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Soil Degradation Mapping in Sulaimani Territories, Kurdistan Region of Iraq using GIS Techniques

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Abstract

The phenomenon of desertification refers to the degradation of lands that cause instability in social and economic conditions. This study aims to evaluate desertification intensity in the Sulaimani area, Kurdistan Region, Northeastern Iraq. For this study, the Iranian Model of Desertification Potential Assessment (IMDPA) is adopted to evaluate the intensity based on different soil criteria, including; (i) Soil Depth, (ii) Electrical Conductivity (Ec), (iii) Texture, (iv) Gravel percentage. Three interpolation techniques (Inverse distance weighting (IDW), Kriging, and Spline) are applied to create a spatial distribution map. The results indicated that the soil depth has a significant effect, but Ec and rock fragments have less effect. The desertification map showed that 53.7% and 46.3% of the total study area are classified as low as a medium class of desertification intensity, respectively. These results have a significant role in the decision-making process for better land management.

Introduction

Desertification is a process that occurred in arid, semi-arid and dry sub-humid areas resulting from several factors, including climatic alterations and human actions ***[1]***. Jafari *et al.* ***[2]*** argued that to control or mitigate desertification processes, it is crucial to understand the relationship between desertification and climate, soil, water, vegetation and socio-economic. Desertification results from several degradation processes that are active in the Mediterranean environments, especially in arid and semi-arid environments, where water is a limiting factor of land use ***[3]***.

The effects of desertification are the degradation of ecosystems, a complex phenomenon that leads to the reduction of land productivity and the decline of croplands, leading to problems of food availability and security ***[4 , 5]***. Several factors exacerbate this phenomenon, such as climate dryness, geological and morphological characteristics of the terrain, increasing populations, and pressure on the exploitation of plant and water resources ***[6]***.

Iraq is located in the range of semi-tropical latitude in the Northern Hemisphere between longitudes (38.45°-48.45° E) and 46.3% and latitudes (29.5°-37.5° N). Most of the Iraqi soils are considered arid land (more than 75%). The rest is a semi-arid area where crops experience moisture stress ***[7]***.

Different models can be used to assess degradations, such as UNEP-FAO ***[8]***, Iranian Classification Desertification (ICD) ***[9]***, Mediterranean desertification and land use (MEDALUS) ***[3]***, Modified Iranian Classification Desertification (MICD) ***[10]***, Environmentally Sensitive Areas (ESAs) ***[11-15]***, and Iranian

Model of Desertification Potential Assessment (IMDPA) ***[16]***. Soil degradation is one of the processes used on the different desertification methods such as UNEP-FAO, ICD, and IMDPA as desertification criteria ***[17]***.

The IMDPA method makes use of GIS capabilities in mixing information layers providing assessment, and basic data collection, as well as to reducing diagnosis error is of greater accuracy in comparison with other methods ***[18]***. *The* arrangement of criteria and indices is effective in desertification and the possibility of planning and making decisions for the region and the country to control and manage them ***[19].***

In this research, the IMDPA model was tested to determine the areas susceptible to desertification and provide a desertification intensity map of the Sulaimani province of Iraq, emphasizing soil criteria, which ease decision-making and recommendations for recommendations desertification control activities. Also, four desertification parameters were used to assess soil degradation: electrical conductivity (Ec), soil depth, soil texture, and rock fragment percent ***[17]***.

The IMDPA model has been successfully used in Iran. This is a comprehensive desertification model developed by the Faculty of Natural Resources, University of Tehran, as the outcome of a project entitled Determination of Methodology of Desertification Criteria and Indices in Arid and Semi-Arid Regions in Iran. In total, 9 criteria and 130 indices were introduced in the form of quantitative and weighted values which would determine the desertification intensity under all cases ***[20]***.

All the models as mentioned earlier have been designed based on climatic, ecological, biological and socio-economic conditions. Therefore, it is crucial to design a national model for Iraq and Kurdistan Region to assess land degradation to help control and reduce damages resulting from this phenomenon. Because of the lack of adequate studies in this area, this study was conducted to assess the most important criteria regarding the soil and affecting desertification. This study aims to evaluate the desertification intensity and mapping the soil degradation in Sulaimani province. To do this, the IMDPA model is used and different interpolation methods are applied to create a desertification intensity map of the Sulaimani province of Kurdistan-Iraq by using ArcGIS software.

Materials and method

A. Study site

In order to evaluate soil's role in desertification, Sulaimani province was chosen as a study area. The study area is located in Northeastern Iraq, between latitudes 35°13ˉ13.40“ & 35°53ˉ13.2“ N and longitudes 46°0ˉ13.35“ & 44°54ˉ57.7“ E, and, an altitude between 520 and 1232 meters above sea level *(Figure: 1)*. The study area climate is hot and dry in summer and cold in winter. Annual average precipitation is ranged between 450-700 millimeters ***[21]***.

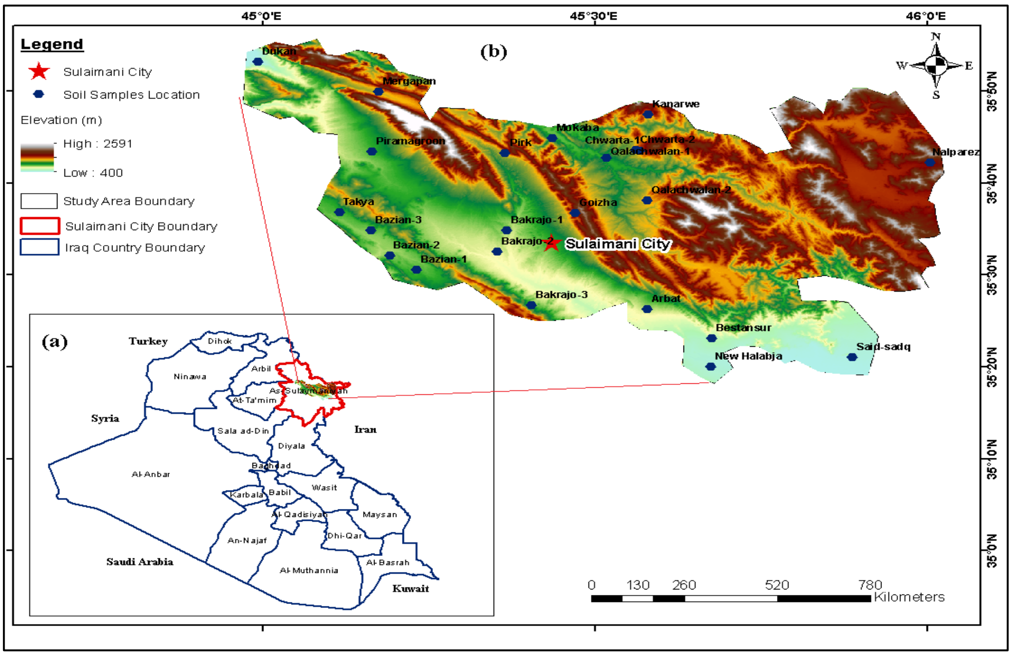

Figure- 1: Map of the studied area showing: (a) Map of Iraq. (b) Location map of the study sites in the Sulaimani City.

B. Methodology

This study included fieldwork, soil sampling, soil physical and chemical laboratory analyses, data analyses according to IMDPA, remotely sensed dataset collections, statistical analyses, and GIS analyses. Figure (2) shows the flowchart of the methodology applied in this study.

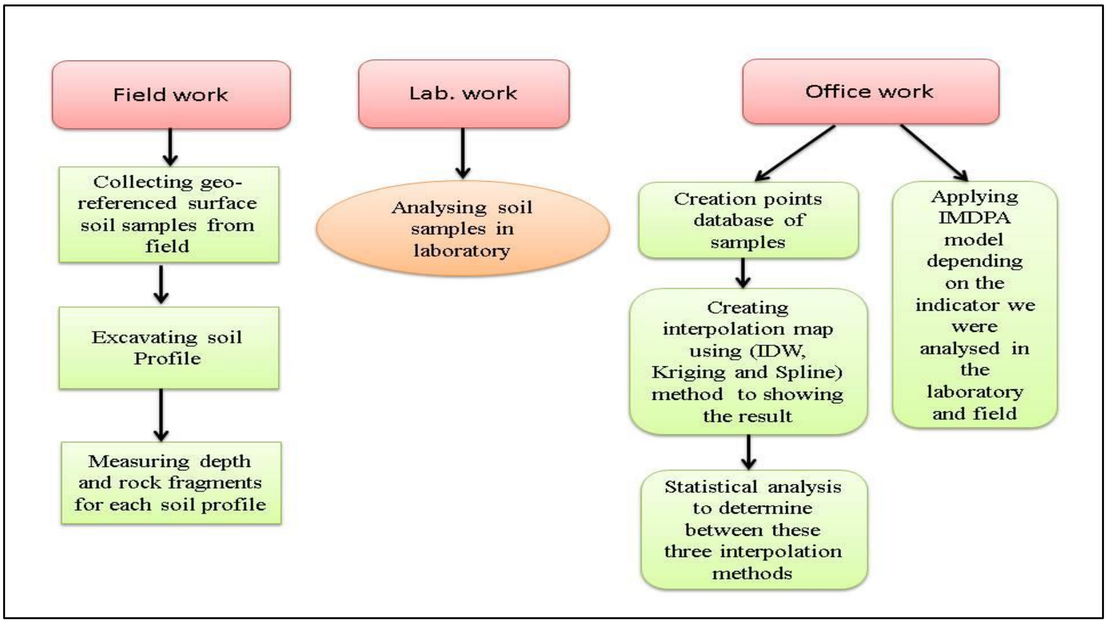

Figure- 2: Methodology Flowchart

C. Fieldwork and laboratory analysis

In order to obtain soil information about the selected area, 23 locations were randomly selected in Sulaimani Province for soil sample collection *(Figure: 1)*. The soil profile was excavated for each point. Depth of soil surface horizon and rock fragments of each soil profile was measured in the field. In contrast, electrical conductivity (Ec) and soil texture were measured in the laboratory. The international pipette method was adopted to measure particle size distribution ***[22]***. Ec (dSm^{-1}) was determined in 1:2.5 soil-water solution ***[23]*** using Ec meter (Betz Dearborn-LF 318/Set-Germany) after being adjusted to 25°C. Both physical and chemical laboratory analyses are shown in *(Table: 1)*.

IMDPA model

IMDPA model is a widespread desertification model that is applied to evaluate the role of soil in desertification. The severity of desertification is assessed in this method through nine criteria including soil, erosion (Aeolian and fluvial), climate, water, vegetation, agriculture, technological development, and management ***[19]***. Its score range from 1 to 4 is assigned to each index based on the weight of each factor.

One of the disadvantages of the proposed procedure is the difficulty of measuring all effective factors because of limiting parameters such as costs, intensive fieldwork, and deficiency of necessary data and information. All indices play major roles in the desertification process ***[20]***.

Hence only soil was used as an index for evaluating the desertification intensity (Soil is a reliable factor) using equation 1. Finally, the desertification intensity will be the outcome of one criterion: Desertification intensity = soil index using equation 2, ***[2]***.

Index-X = [(Layer1)] 1/n ……………………………………….. (1)

where:
Index-X: the required index (soil index).
n: number of indicators for each index.
Layer: indicators for each index (Electrical conductivity (Ec), soil depth (surface horizon), soil texture, and rock fragment %).
Soil index= (Soil texture × Soil depth × Rock fragment% × Electrical conductivity)$^{1/4}$ ….… (2)

Each parameter value was calculated separately with regard to land units. Table (2) indicates how the studied parameters were scored. Finally, a map of soil quality index was obtained by calculating geometric means of relevant indices according to the formula equation 2.
The risk of desertification (final map) is classified into four subtypes or classes, as illustrated in Table: (2).

Table- 1: Soil physical and chemical laboratory analysis.
C: clay Si: silt S: sand L: loam SiCL: silty clay loam CL: clay loam SL: sandy loam SiL: silty loam.

N0	Location	Long.	Lat.	Depth cm	Sand g kg^{-1}	Silt g kg^{-1}	Clay g kg^{-1}	Texture	Ec dSm^{-1}	Rock fragment %
1	Goizha	45.46993	35.61165	22	83.933	388.625	527.442	C	0.1361	<15
2	Chwarta-1	45.56667	35.72395	20	595.404	350.302	54.296	SL	0.3273	<15
3	Chwarta-2	45.56667	35.72395	20	218.526	471.785	309.689	CL	0.1741	<15
4	Kanarwe	45.57987	35.78955	13	319.572	328.384	352.044	CL	0.2291	<15
5	Qalachwalan-1	45.51707	35.711	14.5	314.851	578.979	106.170	SiL	0.1401	<15
6	Qalachwalan-2	45.57861	35.63417	13	145.2	518.1	336.7	SiCL	1.12	<15
7	Mokaba	45.43582	35.74767	11	316.206	361.025	322.769	CL	0.2513	<15
8	Pirk	45.36513	35.72043	19	175.730	344.229	478.471	C	0.1374	<15
9	Mergapan	45.17443	35.83158	17	687.285	175.959	136.756	SL	0.0798	<15
10	Dukan	44.99295	35.88553	13	365.865	385.644	248.491	L	0.3024	<15
11	Piramagrwn	45.16423	35.72322	19	143.724	478.012	378.264	SiCL	0.1911	<15
12	Bazyan-1	45.23171	35.50942	20	123.214	430.358	446.428	SiC	0.1571	<15
13	Bazyan-2	45.19147	35.53515	17	51.601	467.972	480.427	SiC	0.1427	<15
14	Bazyan-3	45.16388	35.58039	17	64.946	468.862	466.192	SiC	0.1584	<15
15	Takiya	45.11594	35.61266	11	41.58	488.27	470.15	SiC	0.37	<15
16	Bakrajo-1	45.35247	35.54228	19	78.53	498.74	422.73	SiC	0.2422	<15
17	Bakrajo-2	45.40389	35.44472	23	68.76	503.59	427.65	SiC	0.23	<15

18	Bakrajo-3	45.40389	35.44472	26	74.5	582.8	342.7	SiCL	0.29	<15
19	Arbat	45.57861	35.43722	22	79.90	490.65	429.45	SiC	0.35	<15
20	Bestansor	45.67583	35.38444	17	99.4	479.3	421.3	SiC	0.57	<15
21	Said-Sadiq	45.88727	35.35089	26	242.45	375.32	382.23	CL	0.28	<15
22	New Halabja	45.67425	35.33289	28	54.8	512.4	432.8	SiC	0.44	<15
23	Nalparez	46.00371	35.70351	17	378.15	298.90	322.95	CL	0.1885	<15

Table- 2: Soil degradation classification based on IMPDA model ***[2 and 17]***

		Potential of land degradation			
Class		**Low**	**Medium**	**High**	**Very high**
	Numerical Value	**0-1.5**	**1.6-2.5**	**2.6-3.5**	**3.6-4**
1	Ec (dSm^{-1})	<5	5-8	9-16	>16
2	Soil depth (cm)	>80	50-80	20-50	<20
3	Soil texture	SC - SiC	L- SCL- SiCL- SiL	LS - SL	S – C>%60
4	Rock fragment %	<5	15-35	35-75	>75

Interpolation methods

In this study, three interpolation methods were applied. They include (IDW, Kriging, and Spline). We selected three methods to explore which method is reliable for our work. Description of the methods explained in ***[24]***.

Results

A. Desertification index and quality

Table (3) shows the desertification index values and desertification quality classes for studied locations based on soil index. The desertification index value is ranged between 1.31-1.86. It is equal to the low and the medium class as desertification quality.

Table- 3: Location of the studied area and classification of the desertification intensity based on soil index.

No	Location	(Soil) Desertification index	Desertification quality
1	Goizha	1.73	Medium
2	Chwarta-1	1.31	Low
3	Chwarta-2	1.31	Low
4	Kanarwe	1.41	Low
5	Qalachwalan-1	1.68	Medium
6	Qalachwalan-2	1.68	Medium
7	Mokaba	1.41	Low
8	Pirk	1.86	Medium
9	Mergapan	1.41	Low
10	Dukan	1.41	Low
11	Piramagrwn	1.68	Medium
12	Bazyan-1	1.73	Medium
13	Bazyan-2	1.86	Medium
14	Bazyan-3	1.86	Medium
15	Takiya	1.86	Medium
16	Bakrajo-1	1.86	Medium
17	Bakrajo-2	1.73	Medium-
18	Bakrajo-3	1.56	Medium
19	Arbat	1.73	Medium
20	Bestansor	1.86	Medium
21	Said-Sadiq	1.31	Low
22	New Halabja	1.73	Medium
23	Nalparez	1.41	Low

Table- 4: The Geometric average of quantitative values studied indicator

Order	Index	Value	Class
1	Ec	1	Low
2	Depth	3.5	High
3	Texture	2	Medium
4	Rock fragment	1	Low

In table 4, the average of each indicator, explains the effective mean value of four studied indices on soil degradation. It reveals that soil depth is the most effective element in intensifying soil degradation intensity, soil depth has a high effect on soil desertification in the Sulaimani governorate because of the shallow soil profile, and the geometric average of soil depth is 3.5. It indicates a high value of desertification risk intensity.

B. Map of the spatial distribution of desertification indexes.

Figure *(3, 4, and 5*) shows the spatial distribution of soil index using different interpolation techniques. The correlation coefficient between observed and predicted soil index values was 0.62, 0.66 and 0.32 for IDW, Kriging and Spline, respectively *(Table: 5)*. According to the spatial distribution map based on Kriging method, the study found (*Table: 6*) that 1874.6153 km^2 and 1616.5809 km^2 of the total studied area are laid in negligible-low and medium desertification severity classes, respectively. The geometric and means of quantitative values of soil parameters indicated that the most effective factor in increasing the soil degradation intensity based on soil index is soil depth (numerical value = 3.5).

C. Validation of interpolation methods

Table 5 illustrate the correlation coefficient between observed soil and predicted soil index values, while Table (6) show area of desertification quality classes based on Kriging method map. In this study desertification classes descripted to low and medium classes which covered 53.7% and 46.3% of the total study area, respectively.

Table- 5: Correlation coefficient between observed soil and predicted soil index values.

Methods	Correlation coefficient
IDW	0.62
Kriging	0.66
Spline	0.32

Table- 6: Area of desertification quality classes based on Kriging method map

Classes	Description	km^2	Area%
1	Low	1874.6153	53.7
2	Medium	1616.5809	46.3

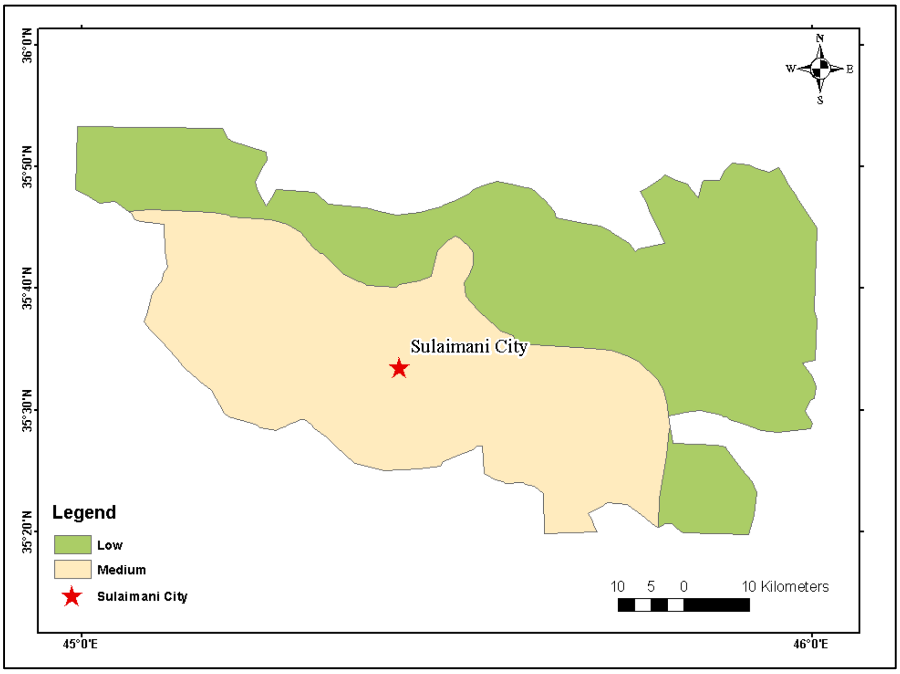

Figure- 3: Spatial distribution of desertification quality classes using the IDW method.

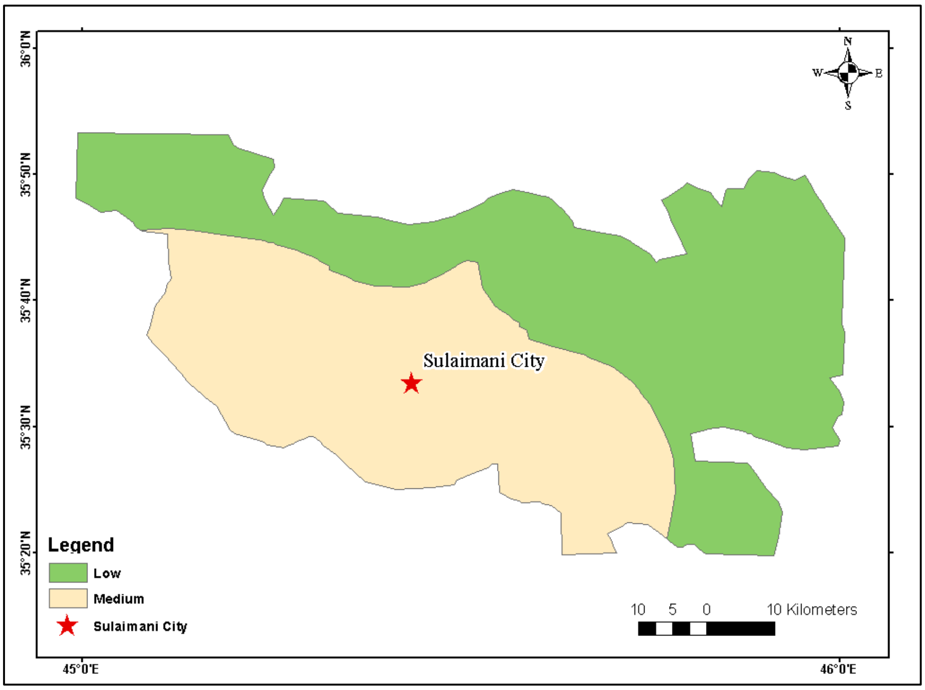

Figure- 4: Spatial distribution of desertification quality classes using the Kriging method.

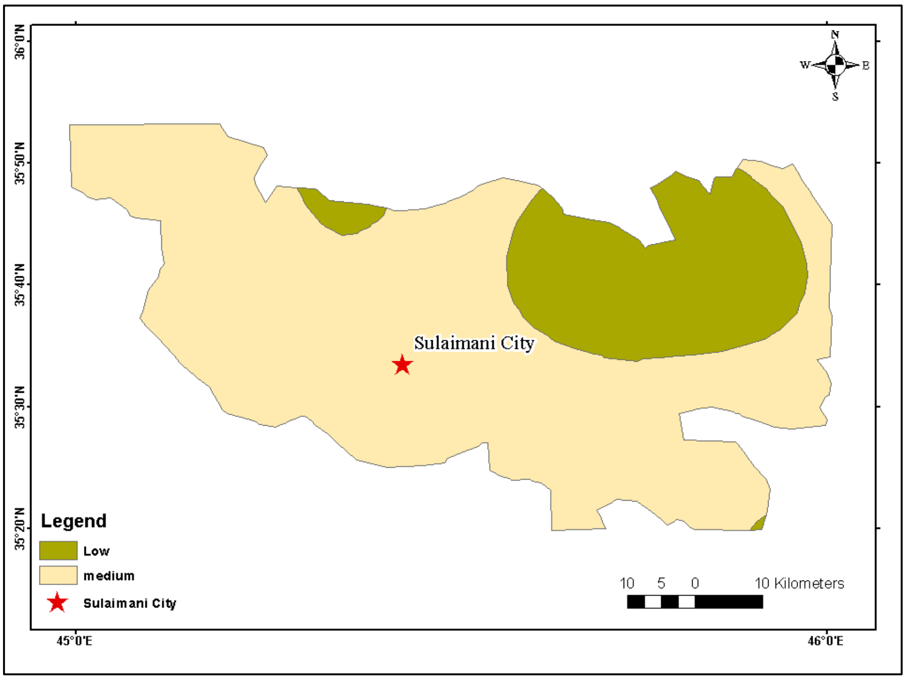

Figure- 5: Spatial distribution of desertification quality classes using the Spline method.

Discussions

There are some researches in Iraq (Especially in Kurdistan Region) dealt with desertification such as ***[7 , 25]***. In addition, only limited information is available regarding the desertification of arid and semi-arid areas. It is essential to design a model that is appropriate with the diverse environmental conditions of Iraq, considering the most influential factors in desertification. Generally, since each country or region has a distinctive climate and human structure, therefore, the assessment of desertification is different from country to country and region to region.

In this study, IMDPA model was selected among different existing methods, which is adequate to assess the land quality indices, according to some researches which selected one or two indices to determine desertification severity such as ***[2 ,17 , 20, 26, 27]***, one of the characters is soil, and ***[7]*** using soil quality by MEDALUSE project. Also, four desertification parameters were used to assess the soil: Ec, soil depth, soil texture and rock fragment percent.

Soil is the main factor in evaluating the environmental sensitivity of an ecosystem, particularly in the arid, semi-arid, dry and sub-humid regions ***[17]***. Soil characteristics directly affect the desertification severity and degradation phenomena, especially water retention and storage capacity, and resistance to erosion. Soil depth is one of the essential factors in measuring the susceptibility to desertification. The shallower the soil, the more sensitive to desertification, and vice versa ***[17]***. Soil depth is divided into four classes according to its depth (i.e., deep, moderately deep, not deep, and very thin soil). The very thin soil is highly vulnerable and sensitive to desertification and takes a score of 4.0 on the desertification sensitivity index ***[17]*** *(Table: 1)*. Hence, two classes of soil depth were determined. They are not deep or very thin soil. Table 4 shows a geometric average of the quantitative value of soil depth. Soil depth is linked to water availability, a deep soil can assure water reserves and can then provide a good condition for vegetation development and growth ***[28]***.

Another significant factor in determining the susceptibility to desertification is soil texture. Based on soil texture, soils are divided into four classes (Based on IMDPA; *Table: 2*). Three classes of determining soil texture have a low, medium and high potential of land degradation, which similar results finding have been reported by ***[7]***. The coarse-textured soils are the most susceptible to desertification which takes a score of 4 on the sensitivity index of desertification *(Table: 1)*, and the geometric average of soil texture is 2. It indicates a medium value of desertification risk intensity (*Table: 4*).

Rock fragment percentage in soil surface can be classified into four classes according to their capability to sustain soil water and protect soil from erosion, as illustrated in (Table: 1). The result of the rock fragment index shows that the Sulaimani region falls within the low class of desertification. Soil Electrical Conductivity is regarded as one of the key factors of soil degradation employed in several desertification models as a soil-criteria index. In this study, only one class of electrical conductivity index was noted (*Table: 4*), which is very low because Ec is less than 4 dSm^{-1} (According to IMDPA model).

Based on the current study's results, the studied locations have low and medium intensities of soil desertification. The soil criterion (average weight = 1.63) has a medium effect on the Sulaimani region's desertification process. Analysis of soil criteria reveals that the desertification rate in the Sulaimani is not intensive, the same result as ***[7]*** they studied desertification of the part of Iraq, they indicated that the soil quality indicator and comparing it with the quality classes in the MEDALUS model, it seems that the soil of the study area is divided into two classes low and moderate quality.

The soil is crucial in assessing an ecosystem's environmental and desertification sensitivity, particularly in arid and semi-arid zones. The soil criteria were evaluated, depending on soil texture class, soil depth (cm), electrical conductivity, and the rock fragment (%). The classes, description and areas of soil criteria of Sulaimani territory represented in Figure (1). The area is of medium soil quality (value 1.6-2.5), representing the soil coverage. The medium class of soil degradation dominates the studied area, characterized by shallow depth; the depth has a significant effect on soil desertification in the study area because its average value is 3.5, which in turn belongs to the very thin soil depth medium class texture. Besides, rock fragment% and Ec represent low class and have a low effect on desertification intensity in the study area. So, to increase the soil depth, it must be protected from erosion. This can be executed by implantation those plants that their roots protect soil from erosion.

Conclusions

The variation and intensity of desertification have become increasingly severe in some dry areas in recent decades. This study applies the IMDPA model and different interpolation techniques to evaluate land degradation in Sulaimani province, a semi-arid environment. The results indicated that the south part of the study area is more susceptible to desertification than the north part. Soil depth is the most significant parameter affecting these processes compared to the other parameters such as soil texture, Ec and rock fragmentation%. Kriging's interpolation method gave a most reliable result than IDW and Spline. The desertification assessment is rather important to plan a sustainable development in medium desert areas such as the south of Sulaimani province. Mathematical modeling is recommended for the operational monitoring of different elements that contribute to the desertification process.

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