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Integrating Remote Sensing Techniques and Geographic Information Systems to Assess the Environmental Impacts of Urban Sprawl on Agricultural Lands: A Case Study from Suq Al-Shuyoukh City, South of Iraq

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Abstract

The current study aims to determine the size, type, direction and causes of urban encroachment on agricultural lands as well as its environmental impact. The remote sensing and geographic information systems techniques are integrated to determine the extent of horizontal urban growth in Suq Al-Shuyoukh City for two periods (3/2003 and 4/2020). The normalized difference vegetation index (NDVI), accumulated normalized difference index (NDBI), and normalized difference water index (NDWI) are used. A supervised classification technique using ArcGIS software is used to map the different land use land cover (LULC) classes. The LULC map indicates a significant increase in urban (+10%) areas and arid lands (+6%), and a significant decrease in agricultural land (-17%). The city underwent major urban expansion towards the north and northeast. The chaotic urban sprawl in the study area can be classified as irregular urban sprawl. The population increase (+2.31%) has a role in urban expansion. The environmental impacts are rising temperatures, desertification, and an increased frequency of dust storms.

Keywords: Geomorphological Units, Encroachment, Man-Made, Supervised Classification, Desertification.

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تكامل تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية لتقييم الآثار البيئية للزحف العمراني على الأراضي الزراعية: دراسة حالة من مدينة سوق الشيوخ، جنوبي العراق

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الخلاصة

تسعى الدراسة الحالية إلى تحديد حجم ونوع واتجاه وأسباب زحف المناطق الحضرية على الاراضي الزراعية، بالإضافة إلى تأثيره البيئي. تم دمج تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية لتحديد مدى النمو العمراني الأفقي في مدينة سوق الشيوخ لفترتين (2003/3 و 2020/4). تم استخدام مؤشر الفرق الطبيعي للغطاء النباتي (NDVI) ومؤشر الفرق الطبيعي المتراكم (NDBI) ومؤشر الفرق المائي الطبيعي (NDWI). تم استخدام تقنية التصنيف الخاضع للإشراف باستخدام برنامج ArcGIS لرسم خريطة الفئات المختلفة لغطاء واستخدامات الأرض (LULC). تشير خريطة LULC إلى زيادة كبيرة في المناطق الحضرية (+10%) والأراضي القاحلة (+6%)، وانخفاض كبير في الأراضي الزراعية (−17%). شهدت المدينة توسعًا حضريًا كبيرًا باتجاه الشمال والشمال الشرقي. يمكن تصنيف الزحف العمراني في منطقة الدراسة على أنه زحف عمراني غير منتظم. للزيادة السكانية (+2.31%) دور في التوسع العمراني. تمثلت الآثار البيئية بارتفاع درجات الحرارة والتصحر وزيادة وتيرة العواصف الترابية.

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Introduction

Urban encroachment on agricultural land is a global problem that particularly affects developing countries. This imbalance has serious environmental consequences, especially in areas with an arid or semi-arid climate such as southern Iraq. Sprawl of Man-Made Geomorphological Unit-Urban (MMGUU) is defined as the city center and its areas expanded at the expense of the surrounding agricultural areas, while Man-Made Geomorphological Unit–Agriculture (MMGUA) means a specific area of land covered with soil of sufficient thickness for living organisms in it. It is a closed ecosystem in which all interactions between different elements are intertwined. In this system, energy and matter are transferred from one element to another. It is used for agricultural crop production and livestock breeding. It aims to produce food for humans (Al-Tafili and Al-Jassani, 2021). Studying human-caused environmental problems has become the focus of researchers' efforts nowadays. Environmental impact assessment is an important component of development and planning. The problem of encroachment of MMGUU on MMGUA is an issue that all countries of the world suffer from. It is one of the main causes of desertification (Hasan et al., 2021). The phenomenon of desertification threatens about 110 countries in the world. The world loses about 24 billion tons of topsoil annually. About 70% of the agricultural land area in arid and semi-arid regions is affected by varying degrees of desertification (Ankush, 2019). The

MMGUA surrounding cities decreased day after day as a result of the expansion of the MMGUA above them. The continuation of this encroachment in the cities of Iraq and the absence of effective policies to control urban growth make Suq Al-Shuyukh City (one of the most eye-catching Iraqi cities) an example. The city is located in an area that literally inherited the land of Sumer. This city was built on one of the ancient Sumerian hills. It is still developing and expanding until it has become a large city. It consists of a palm forest, several swamps, water bodies, and urban areas, in addition to barren lands. In this city, the percentage of MMGUA decreased, and the palm forests and areas designated for growing vegetables, green fodder, and the like were affected. As a result of this rapid urban growth, the city's area expanded in the past two decades after the change of the political regime in 2003. The horizontal growth pattern in this city was responsible for the subtraction of part of its productive lands and neighboring lands. Desert grasslands, and this had environmental repercussions. Urban sprawl threatens agriculture in this city, which was considered as one of the richest areas in agricultural production as an important food basket, not only for the residents of the city or regions of Iraq, but even for some countries of the world, especially in terms of dates and other palm tree products. The aforementioned progress has spread on a large scale, and this can be clearly seen in the Al-Aqiqah area, in addition to most of the city's villages. Studying this problem from its various aspects is a vital and necessary matter that must be taken into consideration and transformed into strategic action while developing a well-thought-out and clear plan that prevents cutting off large areas of MMGUA. It must be exploited to achieve promising agricultural development and stop encroachment. Conservation Areas MMGUA are consistent with prevailing trends in supporting the natural environment and the Sustainable Development Goals (Shareef et al., 2020). Many studies have addressed the issue of urban sprawl, including Rahman et al. (2023) study about the effects of urbanization on agricultural land and thermal environment in Larkana, Pakistan. The results of the study showed that the built-up area increased from 12.31 to 43.83 km², while the area of barren lands in the study area decreased from 56.51 km2 to 11.62 km². The area of agricultural land reached 66.66 km² in 1990, then expanded to 101.38 km², and then decreased to 79.49 km² in 2020. The results also revealed that most of the urban expansion in the last decade (2010-2020) occurred on agricultural land. The urban thermal environment also showed a gradual increase in the surface temperature, as recorded by the LST results. Through the use of LST, it was concluded that the highest limit in 1990 was 33.4 degrees Celsius, rising in 2020 to 36.1 degrees Celsius. On the other hand, in 2020, the minimum was 25.1 degrees Celsius and rose to 26.6 degrees Celsius. This study produced useful results for decision makers in order to develop better plans and means for managing urban expansion on arable land.

(Al-Wahaibi and Al-Zamil, 2021) discussed the impact of urban sprawl on agricultural lands, a case study of the factory area in Riyadh. The research found that urban encroachment on arable land affected natural spaces and contributed to the decline of vegetation cover. The researchers proposed drawing up a comprehensive land management strategy to serve the principle of integration between agricultural lands and urban areas and to achieve optimal exploitation of natural resources.

(Al-Shahwan, 2023) In her research entitled "The Impact of Urban Sprawl on Agricultural Lands in Jordan", she highlighted the lost areas of agricultural land, the reasons that led to this, and then the environmental dimensions that resulted from that. The most important finding of the study is the presence of urban encroachment on agricultural lands. Many factors contributed to this, the most important of which were rapid population growth, lack of planning, and the move away from agriculture.

(Abdel Lala, 2018) showed in research entitled "urban encroachment on agricultural lands in the city of Kafr al-Dawwar using geographic information systems and remote sensing" that there was a significant increase in the area of the urban block. At the expense of agricultural land and the conversion of agricultural land plots, there is a discrepancy in the average per capita share of the urban area for the Kafr al-Dawwar areas.

Abed, and Sabtu (2024) in research entitled “Urban context analysis according to the concept of Spencer's biological theory using GIS: Balad City case study”, declared that the study concluded that changing urban laws, increasing population growth, non-compliance with basic plans and turning a blind eye to encroachment on agricultural lands play a role in increasing the extent of urban expansion, encroachment on agricultural lands and their desertification. The research recommended taking appropriate methods to stop this problem and solve it through correct urban planning.

It is clear from the above that previous studies shed light on the problem of urban expansion on agricultural lands locally, regionally, and globally. It is worth noting that this problem has not been previously studied in the city of Souq Al-Shuyoukh.

From this standpoint, the importance of this study lies in shedding light on the encroachment of urban geomorphological units and their effects on agricultural geomorphological units during the study period and the subsequent environmental deterioration.

This study attempts to answer the following questions: Was the city of Suq Al-Shuyukh subjected to a major urban expansion in the period from 2003 to 2020 AD? What are the urban expansion trends in this city? What is the type of urban expansion? What are the reasons behind urban expansion? Is there any significant effect on the environment?

Study area

Suq Al-Shuyukh City is the oldest city in Thi Qar Governorate. It occupies the right bank of the Euphrates River. It is located at the western end of Al- Hamar marsh and its wetlands. It is surrounded by desert to the west, and water and greenery to the east and south, with swamps and eroded palm forests. The city of Suq Al-Shuyukh is located about 35 km southeast of Nasiriya City (the Governorate center). It has the following coordinates: latitude 30°53′57.87″ north and longitude 46°27′42.22″ east (Fig. 1). Its area, with its five districts, is 1,374 km² (Kramers, 1997). Its height above sea level is about five meters (5 m). It has a desert climate.

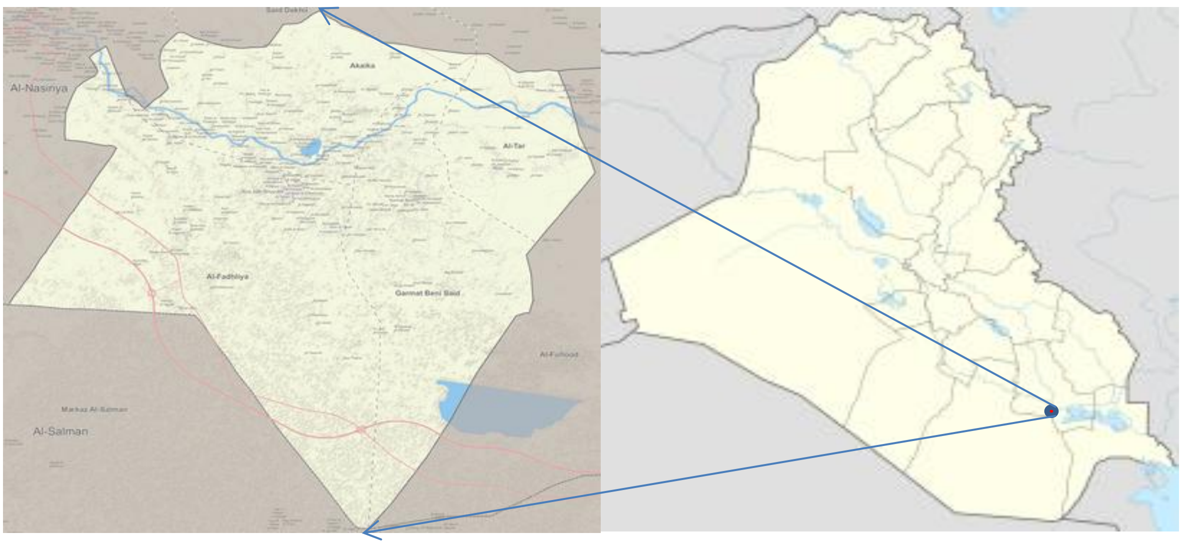

Fig. 1. Location map of the study area.

It is characterized by low rainfall and high temperatures in summer, reaching 50 degrees Celsius, while the weather in winter is warm (Al-Umar et al., 2019). The study area is located in the big Mesopotamian Plain, which is characterized by holes of different sizes, riverbank incision deposits, marsh deposits resulting from laminar flow of water (both active and dry), and estuarine swamp deposits. The sediments of the Mesopotamian Plain consist mainly of silt and clay. Some ground depressions are spreading locally. Some organic soil may be present with silt and clay. In the swampy area, the sediments are heavily contaminated with organic matter. The age of all these deposits is Holocene (Aqrawi, 1997) (Fig. 2).

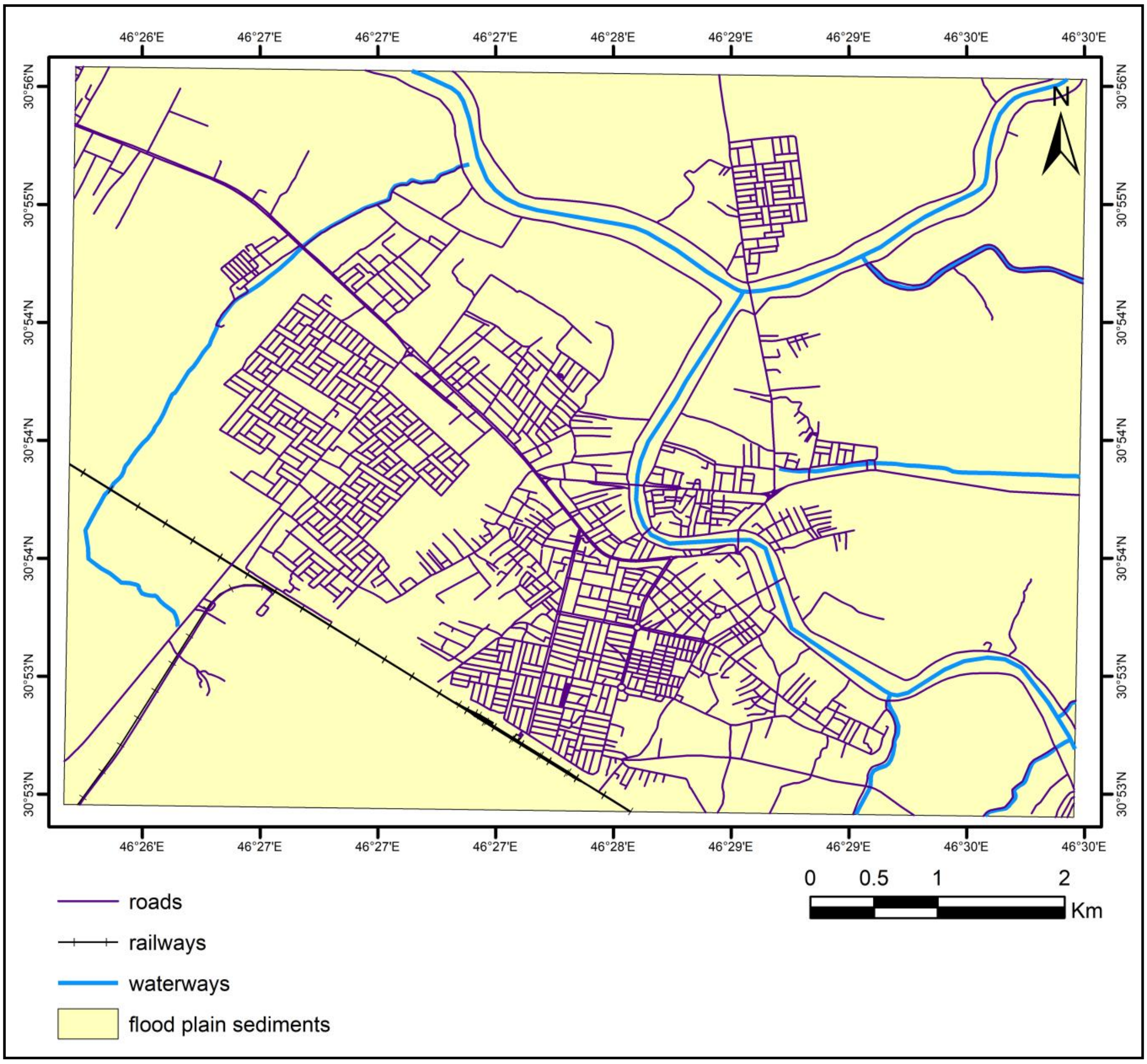

Fig. 2. Brief land cover/land use map of the study area.

Materials and Methods

The methodology of this study is shown in (Fig. 3). This study relied on Landsat 7 and 8 satellite images from 2003 and 2020 (Fig. 4) obtained from the US Geological Survey (USGS) website (Table 1). Both of these images cover the study area (Suq Al-Shuyukh City). These dates are the closest data available for the same period designated for research. The year of 2003 represents the state of the region when political change occurred in the country, as political and security chaos and violations of land law occurred. The 2020 image is the most recent clear image available of the region without clouds. The study area was cropped from the two satellite images.

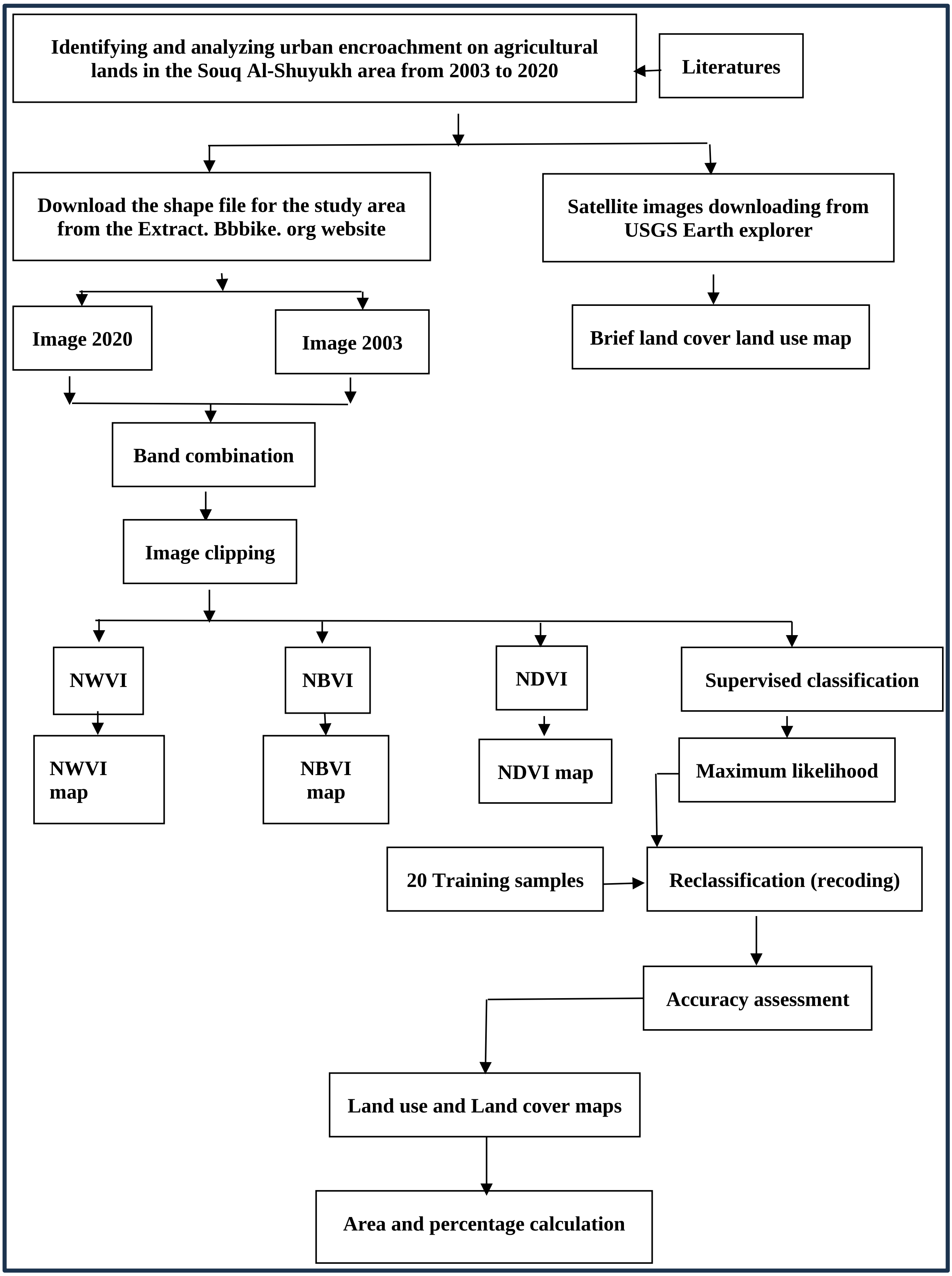

Fig. 3. Methodological flow chart.

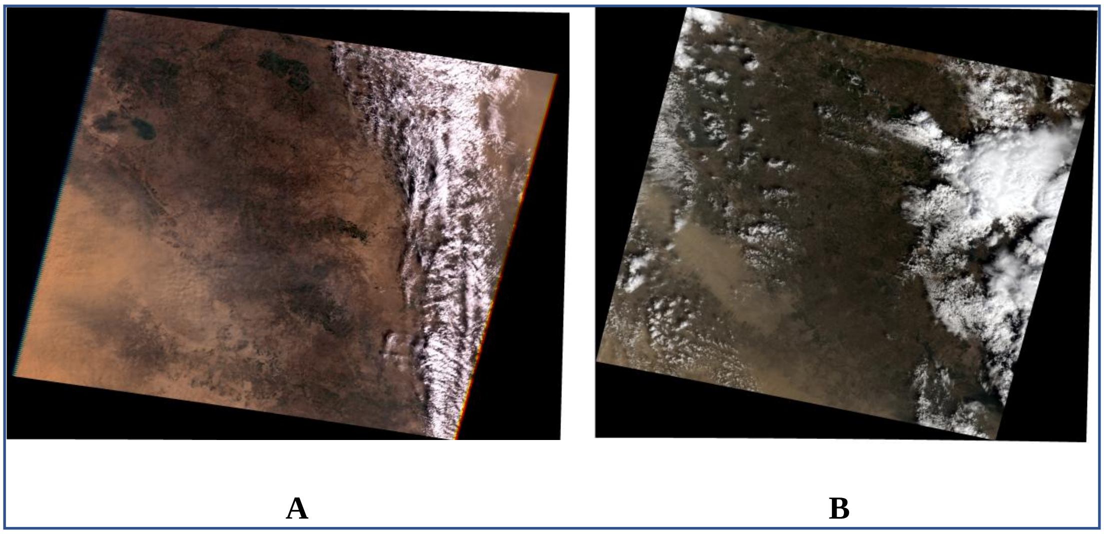

Fig. 4. (A) MTL 3/2003 Path167 Row 38, (B). MTL 4/2020 Path167 Row 38.

Table 1: Details of the Landsat 7 and 8 satellite images used in this study.

Year	Satellite sensor	Spatial resolution	Acquisition date	Path	Row
2003	Landsat ETM+ 7	30 m × 30 m	26/3/2003	167	38
2020	Landsat OLI 8	30 m× 30 m	1/4/2020	167	38

The software used in this study is Erdas 14 and Arc Map 10.8.1. These visual elements have been addressed and improved.

The 1,4,7 band mix was adopted for the Landsat 7 satellite image, and the 5,2,7 band mix was adopted for the Landsat 8 satellite image (Fig. 5).

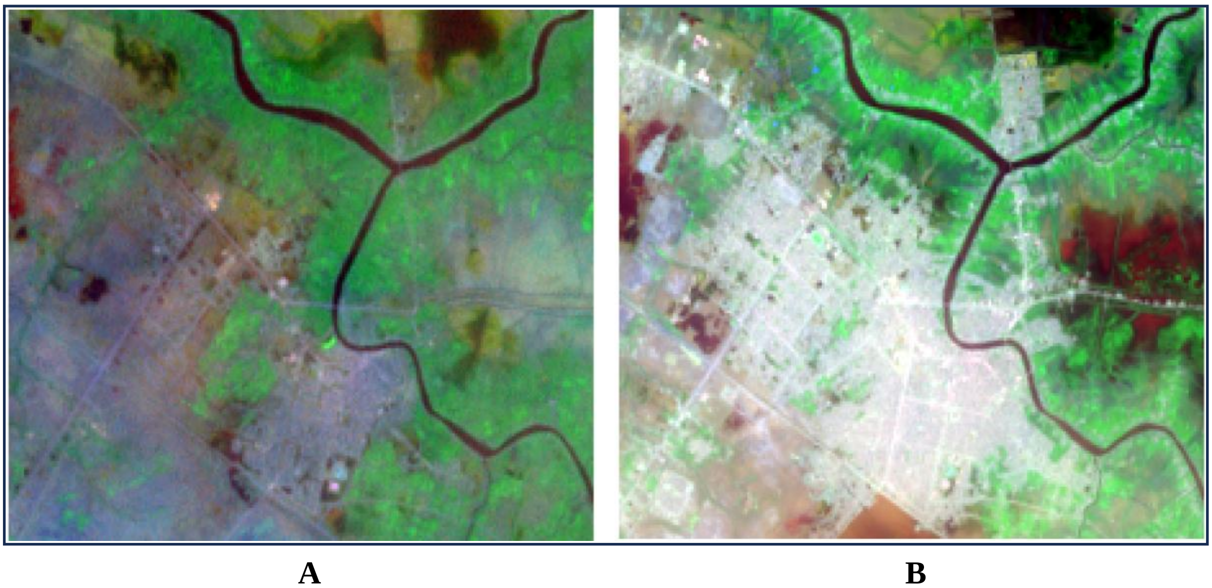

Fig. 5. (A) 1, 4, and 7 band combination date 3/2003, (B) 5, 2, and 7 band combination date 4/2020 showing study area.

A supervised classification technique is conducted for both images. The maximum likelihood classification option is used. Spectral reflectivity values (spectral signature) were determined for each of the classes present on the satellite image. Sample sites representative of known classes of land cover are used as training areas. It was chosen randomly in the form of approximately twenty polygons. The training areas for each class were combined to achieve the highest classification accuracy.

The training areas represent a numerical classification guide describing the spectral characteristics of each class studied. Digital processing is conducted to calculate the spectral reflectivity values for each class to classify them and determine their classes (Fig. 6). These results of the supervised classification technique for both images and for the two years in question are listed in Table 2. It includes the areas and percentages of the four classes of land cover and land use of the study area and the changes that occurred over time. (Fig. 7) summarizes the comparison between areas and percentages of LCLU classes for both satellite images obtained in 2003 and those obtained in 2020.

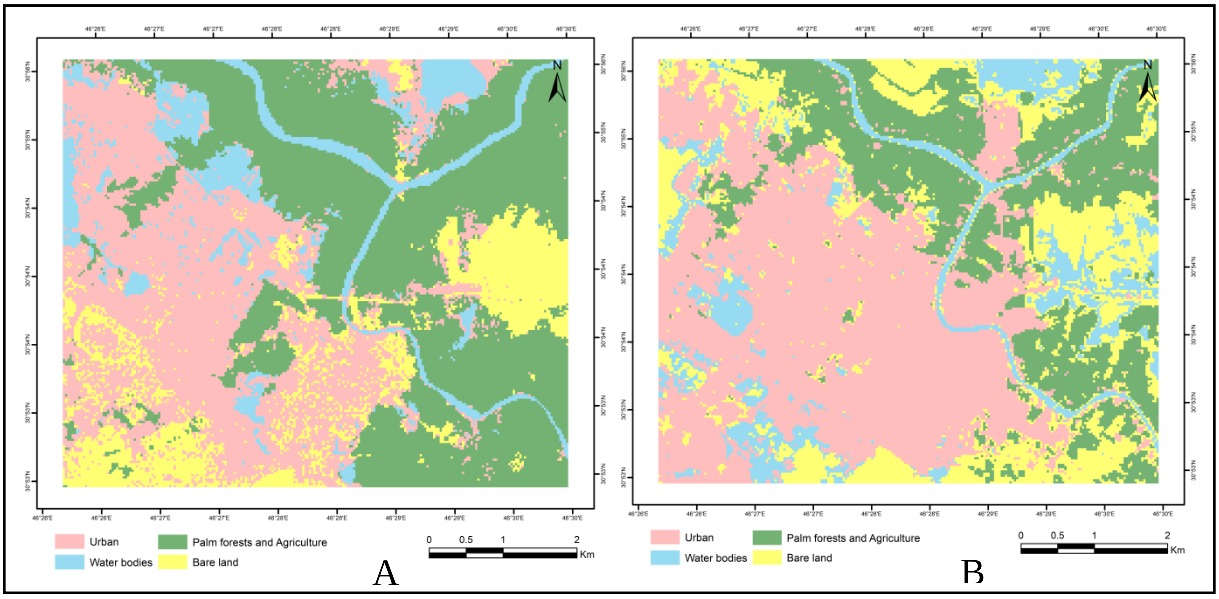

Fig. 6. (A) Supervised classification map 3/2003, (B) Supervised classification map 4/2020.

Table 2: Comparison of areas and percentages of land cover land use classes for the years 2003 and 2020.

Class name	Class color	Landsat ETM+ 7 2003		Landsat OLI 8 2020		Area (km²) (2020-2003)	PRS (2020-2003)
		Area (km²)	PRS %	Area (km²)	PRS %		
Water bodies		4.0248	10	4.455	11	0.4302	1
Urban		13.4577	34	17.4213	44	3.9636	10
Palm forests and Agriculture		16.4592	42	9.7605	25	-6.6987	-17
Bare land		5.6619	14	7.9668	20	2.3049	6

For the purpose of showing the percentages represented by land cover land use classes for the study area, Microsoft Excel is used for drawing (Fig. 7).

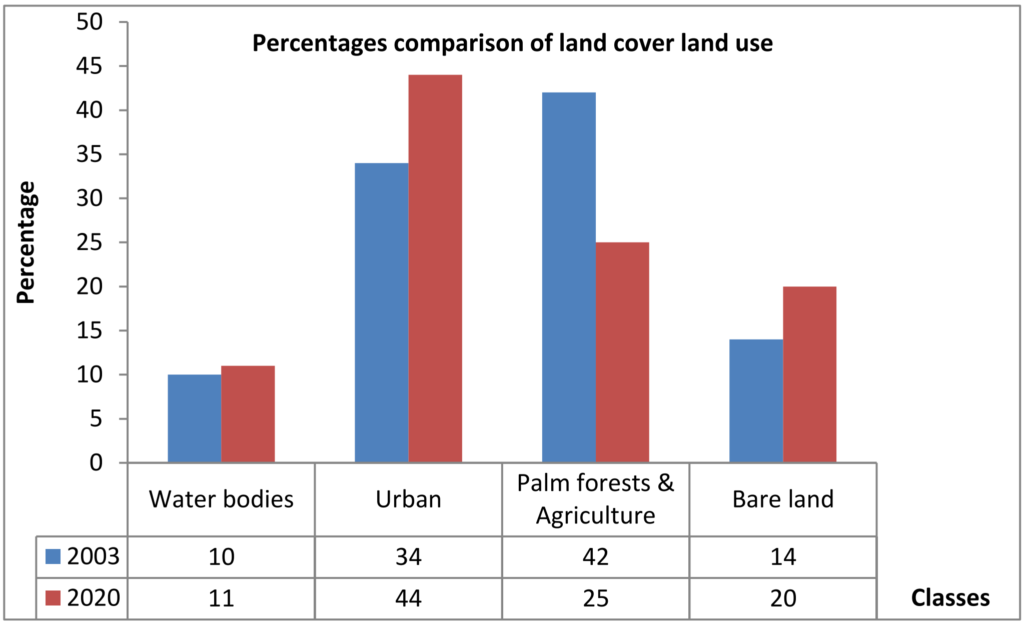

Fig. 7 Percentages comparison of land cover land use classes for the years 2003 and 2020.

Accuracy assessment

The supervised classification results are validated using 10 randomly selected points per class. Overall Accuracy and the Kappa coefficient are used. The validation dataset points are used to compare the original land-use class with the classified image. The classified image value assigned to each point is extracted using ArcGIS, and then Google Earth images are used as reference data in addition to visiting the study area in the field. An error matrix table is created to determine and improve the overall accuracy of the classified images. The overall accuracy in 2003 was 88.461%, and 87.5% in 2020. As for the Kappa coefficient, its value in 2003 was 85.086 and 84% in 2020. The accuracy of the resulting images is acceptable for the study. Shallow water and land cultivated with vegetables show the same spectral reflectivity. This problem is solved using a reclassification (recoding) step.

Indexes used

Many Indexes related to the subject of the study are used, such as: 1-Normalized Difference Built-up Index (NDBI) calculated for both images; 2-NDBI using the NIR and SWIR bands to confirm manmade built-up areas, depending on the ratio to mitigate the effects of terrain lighting differences, in addition to atmospheric effects (Xi et al., 2019) using the following equation:

$$NDBI = (SWIR - NIR) / (SWIR + NIR)$$

For Landsat 7, the formula is:

$$NDBI = (Band\ 5 - Band\ 4) / (Band\ 5 + Band\ 4)$$

As for Landsat 8, the formula will be:

$$NDBI = (Band\ 6 - Band\ 5) / (Band\ 6 + Band\ 5)$$ (Zha et al., 2003).

The NDBI maps of 2003 and 2020 in the study site are depicted in Fig. 8. 3-The vegetation index (NDVI) is also used usually for various purposes related to vegetation cover. It is used in this study to isolate vegetation cover of various types from the rest of the land cover classes. NDVI is calculated by the following equation:

$$NDVI = (NIR - R) / (NIR + R)$$

Where: *R* represents the infrared value, and *NIR* represents the near infrared value.

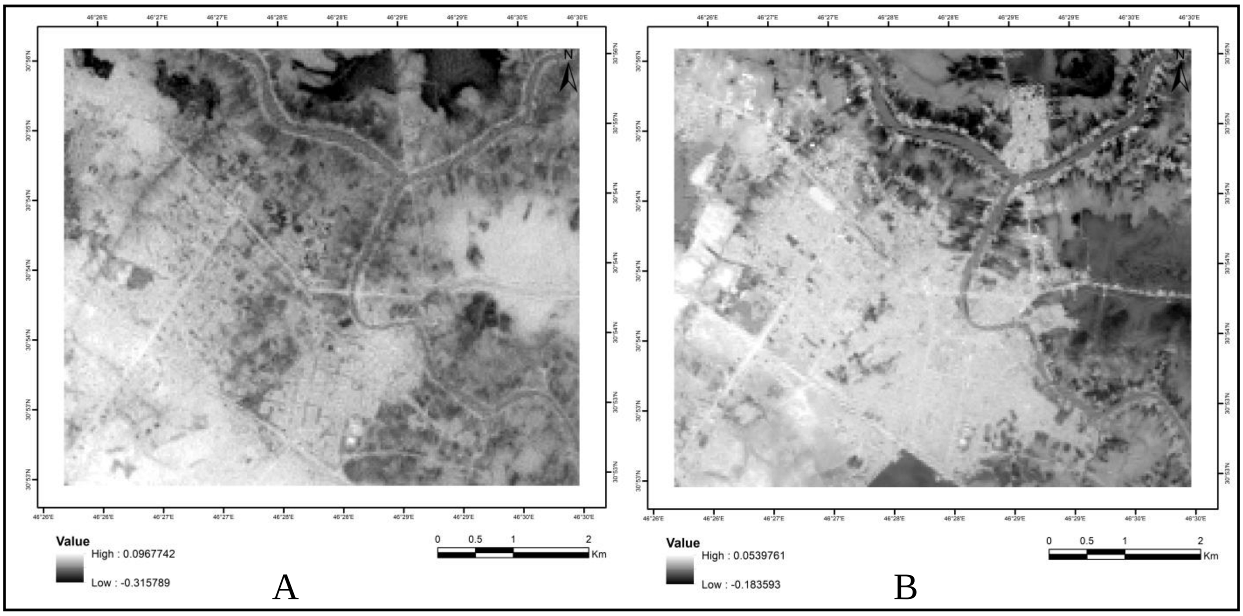

Fig. 8. Spectral indices result used in the study (A) NDBI date 2003, (B) NDBI date 2020.

The equation needed to calculate the NDVI value for Landsat 7 images is:

NDVI = (Band 4 – Band 3) / (Band 4 + Band 3).

As for Landsat 8 images, the equation is as follows:

NDVI = (Band 5 – Band 4) / (Band 5 + Band 4).

This method is useful to focus on evaluating vegetation and removing other land cover features in the study area, which helps increase the accuracy of vegetation data (Al-Mutairi and Warner, 2010). The NDVI maps of 2003 and 2020 in the study area are depicted in Fig. 9.

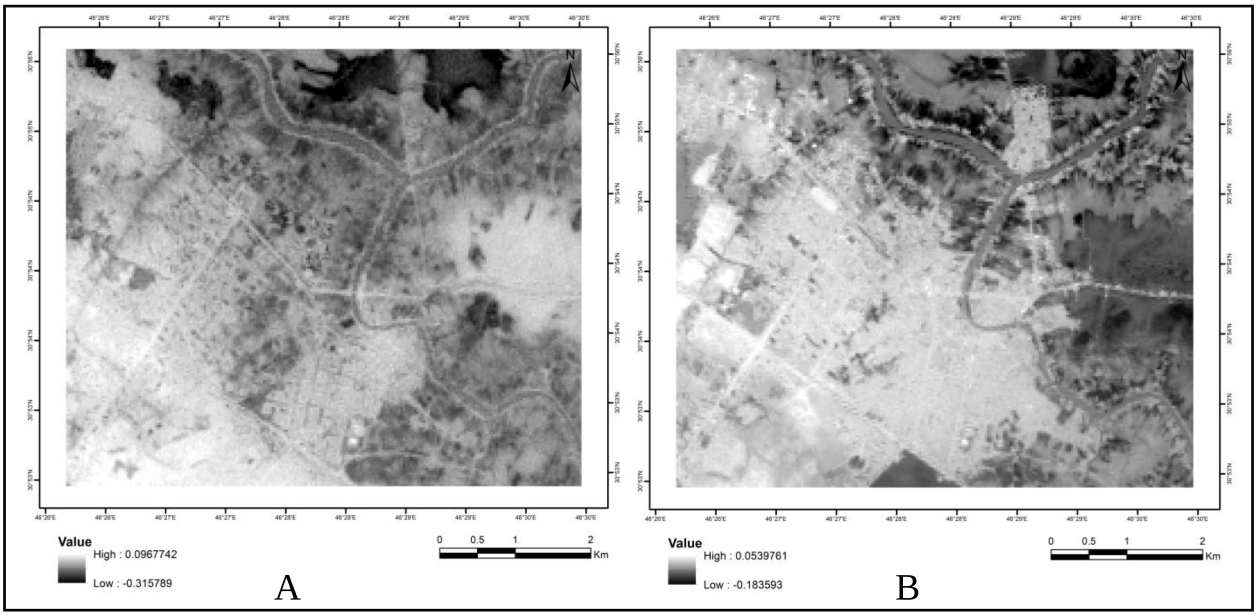

Fig. 9. Spectral indices results used in the study (A) NDVI date 2003, (B) NDVI date 2020.

(Gao, 1996) developed SWIR for the purpose of separating water bodies from the rest of the land cover types. This indicator is based on the NIR band and SWIR band of Landsat 7 and Landsat 8.

NDWI values can indicate the amount of water in water bodies (Mondejar and Tongco, 2019):

$$NDWI = (Red - NIR) / (Red + NIR)$$

In Landsat 7:

$$NDWI = (Band\ 4 - Band\ 5) / (Band\ 4 + Band\ 5)$$

While for Landsat 8, the formula is:

$$NDWI = (Band\ 5 - Band\ 6) / (Band\ 5 + Band\ 6).$$

The NDWI maps of 2003 and 2020 in the study site are depicted in Fig. 10.

The study area is divided into four main land use and land cover classes: Water bodies, Urban, Palm forests, Agriculture, and Bare land.

Urban areas include building areas such as residential areas, commercial areas, and roads, while Palm forests and agricultural land include natural vegetation, croplands, and orchards.

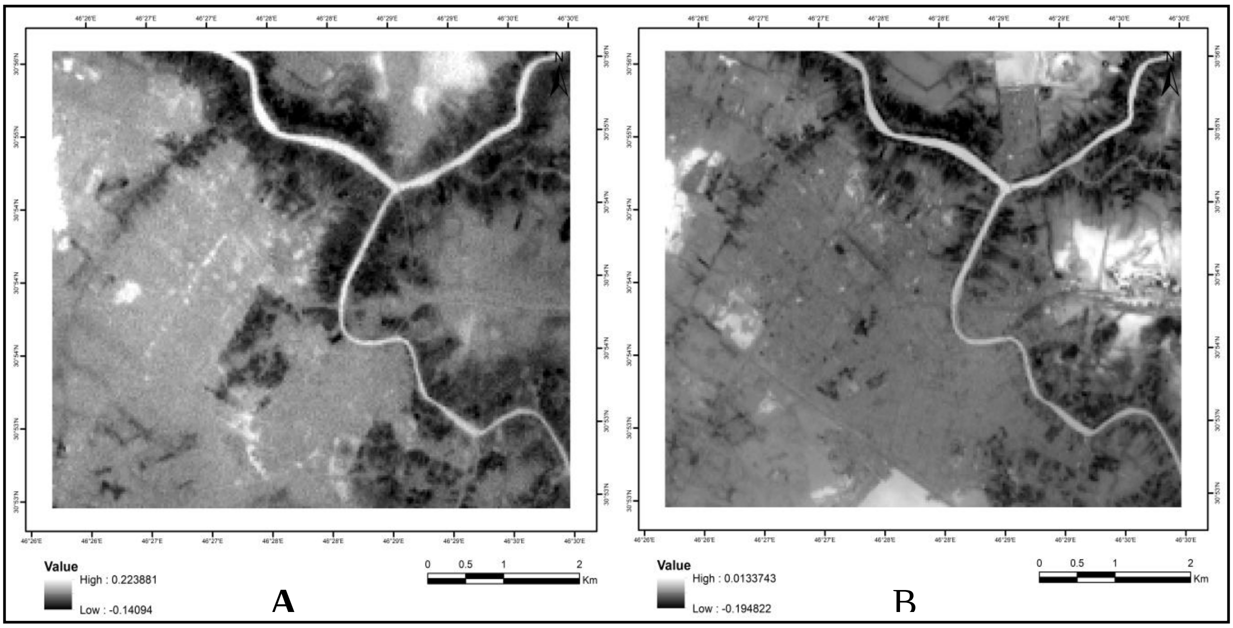

Fig. 10. Spectral indices result used in the study (A) NDWI date 2003, (B) NDWI date 2020.

Detecting the change depends on several methods. It is used to identify the differences between images taken for the same area on different dates. Many tools may be used individually or in combination, including image difference, image division, and change detection in classified images. The last method is adopted in this study because the results obtained from the other methods are not satisfactory, as they are not consistent with reality. This is believed to be due to the small size of the study area and the low spatial resolution of the images used. For the purpose of assessing change in LCLU, the results of directed classification are used to monitor the trend of land use change and are analyzed by applying the ArcGIS 10.8.1 software. Digital maps of the region are also prepared using the same program.

Urban expansion trends

The city was subjected to a noticeable urban expansion (MMGUU) in the period between 2003 and 2020 AD, as its percentage of the total LCLU was 34% and became 44%, meaning there is an increase of 10%.

The LCLU map of the study area shows that urban expansion was towards the north and northeast, where fertile agricultural lands and water bodies are located.

Urban sprawl is classified into two main types:

First: ***Regular urban sprawl***, which in turn is divided into:

A- Right-angle plan (chess plan)

B- Radial plan

C- Linear plan

Second: ***irregular urban sprawl***: it is represented by the construction and establishment of illegal and chaotic neighborhoods, and this negative phenomenon is experienced by most developing countries (Abidin et al., 2019).

The chaotic urban sprawl in Suq Al-Shuyukh City can be classified as irregular urban sprawl.

The population increase has a role in urban expansion, as the city's population jumped from 450 thousand people in 2003 to about 865.8 thousand people in 2020, considering the population growth rate of 2.31% (Matta et al., 2022).

Other reasons for this encroachment are the low prices of agricultural land, non-compliance with the city's basic plans, lack of environmental awareness of the value of agricultural land, and the desire of city residents to move and live outside the city to avoid crowding and pollution.

The environment has been severely damaged as a result of the noticeable decline in the area of vegetation cover and water bodies, which has contributed to an increase in the rate of air pollution, a rise in temperatures, an absence of control over air movement, a decrease in humidity, and the prevention of biodiversity, which is responsible for the disappearance of many species, including migratory birds (Madallah, and Tarawneh, 2014).

The expansion of the MMGUU also removed shallow water bodies, causing the degradation of aquatic resources such as fish and birds. The receding waters of Lake Al-Hammar led to the disappearance of rice farms that were produced from the lands north and west of the lake, which increased.

Results and discussion

By applying the NDVI, NDBI and NDWI technology to the two satellite images for the period from 2003 to 2020, it is found that there is an encroachment of MMGUU on other geomorphological units by about 28%, a deterioration in MMGUA by about 1%, and a decline in the area of water bodies by about 31%, and since these results are not convincing because they are not consistent with reality, they are therefore neglected and other methods are resorted to such as the supervised classification technique to reveal the difference between the increase and decrease in the four classes of LCLU: Water bodies, Urban, Palm forests and Agriculture, and Bare land (Fig. 6), where it appears that the area had undergone many changes presented in Table (2) and (Fig. 7).

We note that there is an increase in the percentage of water bodies estimated at about 1%. This result is not expected due to the state of drought and desertification that the region has witnessed recently. The reason for this increase is unusually heavy rains in the winter of the last three years, 1918, 1919, and 2020.

An increase in urban areas is detected by about 10% of the study area, and this is a large percentage for the 17 years included in the study, especially since it was towards agricultural lands. Most of this increase consists of low-cost homes and slums that lack the minimum components of urban planning and basic services, which have made most of them incubators for social diseases and constitute a large and clear burden on the environment. This urban sprawl is chaotic and irregular.

A high value of deterioration in vegetation cover reaches 17% of the total fertile land. 10% of it is due to urban sprawl, and 7% is due to neglect and abandonment of agricultural activity, in addition to desertification due to climate change and high temperatures. This deterioration is concentrated around the villages and on both sides of the Euphrates River. These areas occupy the northern and eastern parts of the study area. The loss of agricultural land occurred not only due to urban sprawl, but also due to the increase in the establishment of illegal warehouses for construction materials and goods.

It is found that there is an expansion of the bare land estimated at 6%, contributed by erosion processes as a result of the worsening problem of desertification, high temperatures, and the increase in the frequency of dust storms, in addition to abandoning the practice of agricultural activity. This is a dangerous indicator for the growing phenomenon of desertification over time, which calls for taking serious and practical measures to reduce it. As for water bodies, there is no clear difference between the two mentioned years that calls for concern.

The current study agrees with the literature review in principle and in general doubt that there is an encroachment of MMGUU towards MMGUA in developing countries, especially in the last ten years, and this contributes to rising temperatures, desertification, and an increase in the frequency of dust storms. The Iraqi Ministry of Environment announced that during the past two decades, days affected by dust and sandstorms have increased from 243 to 272 days per year (Attiya and Jones, 2020) with serious environmental repercussions. But it differs in terms of the percentages of increase and decrease in the different LCLU areas.

Since vegetation cover has, in general, a fundamental role in stabilizing the soil, lowering temperatures, withdrawing carbon dioxide from the atmosphere, and improving the natural landscape, its decline contributes to increasing the greenhouse gases that cause climate change, allowing the winds to scatter the soil, increasing the frequency of dust storms, and so on. It has serious consequences for public health and visibility on main roads, and contributes to car accidents. The dust also suffocates remaining plants and makes the environment repulsive to many living organisms.

Based on the findings of this study, the following points should be taken into consideration:

1) The Directorate of Urban Planning on agricultural lands should defend against further urban sprawl by restricting and avoiding expansion of the urban area to protect the agricultural sector.

2) The Directorate of Urban Planning should be concerned with developing rural areas and preserving the agricultural character. This will support the agricultural area because it will increase the profit of farmers' agricultural production, which will make farmers more interested in protecting their cultivated land.

3) GIS and remote sensing have proven to be effective tools for assessing urban encroachment and also for studying land cover and use changes over a wide area.

4) The same method can be used to monitor the change in LULC for other regions in Iraq, especially in the alluvial plain area close to water sources and suitable for agriculture.

5) Refrain from illegal construction violations of buildings and warehouses that lead to urban sprawl by strengthening law enforcement in rural areas and activating strict regulations to preserve them.

Conclusion

The problem of urban encroachment on agricultural lands is suffered by all countries of the world, including Iraq, and is one of the main causes of desertification, so it deserves research and study. Studying this problem from its various aspects is vital, and must be taken into account and transformed into a strategic action that sets a well-thought-out and clear plan that prevents the loss of large areas of fertile lands in line with the trends of supporting the natural environment and the goals of sustainable development. Therefore, there is an urgent need to identify green areas in the city under study (Souq Al-Shuyukh) and not to establish various urban projects on them. This study aims to determine the extent to which Souq Al-Shuyukh city was exposed to urban expansion during the period from 2003 to 2020 AD, what the trends of this expansion are, what its type is, and to identify the underlying causes behind it, and whether there is any damage to the environment as a result. It is found that there is an encroachment of urban areas on other geomorphological units by about (10%) and an increase in the area of barren lands estimated at (6%) and a deterioration in agricultural areas by about 17%. In brief, the aforementioned city was exposed to a large, irregular urban expansion towards the north and northeast, and the population increase played a role in this expansion. This resulted in serious environmental impacts represented by rising temperatures, desertification, and an increase in the frequency of dust storms. In conclusion, there is an urgent need for environmental awareness and for urban expansion to move towards barren areas.

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