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Hassan Hadi Alkarawi
Soil and Water Department, Technical College Al-Mussaib, Al-Furat Al-Awsat Technical University, Iraq

Ahmed Abdulhadi Aljanaby
National Center for Water Resources Management, Ministry of Water Resources, Iraq

Ghassan Adnan Abdul Ameer
Soil and Water Department, Technical College Al-Mussaib, Al-Furat Al-Awsat Technical University, Iraq

Corresponding Author:
Hassan Hadi Alkarawi
Soil and Water Department, Technical College Al-Mussaib, Al-Furat Al-Awsat Technical University, Iraq

Fuzzy logic technology via inverse-distance method to predict the temporal variability of soil degradation in District Saddha Al-Hindia, Iraq

Hassan Hadi Alkarawi, Ahmed Abdulhadi Aljanaby, and Ghassan Adnan Abdul Ameer

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Abstract
The present research work aimed to employ a fuzzy logic model as a developed tool that represents the integration between remote sensing and geographic information systems to assess the prevailing status of land use and land cover in District Saddha Al-Hindia, Babil, Iraq. The results revealed that there are five types of land degradation in the study area including i) area without deterioration comprising 69.4% (195 Km^2) of the area, ii) area with mild deterioration comprising 11.9% (32.6 Km^2) of the area, iii) area with medium deterioration comprising 6.11% (17.2 Km^2) area, iv) area with severe deterioration comprising 8.6% (24.2 Km^2) area, and v) very severely deteriorated area comprising 4.3% (12.2 Km^2) of the area studied. Based on overall study results, it was concluded that the area studied is dominated by the non-deterioration category followed by the mild deterioration category. The largest percentage of the study area is sited within three irrigated reclamation sites.

Keywords: Fuzzy logic model, inverse-distance method, soil degradation, Saddha Al-Hindia, land deterioration categories, soil characterisicts, land use types

Introduction
The concept of fuzzy logic or ambiguous logic is the logic that is applied with artificial intelligence applications in different expert systems which are being deployed to process data in a better way. Fuzzy logic applications primarilty based on a fuzzy logic chip, that has is being utilized in various sectors like in photography (De Campos, 2020; Omran *et al*., 2025) [11, 23]. It has been indicated that there is a kind of close relationship between the phrase logicalism that has been characterized since the inception of the science of logic with strictness and strength confusion and ambiguity (Patyra and Mlynek, 2012; Peckol, 2021) [23, 25].

Fuzzy logic is a control system for solving systematic problems, where it provides a way to reach a clear conclusion based on a vague problem, and imprecise meaning. When the information is huge or incomplete, it is possible through the use of fuzzy logic also takes control of new problems and make snap decisions faster and more effectively (Bezdek, 2013; Verma *et al*., 2023) [10, 29]. Various motives directed the researchers improve the fuzzy logic work. Along with the advancement of computer-based softwares and logistics, the humans' intention intensified to develop such programs or to invent such systems which can handle imprecise information. However, it was a challenging demand as the computers could interpret and process the accurate dataset only. This situation resulted in the creation of some expert systems, also known as artificial intelligence, and fuzzy logic is a many-valued logic theory by which these expert systems are desgined (Mamdani, 1981; Maria *et al*., 2021) [19, 20]. It is a technique for defining complex models with simple and understandable fuzzy variables and rules that take care of the imprecision of the event or concept itself.

Objectives of the current study provides a mathematically accurate method for dealing with uncertainty in experience systems that handle real-time data. Sobriety and ignoring the minor failure of the traditional systems of experience, as they use one rule and this rule applied, impresses the outcome.

According to Aghadadashi *et al*. (2019) [3], fuzzy logic is an important for transforming fragile aggregates into fuzzy aggregates and mathematics simplifies and accurately explains operations. It is a renewed way of thinking to address cases of ambiguity and inaccuracy that exist in our daily lives.

Fuzzy logic is used in GIS analysis, so it uses binary models, and the degree of affiliation of each value of the data aggregates corresponding to the criteria that was specified to reach them is determined, it takes a value between (0-1) where zero indicates the inability to belong to the group, while the value of 1 indicates the actual belonging to the group. Therefore, the fuzzy logic came to solve the problems resulting from traditional applications and solve the problem of inaccuracy in descriptive values, as the fuzzy logic prepares a technology to solve all kinds of inaccuracies (Dubey *et al*., 2013) [12].

According to Khavarian-Garmsir and Rezaei (2015) [16], Puente *et al*. (2019) [26] and Hembram and Saha (2025) [14], fuzzy logic and geographic information systems can be used in various applications, particularly in selecting ideal locations for pedestrians and urban planning. Some previous studies such as Al-Sulaiman *et al*. (2014) [9] and Abidi *et al*. (2024) [1] concluded that fuzzy logic could predict the presence of high concentrations of salts in irrigation water samples to find the concentration of each of the following elements (iron, magnesium, and calcium).

It has proven that the technology of fuzzy logic is used in uncertain and fuzzy information by setting laws and relationships by the researcher, as well as by producing accurate results that are close to the values that were predicted utilizing multiple linear regression (Hembram and Saha, 2025) [14]. This study aimed to use artificial intelligence with fuzzy logic technology via Inverse Distance Weighted (IDW) model for forecasting the temporal variability of appearances and land cover class of soil degradation in Saddha Al-Hindia District, Babil, Iraq.

Materials and Methods

This research work was based on some sort of spatio-temporal analyses of a phenomenon outlining its path from a temporal perspective and engisaging who this phenomenon reached to its prevailing state (Al Othman, 2009) [8]. Quantitative approach based on the utilization of statistical systems and models is used in this work which depends on the analysis and measurement, and use of numerical values to attain specific and accurate research objectives (Yahia *et al*., 2006) [30]. This is done by fabrication of spatio-temporal data in some numerical or descriptive or tabular way, and by predicting the operations according on the basis of different statistical models.

Area of study

Area of the current research work is situation in the northwestern part of Governorate of Babil in the Hindian city of Sadat lying in geocoordinates among longitudes (E 44° 07′ and 44° 26′) and latitudes (N 32˚38' and 32˚48'). It is surrounded by the Alexandria and Musayyib districts in the North, by Abi Gharq and Al-Hilla districts in the South, by Al-Mashra and Al-Mahaweel districts in the East, and by the Governorate of Karbala in the West. The total area of study was comprised of 388Km2 as shown in Figure 1.

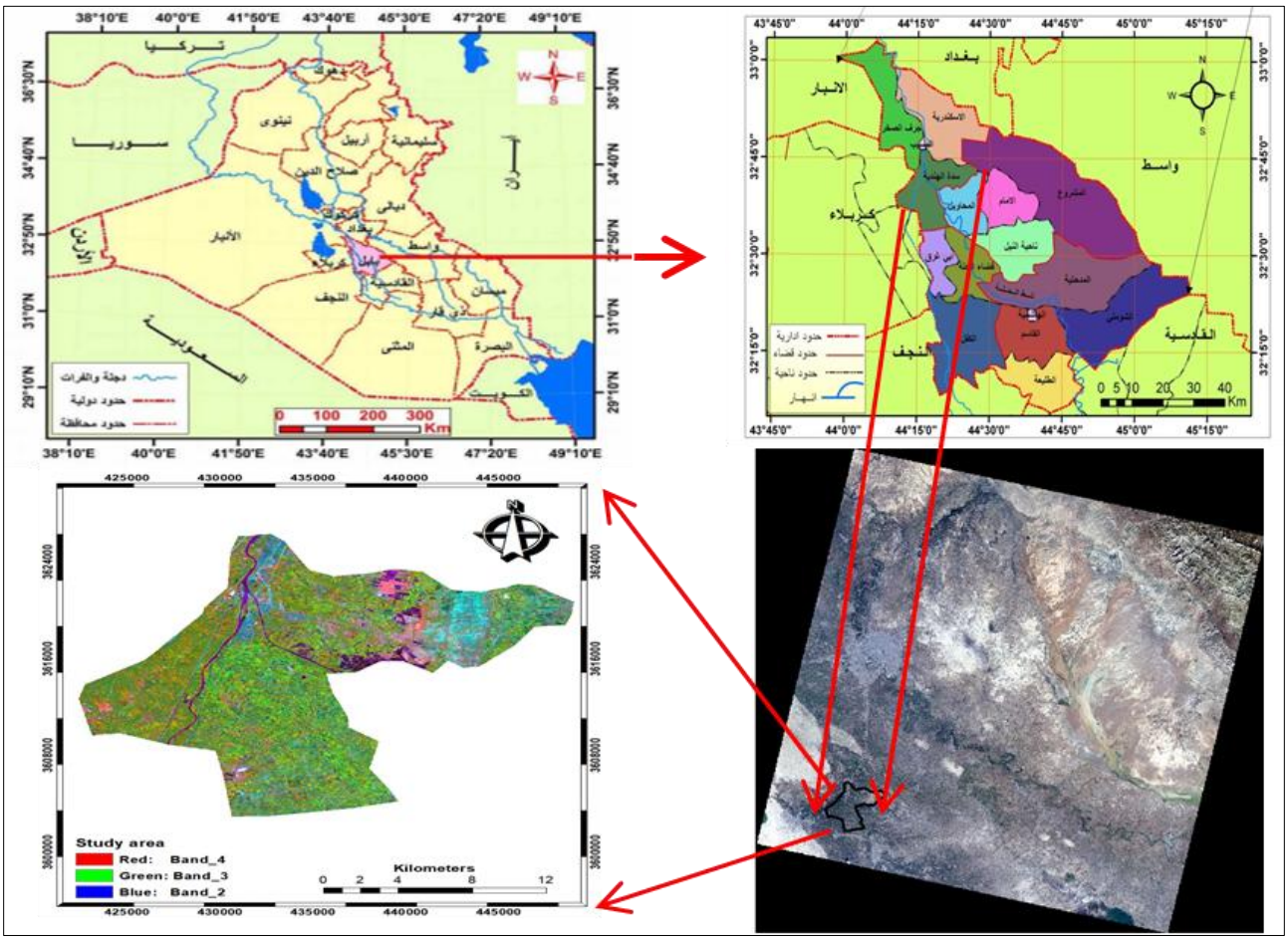

Fig 1: A detailed map of Iraq showing the location of the study area.

Methodology

IDW based spatial interpolation in cartography

The inverse-distance weighting (IDW) method is used when the change of characteristics is regular, especially in flat lands, This method was used to produce maps of soil characteristics included in the land degradation assessment equation, and maps are usually produced in ten ranges, starting from the low values to the high values of the characteristic after it, and then reclassifying them as shown in Figure 2 (A, B, C, D), and Table 1. For each of the four soil characteristics which are salinity, calcium carbonate, organic matter and the percentage of exchangable sodium. For the conduction of land cover prediction process, remote sensing programs and geographical information systems were implemented for the technical integration of data because these systems or programs support each other rather than nullifying each other. The geographic information system (GIS) was utilized in the initialization and conversion of data into different digital file formats.

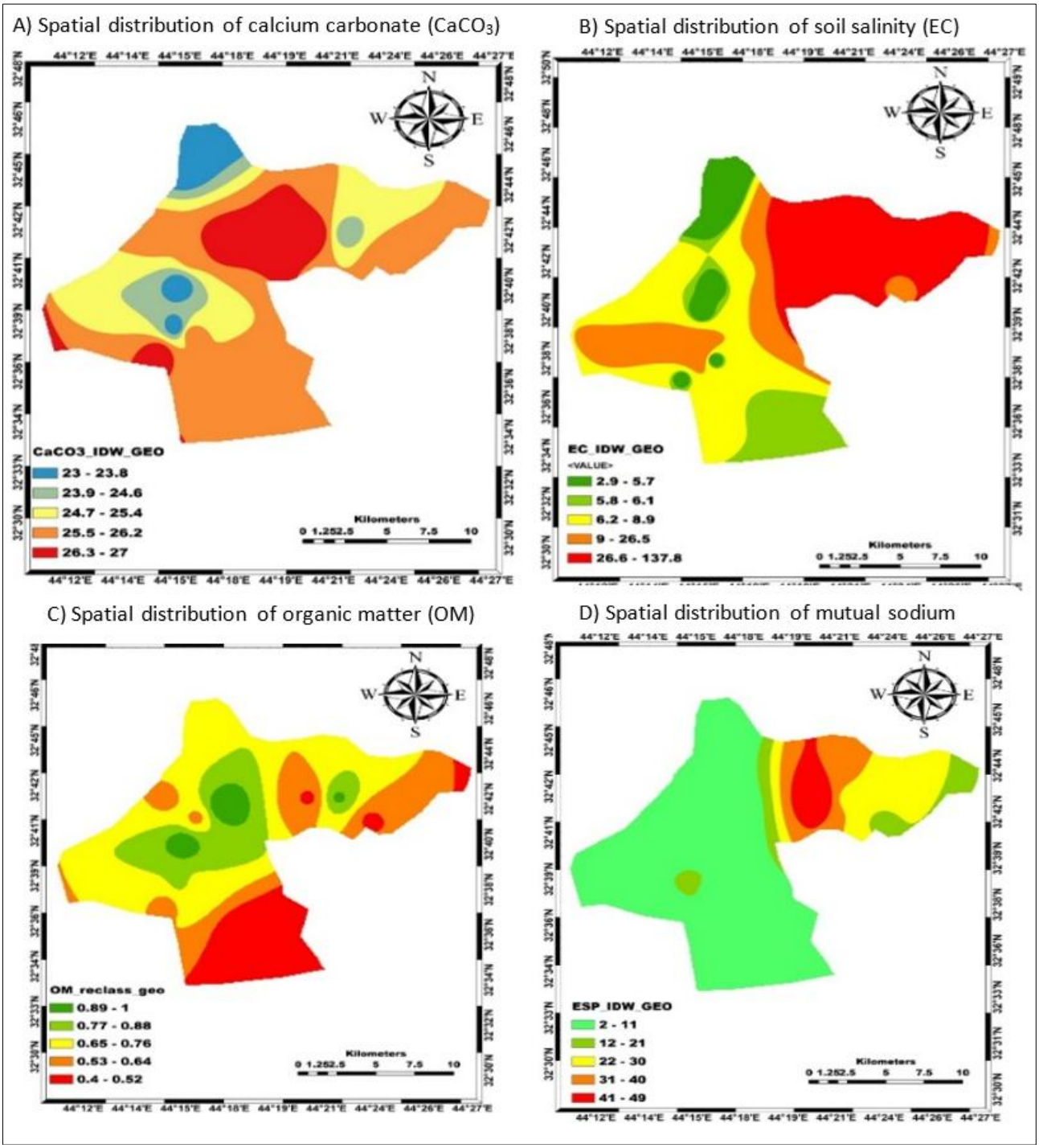

Fig 2: Four soil characteristics of the study area i.e. salinity, calcium carbonate, organic matter and the percentage of exchangable sodium.

Table 1: Soil characteristics included in the assessment of soil degradation and degrees of degradation

Degree of soil degradation	EC (dS.m)	O.M%	ESP%	CaCO3%
Non-Degradation (D0)	0 - 2	0.94-1.16	< 5	< 3
Light Degradation (D1)	2 - 4	0.74-0.94	5-8	3-10
Moderate Degradation (D2)	4 - 8	0.56-0.74	8-16	10-25
Strong Degradation (D3)	8 - 16	0.26-0.4	16-25	25-50
Extreme Degradation (D4)	16	0.13-0.26	> 25	> 50

Production of the final map

Geoprocessing technique of Map Algebra was used in the GIS environment to apply the equation (Abuzaid *et al*., 2022) [2] after reclassifying the map of the soil characteristics included in the equation below, depending on the weights given for each soil characteristic.

Equation 1

$$DI = ((EC * Weight(0.40) + ESP * Weight(0.20) + CaCO3 * Weight(0.10) + O.M * Weight(0.30)$$

Results and Discussion

The image-based disturbance index (DI) based map created on the basis of study results, as shown in Figure 3 and Table 2, indicates that there are five types of land degradation in the study area, represented by the following types: The first category (without deterioration) and was symbolized by "D_0", where it reached 69.4% of the total studied land with an area of 195 Km^2, and the second category (mild deterioration) was symbolized by "D1") and reached a rate of 11.9% of the area, as it occupied an area of 32.6 Km^2, whereas the third category (medium deterioration), symbolized by "D_2", reached a rate of 6.11% and consisting of an area of 17.2 Km^2, while the fourth category (severe deterioration), is symbolized by "D_3", occupied almost 8.6%, of the atudy area that is 24.2 Km^2.

As for the fifth category (very severe deterioration), symbolized by "D_4", that is 4.3% of the total study with covering area is 12.2 Km^2. Accordingly, the study area has the non-deterioration class predominates, followed by the mild deterioration class as a larger percentage compared to the rest of the other degrees of deterioration. The fact that part of the study area located within the Hilla-Kifl project was subjected to complete reclamation projects, which had an effective role in achieving a salt-water balance and maintaining a water depth of more than 200 cm so that the soil does not reach the critical depth and reduce salinization because of the effectiveness of reclamation operation (Haj-Amor *et al*., 2017; Nourani *et al*., 2024) [13, 22], and they are still effective with some exceptions for specific sites where re-salination operations may occur (Alkarawi and Zotz, 2014; Qureshi and Al-Falahi, 2015; Liu *et al*., 2021) [4, 27, 6, 9, 18]. As well as the presence of agricultural rotation and the cultivation of soils with vegetables under the palm orchards helped to prevent the salinity levels from rising, as it was classified under the degree of mathsf S0 to mathsf S1 at specific sites (Zabar *et al*., 2012; Al Kharusi *et al*., 2017; Al-Hamad *et al*., 2021; Hussain *et al*., 2024) [15, 7, 31].

Whereas sedimentary soils with good drainage prevail in current study, followed in terms of the common percentage within the study area, the average degrees of degradation is 25.9%. It is located within the Husseiniya Bani Hassan project, adjacent to the old Husseiniya Bani Hassan canal, and as a result of the (seepages) leaching operations from water sources, which led to a rise in ground water levels to 150 cm, which was reflected in the hydrological and humid conditions of the soil of the study area, that led to the supremacy of the moisture regime (aquatic) as for the severe and very severe deterioration that is 8.6% and 4.3%, respectively. It was located within the Alexandria Mahaweel project due to the high evaporation processes, the lack of drainage and the lack of vegetative cover (Nassif *et al*., 2021) [21]. In addition to the lack of land use, the decrease in the area affected the classification of the soil into saline soils (Al-Ibrahimi and Ghalib, 2018; Li *et al*., 2024) [5, 17].

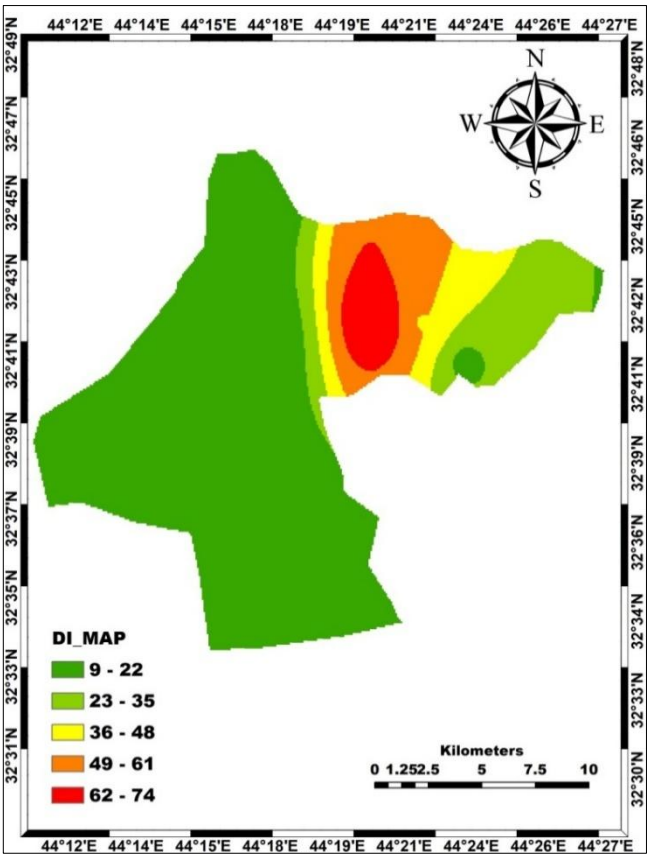

Fig 3: The image-based disturbance index (DI) map of the spatial distribution of the degrees of soil degradation in the study area.

Table 2: Degrees of soil degradation found in the study area.

Degrees of degradation	Area Km^2	Degradation rate%
D0	195.2	69.4
D1	32.60	11.9
D2	17.20	6.11
D3	24.20	8.60
D4	12.20	4.33
Sum	281	100

Conclusion

It has been concluded that the study area (irrigated reclamation sites) is dominated by the nondegradation category, followed by the light degradation category, which has the largest percentage compared to the rest of the degrading degrees. Cultivating fields with vegetables under palm groves with continuous agriculture rotation is recommended to prevent the high levels of salinity, as it was classified under the degree mathsf S0 to mathsf S1 (in some sites). Therefore, this part is dominated by well-drained sedimentary soil.

Author's Contribution
All authors have equal contribution to this work.

Conflict of interest
The authors have declared no conflict of interest.

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