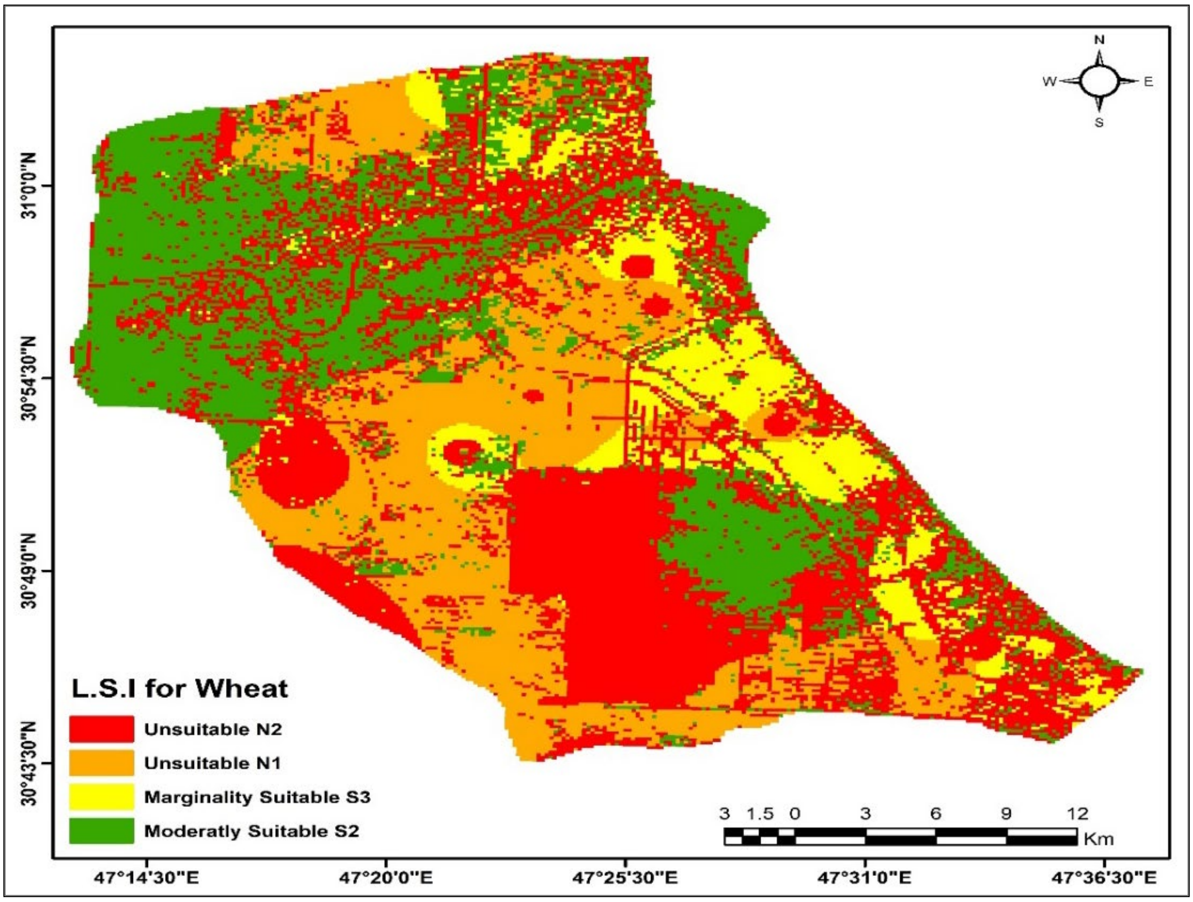

Fig. (4): Land suitability map for wheat.

Unsuitable (2N)

Lands belonging to this category are considered unsuitable for agricultural purposes, as most of them consist of water bodies, urban areas, and roads. The majority of these lands are located in the wetland unit due to the presence of water. Additionally, some areas in the western and southern parts of the city are covered by surface water, forming a layer on the surface. This category covers an area of approximately 31,202.36 hectares, representing approximately 37.76% of the total study area. As most of these lands consist of water bodies, urban areas, and road (Kadhim *et al*., 2020).>

Conclusion

The suitability of agricultural lands in northern Basrah varies between permanently unsuitable areas (N2), currently unsuitable areas (N1), partially suitable areas (S3), and moderately suitable areas (S2) for growing wheat crops.

Most of the lands in northern Basrah are considered unsuitable, with a small percentage of suitable lands for wheat cultivation being devoid of constraints. The unsuitable lands, whether currently or permanently unsuitable, share severe constraints such as soil depth and apparent density, as well as high electrical conductivity values, the presence of carbonate minerals, and low organic carbon content. These factors pose significant challenges for agriculture in the region. This study recommends the adoption of a fuzzy approach to identify the best suitable lands for growing important crops, which would contribute to reducing the necessary agricultural imports. It also emphasizes the need to modify the current land use pattern according to suitability categories and implement effective land management measures based on these classifications. This would contribute to achieving successful land management and provide alternative income for farmers who rely solely on the lands. Additionally, this approach can reduce the pressure on currently used lands, creating important opportunities for rehabilitation and restoration of agriculture in the area.

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Contributions of authors

M.S.A.M: Collection of soil sample, Laboratory techniques, wrote and revised the manuscript.

S.M.A: Suggestion the proposal of the article, revised the manuscript.

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Conflicts of interest

The authors declare that they have no conflict of interests.

Ethical approval

All ethical guidelines related to soil science and care issued by national and international organizations were implemented in this research.

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تقييم ملائمة الأراضي لزراعة الحنطة باستعمال المنهج المضبب والتقانات الجيومكانية شمال محافظة البصرة

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المستخلص: تقييم ملائمة الأراضي هو أساس للتخطيط وإدارة الموارد للحفاظ على التربة من التدهور وزيادة انتاجية الاراضي والحفاظ على استدامة الانتاج الزراعي. في العراق عموما، تكون إنتاجية الأرض منخفضة نتيجة لتدهور الأراضي بسبب سوء إدارة الأراضي وترك الاراضي بورا. لذلك، من الضروري مطابقة متطلبات الزراعة مع الموارد المتاحة من خلال تحليل ملاءمة الأراضي للحفاظ على إنتاجية الأراضي الزراعية في منطقة الدراسة. هدفت هذه الدراسة إلى معالجة تحليل ملاءمة الأراضي باستخدام نظام المعلومات الجغرافية ونهج (F-AHP) شمال محافظة البصرة. العراق. أظهر تحليل ملاءمة الأراضي لزراعة الحنطة، هناك تباين واضح في فئات الملائمة، معظم اجزاء من شمال البصرة غير ملائمة وهي ضمن الفئتين غير ملائمة جدا(N2) بمساحة 31202.36 هكتارا (37.76%)، والفئة (N1) غير ملائمة في الوقت الحالي بمساحة 19956.24هكتارا (24.15%) وكانا يشكلان أكبر مساحة من الأراضي. من جانب أخر، كانت مساحة الفئة حدية الملائمة (S3) 8297.26 هكتارا وبنسبة (10.04%) في حين كانت مساحة فئة متوسطة الملائمة 23177.79 هكتار بنسبة (28.05%) من المساحة الكلية لمنطقة الدراسة. في حين لم تظهر اراضي من الفئة الملائمة جدا بمساحة. وكانت من اهم العوامل المحددة لملاءمة الأراضي لزراعة محصول الحظة هي ارتفاع قيم كل من الايصالية الكهربائية ومعادن الكاربونات وكثافتها الظاهرية وانخفاض محتواها من الكاربون العضوي. يتم استخدام معظم الأراضي الزراعية بشكل يتعارض مع إمكاناتها المناسبة في منطقة الدراسة. وبالتالي، يحتاج نمط استخدام الأراضي الزراعية إلى تعديل استنادًا إلى إمكاناتها الحالية للتقليل من تدهور الترب.

الكلمات المفتاحية: تعدد المعايير الضبابي، المسافة المعكوسة الموزونة، الاستشعار عن بعد، نظم المعلومات الجغرافية.