Iraqi Journal of Agricultural Sciences –2026:57(3):689-698
P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
DOI: https://doi.org/10.36103/njqvkw98

A FUZZY-AHP AND GEOSPTIAL ANALYASIS MODEL FOR LAND SUITABILITY ASSESSMENT OF DATE PALM (*Phoenix dactylifera*) CULTIVATION IN NORTHREN BASARAH, IRAQ.

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ABSTRACT

This study was executed in the northern part of Basrah Governorate in southern Iraq to evaluate the suitability of lands for date palm cultivation by integrating fuzzy logic, remote sensing, and geographic information systems. Nine criteria were studied, including chemical properties (EC, pH, O.C, $CaCO_3$, and CEC) and physical properties encompassing soil particle size distribution, soil depth, and soil bulk density, in addition to the supervised classification map. The importance and influence of all criterion have been determined through a Multi-Criteria Decision-Making (MCDM) method. Fuzzy logic was then employed to develop a specific mathematical model for evaluating land suitability for date palm cultivation and to produce a land suitability map for study area. 73.96% of the studied lands are unsuitable (N1), while moderately suitable (S2) lands constituted 15.45%, and marginally suitable (S3) lands constituted 10.59%. Lands that classified as S1 were missed due to urban expansion, high soil salinity, high carbonate minerals, and unsuitable soil depth for date palm cultivation. moreover, the developed mathematical equation can be applied to assess land suitability for date palm cultivation in areas with similar conditions to the study area.

Key words: F-AHP; GIS; MCDM; IDW; Kriging; RS.

Received: 22/10/2023, Accepted: 31/1/2024, Published: 31/3/2026

INTRODUCTION

The cultivation of the date palm (Phoenix dactylifera), which is primarily found in many countries like Iraq, Iran, and Saudi Arabia, as well as in the United States (California), In these regions, it significantly influences the economic and environmental situation There are approximately 100 million date palm trees worldwide, with 62 million located in the Middle East and North Africa region (Dialami and Givi 2020; Jonoobi *et al*.,2019). The application of Geospatial Technologies has led to significant advancements in assessing land suitability for agricultural purposes, enabling researchers and decision-makers to analyze complex spatial and temporal data. Moreover, integrating Fuzzy Logic methodology allows for handling uncertain variables and comprehensive data, resulting in land suitability assessments with high accuracy, a clear methodology, and results that closely reflect reality (Saleh *et al*.,2019). The advancement of geospatial technologies has significantly enhanced the capabilities for analyzing land suitability for agricultural purposes, particularly for economic crops like date palms. Integrating these technologies with the Fuzzy Analytical Hierarchy Process (FAHP), methods for the spatial distribution of soil properties, terrain characteristics, and climatic conditions effectively contributes to identifying highly suitable agricultural areas (Givi *et al*.,2018). The evolution of remote sensing and GIS has proven effective in land analysis and differentiation, ensuring spatial distribution accuracy. Integrating these tools enables precise land suitability assessments, considering both spatially distributed multi-criteria and expert knowledge (Seyedmohammadi *et al*.,2019; Sarkar et al.,2022). Remote sensing data, when integrated with GIS, provides a dynamic

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approach for mapping and analyzing soil, terrain, and climatic factors relevant to date palm cultivation. Integrating fuzzy logic methodology, GIS, and remote sensing is particularly crucial in regions where traditional data collection methods pose significant challenges. This approach provides a comprehensive understanding of soil agricultural capacity, facilitating optimal decision-making for sustainable agriculture. Studies have demonstrated the applicability of these technologies in selecting optimal sites for date palm cultivation in various regions. In the Qaa Plain in South Sinai, Egypt, and Fars province, Iran, a methodology integrating fuzzy logic with GIS and remote sensing techniques was applied. The results indicated that this approach provides highly accurate outcomes, enabling strategic expansion and planning for cultivation in highly suitable areas while considering environmental conservation and economic feasibility (Dialami and Givi 2020). Furthermore, (Almayyahi and Al-Atab 2024) emphasized, when using the integration of FAHP, RS, and GIS, the necessity of modifying the current land use pattern in northern Basrah Governorate according to suitability classes and implementing effective land management measures based on these classifications. This contributes significantly to achieving successful land management and providing alternative income sources for farmers who heavily rely on agriculture. Additionally, it helps preserve currently utilized lands and prevent their degradation, leading to the restoration of agriculture in the region. Given the notable and tangible decline in date palm productivity and cultivated area in the study area specifically, and Basrah Governorate in general, this study aims to evaluate land suitability for date palm cultivation in the northern part of Basrah Governorate.

MATERIALS AND METHODS

The Study Area : The study area is located in the northern part of Basrah Governorate, southeastern Iraq. The study area is centered between longitudes 47° 24' and 47° 61' East and latitudes 30° 68' and 31° 70' North. It is bounded by Maysan Governorate to the north, Al-Hartha District to the south, the Shatt al-Arab and Tigris River to the east, and Al-Zubair District to the west. The area occupies the northern part of Basrah Governorate, which is part of the Alluvial Plain, with an area of 827 km². The study area falls within a hot and dry desert climate, with an average annual rainfall of 191.9 mm distributed irregularly over eight months, characterized by scarcity and irregularity in rainfall amount. Furthermore, average temperatures are high throughout the year, with an annual average reaching its peak during the summer months, where temperatures can reach up to 50°C in July. Therefore, soils in the study area are classified as hyperthermic in terms of the soil temperature regime (Al-Atab *et al*.,2021). The area consists of riverine deposits extending over relatively wide areas. Due to various geomorphological factors, the area features soils with medium to fine textures, and the thickness of these deposits ranges from 0.5 to 7 meters. Soil salinity affects the area to varying degrees, and the region contains some old dry marshlands with variable groundwater salinity (Kadhim *et al*.,2020).

Field Work: A field survey was conducted through several site visits supported by a Digital Elevation Model (DEM), Supervised and Unsupervised Classification, and Spectral Reflectance. Based on this, 36 sites were selected for soil sampling: 12 Pedons and 24 auger holes from a depth of 0 to 100 cm, across different physiographic units representing the study area in November 2022. Soil samples were collected for studying their physical and chemical properties relevant to assessing land suitability for date palm cultivation.

Laboratory Work: Soil reaction (pH), electrical conductivity in the saturated paste (EC), organic carbon content (O.C), and carbonate minerals ($CaCO_3$) were measured according to the method described in (Page *et al*.,1982). Regarding physical properties, the particle size distribution was estimated using the pipette method, and bulk density was estimated using the paraffin wax method, as described in (Black *et al*.,1965).

Methodology: The Fuzzy Analytical Hierarchy Process (FAHP) developed by

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(Buckley ,1985) and adapted from the Analytical Hierarchy Process (AHP) was used.

Stage 1: Application of the Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) was used as a Multi-Criteria Decision-Making (MCDM) tool. In this stage, the hierarchical structure of the study was constructed based on several main levels (Saaty ,1980. The first level defined the study objective (land suitability evaluation), the second level represented the main criteria, and the third level represented the sub-criteria estimated in the section above. This methodology is based on pairwise comparisons between criteria in the matrix and extracting the consistency ratio of the criteria used. Nine important criteria for evaluating land suitability for date palm cultivation were selected. Since the consistency ratio was 0.041, which is less than 0.1, it can be concluded that the established criteria were highly accurate and could be used in applying the fuzzy methodology for land suitability assessment for date palm cultivation.

Stage 2: Determining Criterion Weights Using the Fuzzy-AHP Methodology Following the validation of the pairwise comparisons and the comparison matrix, the fuzzy methodology, as described by (Bucley,1985), was employed to calculate the weight of each criterion.

First: Constructing the Fuzzy Pairwise Comparison Matrix:

$$A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/a_{1n} & a_{2n} & \cdots & 1 \end{bmatrix} \text{aij} = \begin{cases} 1,2,3,4,5,6,7,8,9 \\ 1 \\ 1^{-1}2^{-1}3^{-1}4^{-1}5^{-1}6^{-1}7^{-1}8^{-1}9^{-1} \end{cases}$$

Second: Preparing the Fuzzy Pairwise Comparison Matrix according to the Analysis Hierarchy Process (AHP) and using the following equations to calculate the Fuzzy Geometric Mean:

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

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

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

The Fuzzy Geometric Mean is used to calculate the weights according to (Chen *et al*.,2008):

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

Third: Extracting the weights according to the fuzzy method (Chen *et al*.,2008)

$$\boldsymbol{LSI\ for\ Date\ Palm} = (0.596749 * \text{Land use}) + (0.132144 * \text{Soil Depth}) + (0.045782 * \text{ECe}) + (0.132144 * \text{Texture}) + (0.045782 * \text{O.C}) + (0.023263 * \text{CaCO3}) + (0.006242 * \text{pH}) + (0.013715 * \text{CEC}) + (0.004178 * \text{Bulk Density}) \ldots (5)$$

Subsequently, this equation was applied within the Geographic Information Systems (GIS) environment. Spatial distribution maps were created for each criterion used in this study. This was accomplished using spatial interpolation techniques, specifically Ordinary Kriging with the Spherical Model. This method has been widely used as an important and prevalent technique due to its accuracy in spatially distributing various soil properties, especially chemical ones. The Inverse Distance Weighting (IDW) interpolation method with Smoothing was used for physical soil properties (Abdulmanov *et al*.,2021), and the correlation coefficient and standard error were calculated for each criterion. The spatial distribution maps were then converted into fuzzy maps with values ranging from 0 to 1 using the Overlay function. This was followed by multiplying the fuzzy maps by the final weight of each criterion using the Raster Calculator. Subsequently, the Overlay function was used again to produce the final map, representing the spatial distribution of land suitability for date palm cultivation. Additionally, the area and percentage for each suitability class were calculated.

RESULTS AND DISCUSSION

Soil properties: The results presented in Tables 1 and 2 outline the physical and chemical properties of the soil. The physical properties included particle size distribution, soil depth, and bulk density, while the chemical properties comprised: pH, electrical

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conductivity of the saturated paste (ECe), percentage of carbonate minerals ($CaCO_3$), percentage of organic carbon (O.C), and cation exchange capacity (CEC).

The Physical Properties: The results in Tables 1 and 2 indicate a clear variation in soil depth. The soils are deep in the river levee areas (160 cm) and gradually decrease towards the marshland areas (72 cm). This is accompanied by a gradual decrease in the percentage of sand particles, which ranged between 5.31% and 18.26%, and a clear, gradual increase in the percentage of silt particles (42.47% to 54.44%) and clay particles (29.15% to 50.11%). Consequently, soil texture was distributed almost homogeneously across the study area, ranging from fine to moderately fine (SiCL, SiC). The predominance of fine silt and clay particles can be attributed to sedimentation conditions, the pedon's location relative to the sediment source, as well as the flow intensity and sediment load of the transporting water. Bulk density ranged between 1.47 and 1.69 g cm^{-3}, with higher values observed in the central and southern parts of the study area. This can be attributed to sedimentation conditions and the dominance of fine particles, in addition to the overburden pressure on subsurface horizons, which are more susceptible to compaction and densification compared to upper surface horizons due to increased moisture content and decreased organic matter content, particularly in the subsurface horizons of the marshland unit (Jabr *et al*.,2022).

The Chemical Properties: The results in Tables 1 and 2 indicate a relatively homogeneous distribution and very slight variation in soil pH, with values ranging between 7.82 and 8.36. The variation between sites in different physiographic units, as well as the vertical distribution of pH values within the same site, can be attributed to differences in soil content of carbonates, calcium sulfates, salt concentration, sodium ions, soil texture, and especially the clay fraction content (Kadhim *et al*.,2020). Electrical Conductivity (ECe) values ranged between 12.1 and 72.19 dS m^{-1}. This elevation is attributed to the desiccation processes the marshes underwent, and the construction of earthen barriers that retain water, leading to increased evaporation and salt accumulation in the soil surface layers, especially with the prevalence of fine pores that contribute to capillary action. Furthermore, the proximity of groundwater to the surface contributes to high EC values in the soil surface horizons. The lack or absence of vegetation cover, particularly during the summer season, also significantly contributes to salt accumulation in the upper horizons of the study area.

Table 1. Results of physical and chemical properties and some statistical analyses

Properties		Min	Max	Interpolation method	Type	Model	R^2	S.E	Regression function
Soil Depth (cm)		72	165	IDW	Smoothing	-	0.78	3.72	0.7663*+13 .3548
Texture	% Sand	5.31	18.26	IDW	Smoothing	-	0.79	0.20	0.9525 * x+0.07026
	% Silt	42.47	54.44						
	% Clay	29.15	50.11						
Ec dsm^{-1}		12.1	72.19	Kriking	Ordinary	Spherical	0.81	9.3	0.8161 * x + 6.552
% $CaCO_3$		38.94	49.17	Kriking	Ordinary	Spherical	0.73	2.34	0.6727 * x + 14.473
pH		7.82	8.36	Kriking	Ordinary	Spherical	10.9	0.11	0.6555* x + 2.8181
% O.C		0.093	0.55	Kriking	Ordinary	Spherical	700.	0.11	0.7157 * x +0.0678
CEC cmol kg^{-1}		22.24	29.16	Kriking	Ordinary	Spherical	0.84	1.21	0.7474* x + 6.5198
$^{3-}$cm Bulk Density g		1.47	1.69	IDW	Smoothing	-	0.84	0.03	0.8386* x + 0.2577

The percentage of Carbonate Minerals ranged between 38.94% and 49.17%. This increase can be attributed to the scarcity or low rainfall, which reduces the redistribution of carbonates within the soil profile, in addition to the source of sediments being calcareous rocks (Alatab *et al*.,2021). This distribution is also significantly influenced by prevailing site conditions and

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can be attributed to the topographic variability of the soil. Slope plays a clear and primary role in the redistribution of carbonate minerals, alongside the depositional site and the soil's carbonate content under the conditions of these soils' formation. Moreover, the soil's clay content contributes to increased carbonate mineral content in the surface layer, as the distribution of carbonate minerals is also affected by prevailing conditions along the rich alluvial plain, which is naturally rich in calcium carbonate. Groundwater depth also influences the distribution of carbonate minerals within the soil profile. Regarding Organic Carbon Content, it ranged between 0.0929% and 0.55062%. The results in Tables 1 and 2 show a clear decrease in the percentage of organic carbon in the river levee unit and some sites within the marshes. This decline in soil organic matter content can be attributed to the prevailing climatic conditions in southern Iraq, including high temperatures and low rainfall, leading to reduced vegetation cover, as well as the prevalent drought and salinity in the region, which contribute to the oxidation of organic matter (jabr *et al*.,2022). Cation Exchange Capacity (CEC) values ranged between 22.24 and 29.16 cmol (+) kg^{-1}. The results in Tables 1 and 2 show a clear decrease across the study area, particularly in the river levee soils. This decline can be attributed to the limited use of a large portion of this unit and its high calcium carbonate and salt content. Additionally, the cation exchange capacity for positive ions in the soil is generally low, except for some samples showing higher values. These variations can be attributed to agricultural activity or differences in the clay and silt content of the soil. The limited use of a large portion of the river levee soil may be due to restricted access to water resources for irrigation, leading to reduced agricultural activity in those areas. Furthermore, the high content of calcium carbonate and salts in the soil can contribute to reducing its fertility and productivity.

Table 2. primary and secondary criteria and area of each category in the study area

Criteria	Sub-criteria classes	Area/Hectares	Criteria	Sub-criteria classes	Area/Hectares
Land Use	Water and Urban	28744.29	O.C	< 0.2	40220.59
	Saline Lands	30717.17		0.2 – 0.4	29046.45
	Agri. Lands	23249.56		> 0.4	13426.99
Soil Depth	< 100	29322.53	Texture	SiCL	13624.71
	>100	53371.04		SiC	69082.69
ECe	12 – 16	3218.15	CEC	16 – 24	11210.41
	16 – 24	11137.23		> 24	71498.96
	>24	68350.32			
$CaCO_3$	30 – 40	78440.6	Bulk density	1.4 – 1.6	31130.67
	40 – 60	4257.8			
pH	7.8 – 8	14354.95		> 1.6	51562.88

Statistical Analysis of Soil Properties

The results in Table 1 show that all the chemical criteria used exhibited a high degree of variation across different sites. The coefficient of determination (R^2) values indicated a high degree of model fit for all criteria, ranging between 0.698 and 0.9078. The use of spatial interpolation via Ordinary Kriging with the Spherical Model yielded positive results for distributing the chemical properties. Meanwhile, the standard error (SE) values ranged from 0.0359 to 9.3. These results indicate a high degree of homogeneity in the distribution models and sampling, as well as convergence in the values of chemical properties between different areas. In contrast, physical properties such as bulk density and texture showed a high degree of homogeneity when using the IDW (Inverse Distance Weighting) interpolation method with the Smoothing type. These findings are consistent with (Saleh *et al*.,2020).

Evaluation of Land Suitability for Date Palm Cultivation: The study results presented

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in Figure 1 and Table 3 reveal three distinct classes of land suitable for date palm cultivation in the study area, as follows:

1. Moderately Suitable (S2): This land class is characterized by a moderate suitability for date palm cultivation. This is primarily due to the presence of one important characteristic: an effective depth for root spread, in addition to suitable organic carbon content. However, soil salinity and relatively high levels of carbonate minerals are the main factors reducing the suitability of these lands (Sengupta *et al*,2022). Some of these limiting factors, such as carbonate mineral content, cannot be easily overcome in the near future. This class includes lands within riverbanks, river basins, and marshes to varying degrees. It occupies an area of approximately 5,860.51 hectares, representing about 15.45% of the total study area. This land class is characterized by lower suitability for date palm cultivation, primarily due to specific constraints that reduce land suitability. The main constraints include the effective depth for root spread, as well as soil salinity and relatively high levels of carbonate minerals (Pilivar *et al*.,2020). As with the S2 class, some factors like carbonate content cannot be easily remediated in the short term. This class includes lands within river levees, river basins, and marshes to varying degrees. It occupies an area of approximately 4,016.51 hectares, representing about 10.59% of the total study area.

Table 3. Land suitability classes for date palm cultivation and their area in hectares

L.S Class	Area hectares	Percentage
Unsuitable (N1)	**28052.31**	**73.96**
Marginality suitable(S3)	**4016.51**	**10.59**
Moderately suitable(S2)	**5860.51**	**15.45**

Marginally Suitable (S3)

This land category is characterized by lower suitability for date palm cultivation, primarily due to specific constraints that diminish land fitness. The key limiting factors include the effective root zone depth, as well as soil salinity and its relatively high levels of carbonate minerals (Al-Mayahi and Mahmoud, 2020). Some of these factors, such as the carbonate mineral content, cannot be easily mitigated in the near future. This category encompasses lands located within river levees, river basins, and marshes, in varying proportions. It covers an area of approximately 4,016.51 hectares, representing about 10.59% of the total study area.

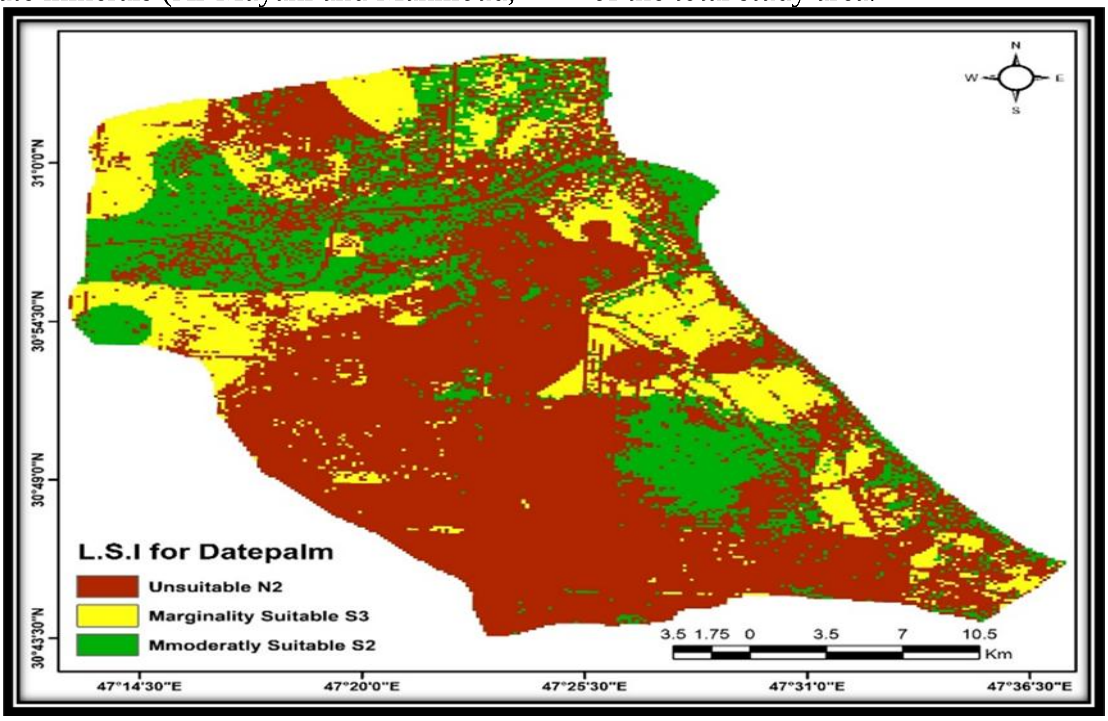

Figure 1. Map of Land Suitability for Date Palm Cultivation in study area

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3. Unsuitable (N1): This land class is characterized by unsuitability for agricultural purposes. Most of these lands consist of water bodies, urban areas, lands with limited soil depth, and roads. The majority of these lands are located within the marsh unit, where water is present and the soil is characterized by shallow depth. Additionally, surface water covers some areas in the western and southern parts of Al-Madinah District. This class occupies an area of approximately 28,052.31 hectares, representing about 73.96% of the total study area. From the results, it is observed that lands adjacent to the Tigris and Euphrates rivers are considered moderately suitable due to lack of farmer attention, in addition to their salinity and increased carbonate mineral content. This has led to their degradation and a reduction in their suitability to a moderate level, despite the presence of otherwise ideal conditions for date palm cultivation. Similarly, lands adjacent to the Shatt al-Arab have become unsuitable for agriculture due to urban expansion, as most have been converted into residential areas. This occurs despite the availability of suitable conditions such as soil depth.

CONCLUSION

The evaluation results clearly revealed the severe degradation of land suitability for agriculture in the northern part of Basrah Governorate, where 73.96% (28,052.31 hectares) of the total area was classified as unsuitable (N1) for date palm cultivation. This sharp decline is primarily attributed to anthropogenic pressures and natural constraints, most notably: urban expansion at the expense of agricultural land, high soil salinity, high calcium carbonate content, shallow soil depth, and low organic matter content. The complete absence of the Highly Suitable" class is particularly striking, indicating a critical situation requiring proactive intervention. The proposed mathematical model and integrated methodology combining Fuzzy Logic (F-AHP) and Geospatial Technologies (GIS & RS) demonstrated high efficacy as a precise and reproducible tool for land suitability assessment. The spatial distribution maps produced using the Spherical Kriging technique for chemical properties and the IDW method for physical properties showed high statistical reliability (R^2 values ranging from 0.698 to 0.9078). We recommend applying this methodology and equation on a broader scale in Basrah Governorate and similar alluvial plains, as they provide a robust scientific framework to support strategic planning for optimal land use, prioritizing reclamation efforts, and mitigating ongoing agricultural degradation, thereby contributing to sustainable agriculture in these vital regions.

ACKNOWLEDGEMENT

The authors would like to express their sincere gratitude to the College of Agriculture for providing the laboratory support necessary to conduct this study.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

AUTHOR/S DECLARATION

We hereby declare that this work is our original research and has not been published previously nor submitted for publication elsewhere. All ethical guidelines for research have been followed, and necessary approvals were obtained from the relevant institutional ethics committee.

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P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
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P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
DOI: https://doi.org/10.36103/njqvkw98
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Iraqi Journal of Agricultural Sciences –2026:57(3):689-698
P-ISSN: 0075- 0530 /E-ISSN: 2410-0862
DOI: https://doi.org/10.36103/njqvkw98

نموذج دمج المنطق الضبابي F–AHP والتحليل المكاني لتقييم ملاءمة الأراضي لزراعة نخيل التمر (*Phoenix dactylifera*) في شمال محافظة البصرة، العراق.

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المستخلص

اجريت الدراسة بهدف تقييم مدى ملاءمة الأراضي لزراعة اشجار نخيل التمر شمال محافظة البصرة في جنوب العراق من خلال دمج المنهج المضبب مع نظم المعلومات الجغرافية. تمت دراسة 9 معايير تشمل خصائص كيميائية (الايصالية الكهربائية والاس الهيدروجيني والنسبة المئوية للكاربون العضوي والسعة التبادلية الكتيونية والنسبة المئوية لمعادن الكاربونات) وخصائص فيزيائية (التوزيع الحجمي لمفصولات التربة وعمق التربة والكثافة الظاهرية)، فضلا عن خريطة الاستعمال الحالي للأراضي. تم تحديد أهمية وتأثير كل معيار من خلال طريقة اتخاذ القرار متعددة المعايير. ثم تم استخدام المنهج المضبب لتطوير نموذج رياضي خاص بتقييم ملائمة الأراضي لزراعة أشجار النخيل وإنتاج خريطة ملائمة الأراضي لمنطقة الدراسة. أظهرت النتائج ان 73.96% من الأراضي المدروسة غير ملائمة (N1) لزراعة أشجار النخيل، بينما كانت الأراضي متوسطة الملائمة (S2) بنسبة 15.45% والحدية الملائمة بنسبة 10.59%، يلاحظ عدم وجود أراضي ملائمة جدا بسبب ارتفاع ملوحة التربة ومعادن الكربونات فضلا عن عمق التربة الغير مناسب لزراعة أشجار النخيل. ويمكن للمعنيين أخذ النتائج بنظر الاعتبار للاستفادة الأمثل من الأراضي في هذه المنطقة. بالإضافة إلى ذلك، يمكن تطبيق المعادلة الرياضية المطورة لتقييم ملائمة الأراضي لزراعة أشجار النخيل على الأراضي المشابهة لمنطقة الدراسة.

الكلمات المفتاحية: التحليل الهرمي الضبابي، صنع القرار متعدد المعايير، نظم المعلومات الجغرافية، الاستشعار عن بعد، الاستكمال الوزني العكسي للمسافة، التقدير الإحصائي المكاني.