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EVALUATING TEMPORAL VARIATIONS IN SOIL DETERIORATION IN IRAQ'S KARMA DISTRICT USING SPECTRAL INDICATORS

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Abstract

This study used spectral indicators to analyze the temporal changes relating to land deterioration and increased desertification in the Al-Karma district of the Anbar governorate in Iraq. Desertification is the main reason for the loss of agricultural lands in the study area and the rise in related environmental issues. The study area was located between two terrain regions: the alluvial plain and the island region between latitudes 33º 41' 30" N and 33º 19' 00" S and longitudes 44º 10' 00" E and 42º 10' 20" W. The study analyzed the environmental elements and data using GIS and RS systems and technologies, in addition to fieldwork. The NDVI vegetation index, NDBI urban mass index, and the LDI soil degradation index were used to compare desertification trends between 2002 and 2023. The indicators revealed the higher levels of desertification in the study area, with the NDVI showing an increase in plantless areas from 42 km^2 in 2002 to 688 km^2 in 2023 while densely planted lands declined markedly in the same period from 522 km^2 to 35 km^2. The NDBI registered an increase in area for medium- and high-density urban land categories to 181 km^2 and 691 km^2, respectively, while soil degradation based on the LDI increased from 99 km^2 to 245 km^2 over the two years.

Keywords: Temporal Analysis, Soil Deterioration, Desertification, Spectral Indicators.

التغير الزمني لتقييم حالة تدهور تربة قضاء الكرمة – العراق باستخدام الأدلة الطيفية

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الخلاصة

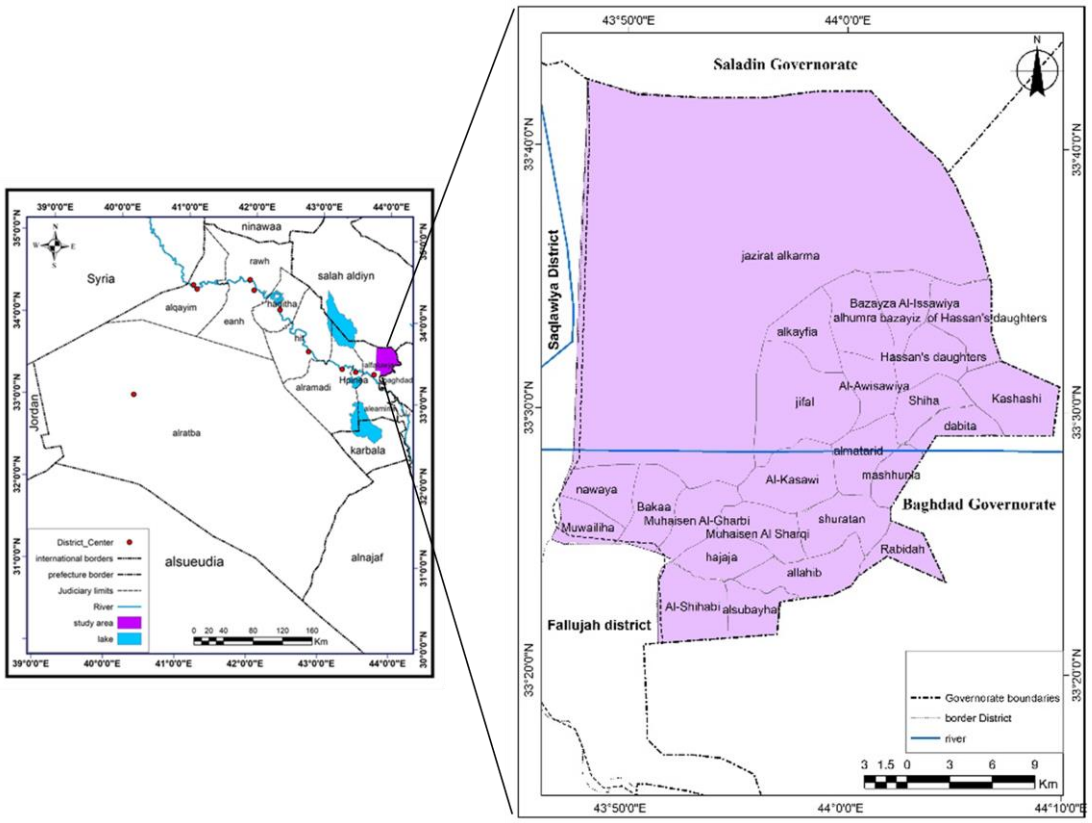
هدفت الدراسة الى التحليل الزماني والمكاني لمؤشرات تدهور الاراضي وزيادة ظاهرة التصحر في قضاء الكرمة، أحد اقضية محافظة الانبار في العراق. اذ تعد مشكلة التصحر هي السبب الرئيس في تقلص الاراضي الزراعية في منطقة الدراسة، مما زاد من بعض المشكلات التي اضرت بالواقع البيئي. تقع منطقة الدراسة بين منطقتين تضاريسيتين: السهل الغريني ومنطقة الجزيرة، وفلكياً بين خطي عرض (`30`41 33 درجة شمالاً و`00`19 33 درجة جنوباً). وقد تم تناول هذه المشكلة من خلال تحليل العناصر والمعطيات البيئية باستخدام أنظمة وتقانات (GIS and RS) بالإضافة الى العمل الحقلي. اذ تم توظيف بعض المؤشرات المهمة لمشكلة التصحر ومساراتها من خلال مقارنة اتجاهات تطورها بين فترتين زمنيتين للفترة بين 2002 – 2023، وهذه المؤشرات تمثلت بـ (مؤشر دليل النبات NDVI، مؤشر دليل الكتلة الحضرية NDBI، ومؤشر تدهور التربة LDI). التي اشارت الى وجود تصحر عالي في منطقة الدراسة، حيث اشارت نتائج مؤشر (NDVI) الى ارتفاع المساحات عديمة النبات حيث ازدادت من 42 كم^2 في عام 2002 الى 688 كم^2 في عام 2023، اما الاراضي الكثيفة النبات فقد تراجعت بشكل ملحوظ بين نفس العامين من 522 كم^2 الى 35 كم^2، اما اهم النتائج حسب مؤشر (NDBI) هي ارتفاع مساحة فئتي الاراضي الحضرية متوسطة الكثافة وعالية الكثافة لتصبح (181 كم^2، 691 كم^2) على التوالي في عام 2023. أما مؤشر تدهور التربة (LDI) فأشارت نتائجه الى ارتفاع تدهور الترب من 99 كم^2 عام 2002 الى 245 كم^2 عام 2023.

كلمات مفتاحية: التحليل الزماني، تدهور الأراضي، التصحر، المؤشرات الطيفية.

Introduction

Desertification is a damaging environmental phenomena that threatens the wellbeing of communities as fertile agricultural lands degrade into barren lands that negatively impact human life and national economies (3). Desertification is a process of reducing or destroying the Earth's vital energy (8), which can ultimately lead to desert-like conditions. It is a manifestation of the widespread deterioration of environmental systems, leading to a reduction in the Earth's vital energy represented by plant and animal production, and ultimately affects human support systems. Climate change is affecting agricultural areas in Iraq, causing desertification, undermining agricultural development, and reducing livestock, leading to the loss and

absence of natural vegetation and threatening humans and the country's food security (16). Some studies in the field of desertification (5) employ surface spectral characteristics that integrate various modern technologies to measure desertification around the world (12). This research examined appropriate indicators to measure the phenomenon of desertification in the Al-Karma district and its spatial variation through geographical information and remote sensing systems (13), the reasons behind this environmental problem, and its impact on the ecosystem. The NDVI, NDWI and LDI were used to detect desert changes and make a post-classification comparison of two main types of land cover, which are plants and water bodies (11), to conduct a change detection analysis in the study area. The research hypothesis was that the study area suffers from the problem of desertification and the deterioration of its land cover, which has affected the productivity of its agricultural land and the ecosystem (4). To investigate this issue and explain its intensity and impacts, some indicators were used to examine the phenomenon spatially and temporally (3). The aim was to analyze the natural and human data of the study area to explain the desertification, its causes, trends and effects on the ecosystem through spectral evidence (14), as well as provide a spatial analysis of the areas and extent of the desertification levels. Desertification is one of the contemporary problems affecting arid and semi-arid regions in particular, due to their special ecosystems. The wide fluctuations in precipitation rates and the impact of climate change in these regions causes a decline in the productivity of the land and creates a desert-like environment (6). In this research, the desertification phenomenon in the study area were measured through three key indicators using GIS and RS (1). The study area covered Al-Karma district in the Anbar governorate of Iraq. Specifically, it is located between two terrains, namely the alluvial plain and the island region between 33^{o} 41' 30" N and 33^{o} 19' 00" S and 44^{o} 10' 00" E and 42^{o} 10' 20" W (9), and includes 25 agricultural districts (Map 1).



Map 1: Location of the study area in Anbar governorate.

Source: Ministry of Water Resources, General Authority for Survey, Administrative Map of Iraq, 2022. Scale 1:1000000.

Materials and Methods

The study used spectral reflectance of the satellite visuals (LANDSAT8) sensor (ETM) with a discriminatory accuracy of 30x30^{m} for 2002 and 2023 in order to conduct a temporal and spatial analysis for detecting changes in the development of the phenomenon of desertification (9) The selected indicators were divided into levels according to the spectral data and their percentages, and spatial and temporal variables based on the appropriate equations below (23).

Results and Discussion

The scientific research was built on a set of evidence and indicators derived using remote sensing (RS) and geographic information system (GIS10.8) channels. They were then matched with the results of field work for the purpose of ensuring the accuracy and validity of the information, as follows:

Vegetation Index (NDVI): The NDVI is one of the important means used in the digital processing of space data. It shows the extent and changes in vegetation cover assuming that the value of the index is positively proportional to the density of vegetation cover for the area concerned (15). These changes are calculated based on the relationship between the amount of reflected rays in the near-infrared and red channels and help monitor seasonal and annual changes in the growth and variations in vegetation cover. This evidence is related to the type of land cover and its ability to absorb or reflect red and infrared rays through chloroplast material, which has the

ability to absorb red rays (18). As for bare and semi-bare areas, they reflect infrared rays, and as a result, areas with dense vegetation differ in their natural characteristics in the red section of the layer from those in which short infrared rays are present (21). NDVI values range from -1 to +2, and the value of the positive number increases in line with the density of the vegetation cover. The lower values of the positive number indicate a decrease in the density and growth of the vegetation cover.

The following equation is used to calculate the value of the NDVI (2):

$$NDVI = \frac{BandNIR - Band\ RED}{Band\ NIR + Band\ RED}$$

Where, NDVI = vegetation cover rate, Band NIR is the infrared rate, and Band RED is the red ray rate

The values for this indicators were compared for two time periods, in 2002 and 2023, to determine the extent of changes in vegetation density (24). Maps 2 and 3, and Table 1 show the four categories of plant index values, as follows:

A. The first category (plantless) was the smallest covering 42 km^2, representing 4.2% of the study area in 2002. It covered areas within the Saqlawiya irrigation project and comprised mainly residential and urban areas. This is an indication of the good condition of the vegetation that did not deteriorate to desertification levels over the study period. By 2023, this category of land had increased significantly to 688 km^2 or 68.2% of the total. It represented the opposite situation, as most of the areas in this category are located within the Al-Jazra and Al-Karma provinces, which represents the state of natural vegetation cover as it is terrestrial areas. This is a clear indication of the decline in the state of vegetation cover, due mainly to drought caused by climate change, and the worsening issue of desertification in the area.

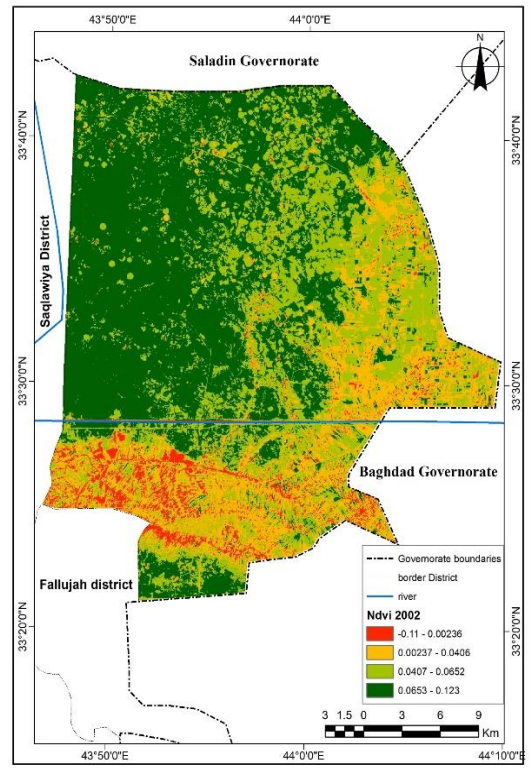
B. The second category (low vegetation) occupied 167 km^2 or 16.6% of the study area in 2002 and was mainly in the southern and eastern parts comprising irrigation projects and rural villages. By 2023 it had increased to 194 km^2 (19.2%), and its geographical location did not change, as in the first category.

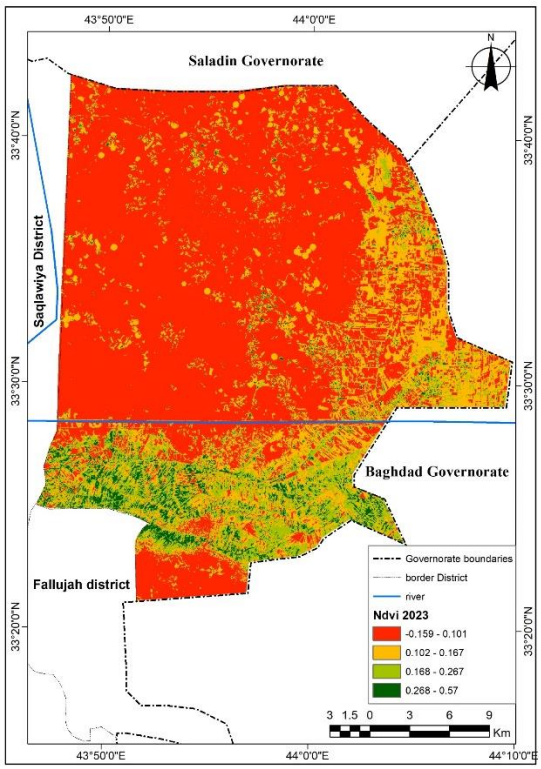
C. The third or medium-vegetation area stood at 278 km^2 in 2002 or 27.6% of the total but its area had decreased markedly to 92 km^2 (9.1%) by 2023. This category was located in the irrigation project areas within the Karma Plain, with simple extensions on the outskirts of the Karma Island plateau in the southern and eastern parts, indicating a deterioration in the situation (10).

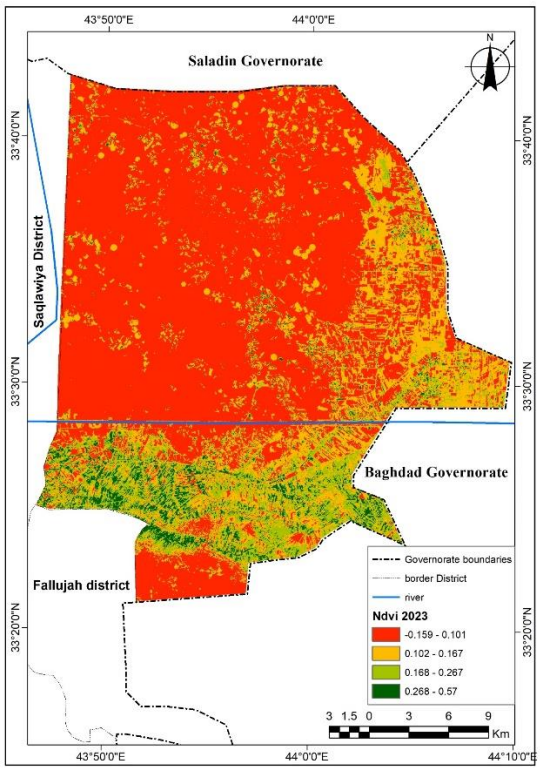
D. The fourth category (dense vegetation) occupied a large portion of the study area at 522 km^2 or 51.7% of the total in 2002 with most of it located in the plateau province of Karma Island. This indicates a good condition of the land with little impact of desertification on the vegetation. However, due mainly to the increased frequency of droughts and its negative impact on vegetation cover, this area had decreased to 35 km^2 (3.5% of the total area) in the same province by 2023.

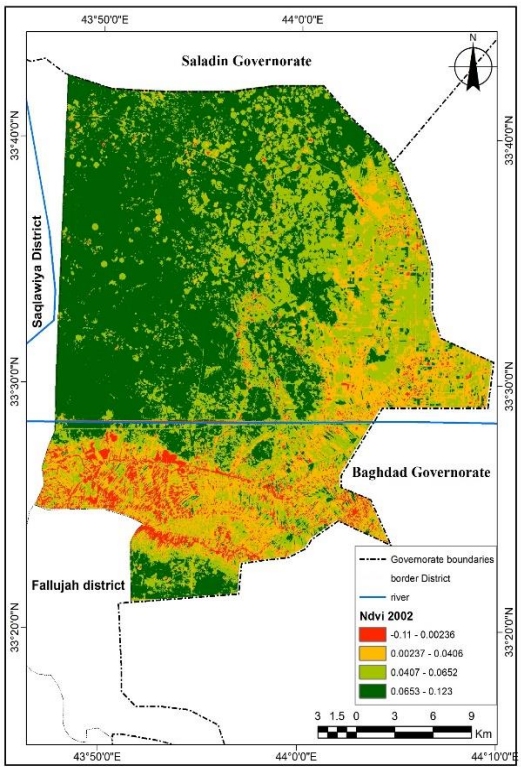
The deterioration in vegetation cover over the study period as shown by the index can be attributed to a number of factors, the most prominent being the problem of drought. Other reasons are climate change and problems related to soil salinity, the expansion of residential areas at the expense of agricultural lands, the decline in groundwater levels, and the lack of water for the areas irrigated by the Saqlawiya

irrigation project. Also, the decline in water volumes from the Euphrates River, farmers' reluctance, and migration due to military and security issues contributed to the worsening desertification in the study area (22).









Map 2: NDVI plant index, 2023.
Source: Landsat satellite data, satellite visual for 2023, (30*30) using Arc GIS 10.8.

Map 3: NDVI plant index, 2002.
Source: Landsat satellite data, satellite visual for 2002, (30*30) using Arc GIS 10.8.

Table 1: Area and percentages of the plant index (NDVI).

	2002		2023	
Category	Area (km^2)	Percentage (%)	Area (km^2)	**Percentage (%)**
Less plants	42	4.2	688	**68.2**
Low plants	167	16.6	194	**19.2**
Medium plants	278	27.6	92	**9.1**
Dense plants	522	51.7	35	**3.5**
Total	1009	100.0	1009	**100.0**

Source: Maps 2 and 3 using Arc GIS 10.8.

NDBI Urban Cluster Index: This index is used to distinguish between built-up and barren areas, and is one of the important indicators showing the extent of their expansion at the expense of cultivated lands or natural plants. The area of the urban block is deduced using the following equation (17).

(ETM-TM) in sensors

NDBI= Band 5 –Band 4/Band 5 +Band 4

Where, NDBI = Urban Block Index, Band 4 = S, and Band 5 = x

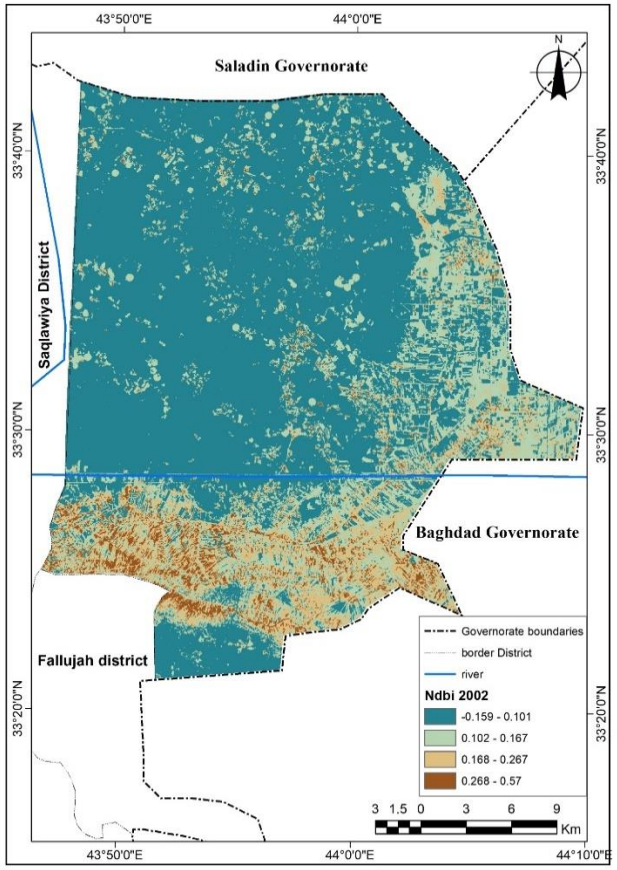
As seen in Maps 4 and 5, and Table 2 the urban mass index can be divided into four categories, as follows:

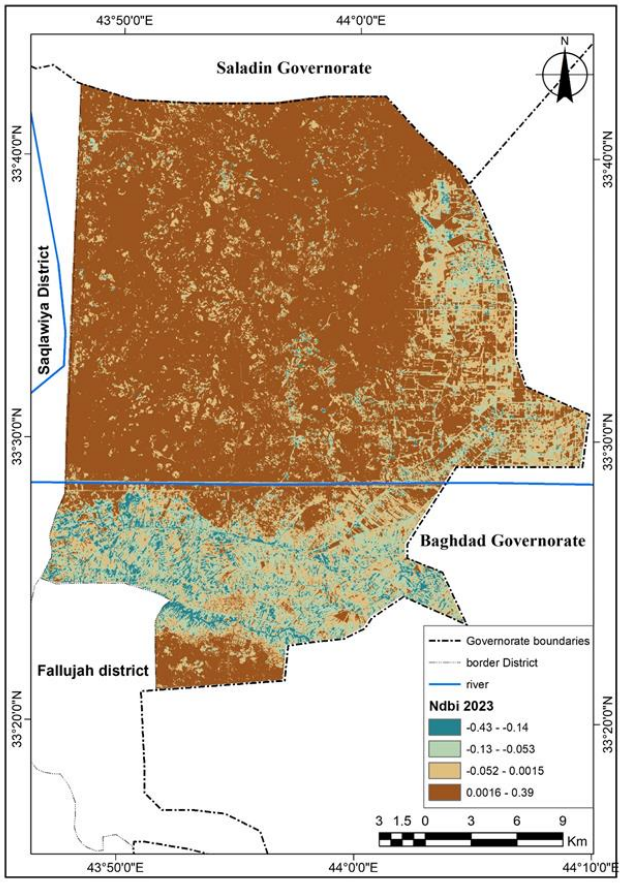
A. The first category (very low density) covered a large area of the study amounting to 670 km^2 or 66.4% of the total area. It was represented geographically by the surface area of the Karma Island plateau and the Fallujah hill, with limited areas within the project's district area. By 2023, the area had decreased significantly to 35 km^2 (3.5%), occupying parts of the areas of the irrigation project's districts and villages. This is due to the expansion of built-up areas, especially in rural areas at the expense of agricultural lands, after the fragmentation of agricultural ownership into small areas in village and rural areas (19).

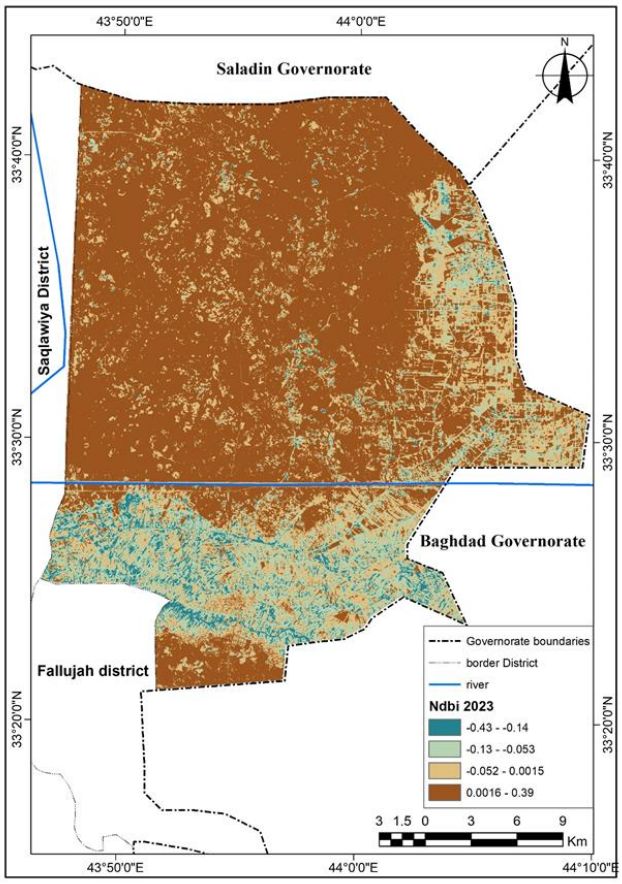
B. The second category (low density) covered 194 km^2 or 19.2% of the total area in 2002 and was located in the southern and eastern parts of the district within the villages of the irrigation project. Its area had decreased by 2023 to 102 km^2 (10.1% of the total), and no change was recorded in its locations from the previous year, for the same reasons noted above.

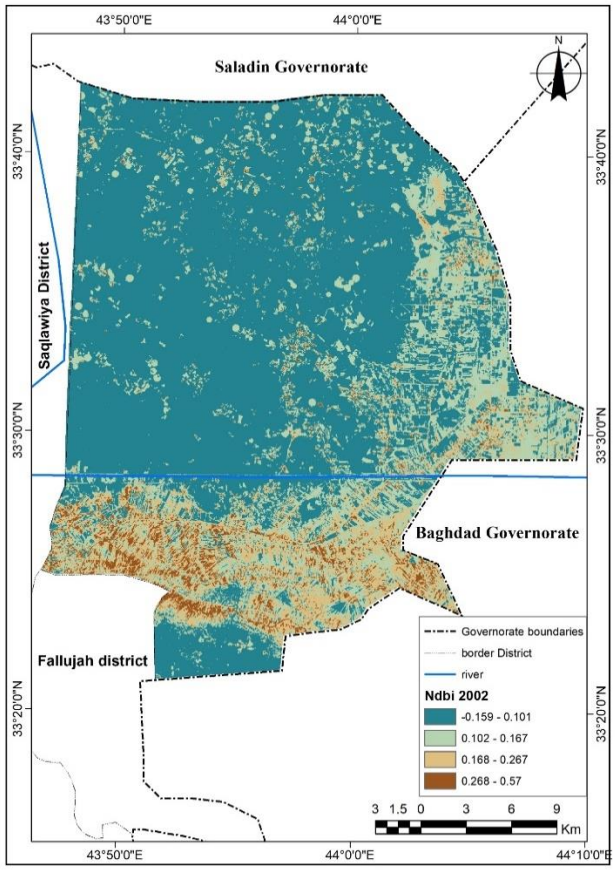
C. The area of the third or medium-density category in 2002 stood at 92 km^2 or 9.1% of the total area. However, by 2023 its area had increased to 181 km^2 (17.9%), indicating an expansion of the area in this category. This was especially evident in the rural areas within the Saqlawiya irrigation project in the Karma Center district and the rural areas in the Khairat district of Karma Island (20).

D. The area of the fourth or high density category in 2002 were covered 53 km^2 or 5.3% of the total area, where it increased into 691 km^2 or 68.5% in 2023 especially in south east districts of study area this shrinkage of agricultural area due to the random growth of urbanization resulting from the increase in population and lack of planning, which will lead to an increase in pollution and then disruption of the environmental system and a decrease in the per capita share of productive agricultural land, so will lead to huge sums of hard currency to import agricultural products.









Map 4: NDBI urban cluster index, 2023.
Source: Landsat satellite data, satellite visual for 2002 (30*30) using Arc GIS 10.8.

Map 5: NDBI urban cluster index, 2002.
Source: Landsat satellite data, satellite visual for 2023 (30*30) using Arc GIS 10.8.

Table 2: Area and percentages of the urban cluster index (NDBI).

	2002		2023	
Category (Density)	Area (km^2)	Percentage (%)	Area (km^2)	**Percentage (%)**
Very low	670	66.4	35	**3.5**
Low	194	19.2	102	**10.1**
Medium	92	9.1	181	**17.9**
High	53	5.3	691	**68.5**
Total	1009	100.0	1009	**100.0**

Source: Maps 4 and 5 using Arc GIS 10.8.

Soil Degradation Index (LDI): An important indicator in studying desertification is the state of soil degradation, which is a key factor and component in land productivity (6). Droughts and climate changes in arid and semi-arid areas ultimately lead to a decrease in land productivity. Examples of such deterioration include a decrease in the density of vegetation cover and erosion of soil by water or wind (7).

The extent of such soil degradation can be derived using the equation**:**

LDI 5.1= (c255− (Green+Red) / (c255+Green+Red

(LDI8= (c65535− (Green+Red) / (65535+ (Green+Red

Where:

LDI = soil degradation index

Green = vegetative system

c65535 = fixed value

c255 = fixed value

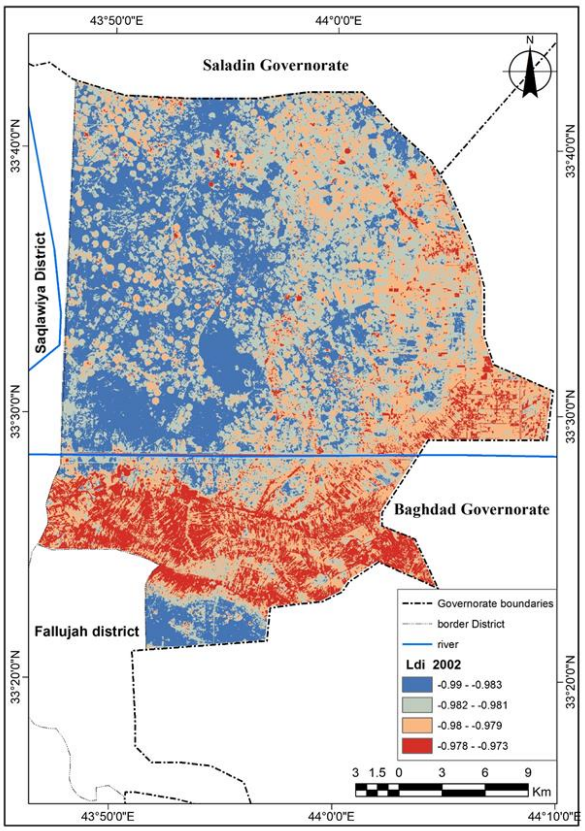
Based on the results of Maps 6 and 7, and Table 3, the values of this indicator can be divided into the following four categories:

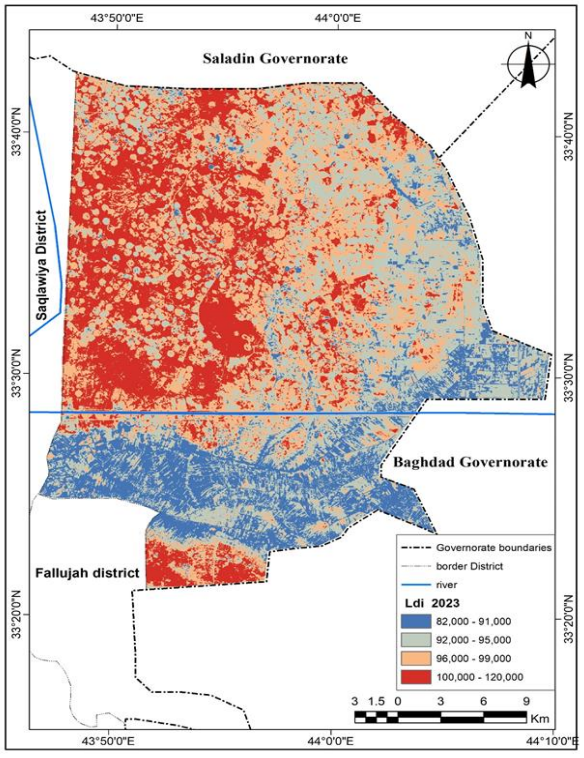
A. The first category, not degraded, occupied 386 km^2 or 38.3% of the study area in 2002. It represented the land cover in its natural state. By 2023, the area of this category had declined to 144 km^2 or 14.3% of the total because of lower land productivity due mainly to drought and increased soil salinity.

B. The second category (slightly deteriorated) represented an area covering 313 km^2 or 31% of the study area in 2002. It had decreased slightly by 2023 to 262 km^2 or 26% of the total study area.

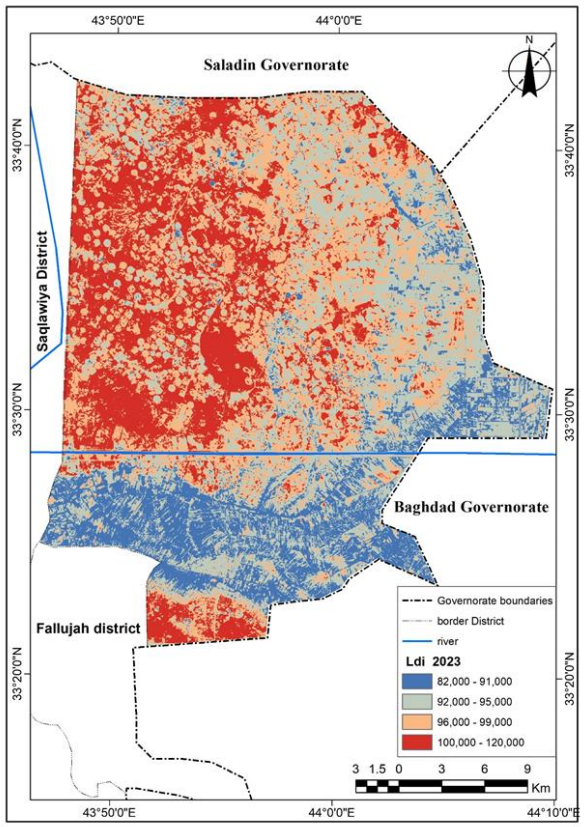
C. The moderate- deterioration category occupied an area of 211 km^2 or 21% of the study area in 2002. Its area increased to 358 km^2 (36% of the total) by 2023, thus confirming the degree of soil degradation in the study area. This degradation is attributed to salinization and logging as the rural areas located within the Karma Plain are occupied by the Saqlawiyah irrigation project.

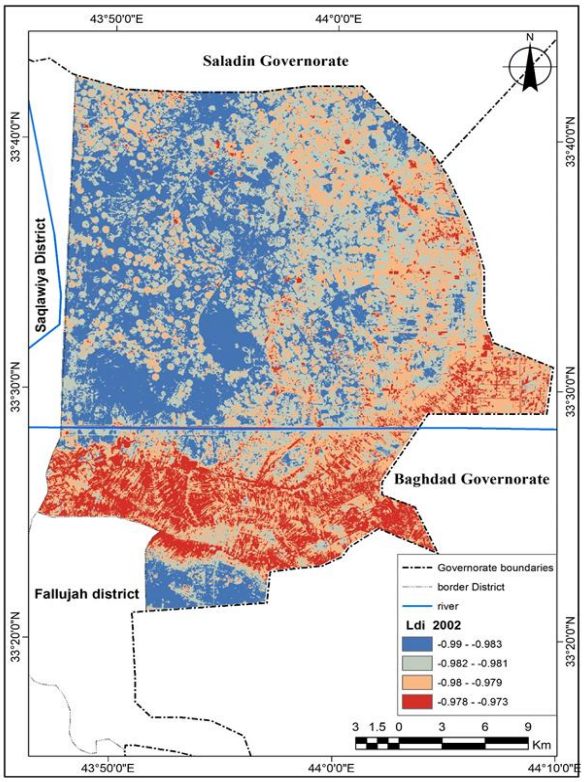
D. The fourth category (highly degraded) comprised a small area of 99 km^2 or 9.8% of the total study area in 2002 but had increased by 2023 to 245 km^2 (24.3% of the total area). This area is located on the Karma Island. The main reason for this degradation is drought caused by climate change, which led poorer soil conditions in various forms (soil erosion, winnowing, salinization) and the disappearance of vegetation cover.





Map 6: Soil degradation index (LDI), 2023.
Source: Landsat satellite data, satellite visual e2023, (30*30) using Arc GIS 10.8.





Map 7: Soil degradation index (LDI), 2002.
Source: Landsat satellite data, satellite visual 2002, (30*30) using Arc GIS 10.8.

Table 3: Area and percentages of the soil degradation index (LDI)

	2002		2023	
Category	Area (km^2)	Percentage (%)	Area (km^2)	**Percentage (%)**
Not deteriorated	386	38.3	144	**14.3**
Little deterioration	313	31.0	262	**26.0**
Moderate deterioration	211	20.9	358	**35.5**
High deterioration	99	9.8	245	**24.3**
Total	1009	100.0	1009	**100.0**

Source: Maps 6 and7 using Arc GIS 10.8.

Conclusions

The vegetation index (NDVI) showed a deterioration in vegetation cover during the study period between 2002 and 2023. This can be attributed to a number of reasons mainly drought and increased soil salinity. Also, the expansion of residential areas, the reluctance of farmers, and migration due to military and security issues exacerbated the problem of desertification in the study area. The urban cluster index (NDBI) indicated a marked expansion in its area, rising in 2023 to 691 km^2 or 68.5% of the total compared to 53 km^2 (5.3%) in 2002.

As for the soil degradation index (LDI), it revealed a state of soil deterioration in all provinces of the study area, due to the growing problem of soil salinity which is a major contributor to increased desertification. Other causes included issues related to soil texture, concentration of salt in the soil and irrigation water, old irrigation methods (dumping), the type of unlined irrigation channels, high groundwater levels, and leaching.

This study recommends that officials and decision-makers take comprehensive measures to address the phenomenon of desertification in this critical region which is a vital link between the agricultural lands belonging to the Fallujah district and bordering the Baghdad governorate. The findings of this research can contribute towards formulating and implementing appropriate solutions in ensuring natural sustainability for the agricultural communities in the region.

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No Supplementary Materials.

Author Contributions:

Author 1: methodology, writing original draft preparation; Authors 2 and 3: writing, review and editing. All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement:

No Informed Consent Statement.

Data Availability Statement:

The study was carried out following the guidelines approved by the ethics committee at the University of Anbar.

Conflicts of Interest:

The authors declare no conflict of interest.

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References

1. Akbari, M., Shalamzari, M. J., Memarian, H., and Gholami, A. (2020). Monitoring desertification processes using ecological indicators and providing management programs in arid regions of Iran. Ecological indicators, 111: 106011. https://doi.org/10.1016/j.ecolind.2019.106011.
2. Bakr, N., Weindorf, D. C., Bahnassy, M. H., and El-Badawi, M. M. (2012). Multi-temporal assessment of land sensitivity to desertification in a fragile agro-ecosystem: Environmental indicators. Ecological indicators, 15(1): 271-280. https://doi.org/10.1016/j.ecolind.2011.09.034.
3. Becerril-Piña, R., Díaz-Delgado, C., Mastachi-Loza, C. A., and González-Sosa, E. (2016). Integration of remote sensing techniques for monitoring desertification in Mexico. Human and Ecological Risk Assessment: An International Journal, 22(6): 1323-1340. https://doi.org/10.1080/10807039.2016.1169914.
4. Chabrillat, S. (2006). Land degradation indicators: Spectral indices. Annals of Arid Zone, 45(3/4): 331.
5. Chabrillat, S., Kaufmann, H. J., Hill, J., Mueller, A. A., Merz, B., and Echtler, H. (2003). Research opportunities for studying land degradation with spectroscopic techniques. Remote Sensing for Environmental Monitoring, GIS Applications, and Geology II, 4886: 11-19. https://doi.org/10.1117/12.462362.
6. Dalantai, S., Sumiya, E., Bao, Y., Otgonbayar, M., Mandakh, U., Batsaikhan, B., and Natsagdorj, B. (2021). Spatial-temporal changes of land degradation caused by natural and human induced factors: Case study of bulgan province in Central Mongolia. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, 43: 79-85. https://doi.org/10.5194/isprs-archives-XLIII-B4-2021-79-2021.
7. Dalantai, S., Sumiya, E., Bao, Y., Otgonbayar, M., Mandakh, U., Batsaikhan, B., and Natsagdorj, B. (2021). Spatial-temporal changes of land degradation caused by natural and human induced factors: Case study of bulgan province in Central Mongolia. The International Archives of the Photogrammetry, Remote Sensing

and Spatial Information Sciences, 43: 79-85. https://doi.org/10.5194/isprs-archives-XLIII-B4-2021-79-2021.

8. Ghanem, A., S., & G. Ibrahim, A. (2024). The Mineral Composition Of Some Soil Formed On Different Source Materials And Its Relationship To Their Properties And Degree Of Development. Anbar Journal Of Agricultural Sciences, 22(1), 455–470. https://doi.org/10.32649/ajas.2024.183745.
9. Hill, J., Megier, J., and Mehl, W. (1995). Land degradation, soil erosion and desertification monitoring in Mediterranean ecosystems. Remote sensing reviews, 12(1-2): 107-130. https://doi.org/10.1080/02757259509532278.
10. Hostert, P., Roder, A., Jarmer, T., Udelhoven, T., and Hill, J. (2001). The potential of remote sensing and GIS for desertification monitoring and assessment. Annals of Arid Zone, 40(2): 103-140.
11. Jiang, M., and Lin, Y. (2018). Desertification in the south Junggar Basin, 2000–2009: Part I. Spatial analysis and indicator retrieval. Advances in Space Research, 62(1): 1-15. https://doi.org/10.1016/j.asr.2017.11.038.
12. Jiang, Z., Ni, X., and Xing, M. (2023). A study on spatial and temporal dynamic changes of desertification in northern China from 2000 to 2020. Remote Sensing, 15(5): 1368. https://doi.org/10.3390/rs15051368.
13. Lamqadem, A. A., Saber, H., and Pradhan, B. (2018). Quantitative assessment of desertification in an arid oasis using remote sensing data and spectral index techniques. Remote Sensing, 10(12): 1862. https://doi.org/10.3390/rs10121862.
14. Liu, S., Wang, T., Kang, W., and David, M. (2015). Several challenges in monitoring and assessing desertification. Environmental Earth Sciences, 73: 7561-7570. https://doi.org/10.1007/s12665-014-3926-x.
15. Masoudi, M., Jokar, P., and Pradhan, B. (2018). A new approach for land degradation and desertification assessment using geospatial techniques. Natural Hazards and Earth System Sciences, 18(4): 1133-1140. https://doi.org/10.5194/nhess-18-1133-2018.
16. Minaei, M., Shafizadeh-Moghadam, H., and Tayyebi, A. (2018). Spatiotemporal nexus between the pattern of land degradation and land cover dynamics in Iran. Land Degradation and Development, 29(9): 2854-2863. https://doi.org/10.1002/ldr.3007.
17. Mohammad, K. S., Samat, N., and Khalid, H. N. (2011). 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. 32nd Asian Conference on Remote Sensing 2011, 3: 1697–1715.
18. Ndabula, C., Jidauna, G. G., Oyatayo, K., Iorkua, S. A., and Iguisi, E. O. (2018). Spatio-Temporal Variations of Top Soil Coarsening as a Pedo-Geomorphic Indicator of Land Degradation and Desertification Status in a Part of Semi-Arid Zone of Nigeria. Science World Journal, 13(1): 70-76.
19. Perez-Marin, A. M., Vendruscolo, J., Zárate-Salazar, J. R., De Araújo Queiroz, H. A., Magalhães, D. L., Menezes, R. S., and Fernandes, I. M. (2022). Monitoring desertification using a small set of biophysical indicators in the Brazilian semiarid region. Sustainability, 14(15): 9735. https://doi.org/10.3390/su14159735.

20. Pinet, P. C., Kaufmann, C., and Hill, J. (2006). Imaging spectroscopy of changing Earth's surface: a major step toward the quantitative monitoring of land degradation and desertification. Comptes Rendus Geoscience, 338(14-15): 1042-1048. https://doi.org/10.1016/j.crte.2006.09.012.
21. Seboka, G. N. (2016). Spatial Assessment of NDVI as an Indicator of Desertification in Ethiopia using Remote Sensing and GIS. Mater Thesis in Geographical Information Science, (51).
22. Shoba, P., and Ramakrishnan, S. S. (2016). Modeling the contributing factors of desertification and evaluating their relationships to the soil degradation process through geomatic techniques. Solid Earth, 7(2): 341-354. https://doi.org/10.5194/se-7-341-2016.
23. Wang, J., Wei, H., Cheng, K., Ochir, A., Davaasuren, D., Li, P., ... and Nasanbat, E. (2020). Spatio-temporal pattern of land degradation from 1990 to 2015 in Mongolia. Environmental Development, 34: 100497. https://doi.org/10.1016/j.envdev.2020.100497.
24. Zhao, X., Yu, M., Pan, S., Jin, F., Zou, D., and Zhang, L. (2023). Spatio-temporal distribution and trends monitoring of land desertification based on time-series remote sensing data in northern China. Environmental Earth Sciences, 82(11): 263. https://doi.org/10.1007/s12665-023-10950-y.