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Urban Expansion Study of Karbala City (1976-2022) Using Remote Sensing Data and GIS

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ABSTRACT

This study aims to elucidate the urban expansion that occurred in Karbala City during the study period from 1976 to 2022. The city holds significance as the capital of religious tourism in the country. The study monitors the rate and trends of urban growth in the study area. This is achieved by employing spatial analysis methodology to monitor urban growth using (GIS) and (RS) techniques. Four Landsat satellite images for the years 1976, 1990, 2013, and 2022 are downloaded from the USGS website. The first and second satellite images are captured from the (Landsat 5 TM) sensor, while the third and fourth are captured from (Landsat7 ETM+) and (Landsat 8 OLI) sensors. Quantitative methods, such as the chi-square test, are used to determine degrees of freedom for the purpose of evaluating and analyzing patterns of urban expansion in the study area. The results show a noticeable increase in the urban growth area in Karbala City; it reached ten times its previous size. In the year 1976, the urban growth area was 9.75. Km^2, while in the year (2022) it increased to (122) Km^2. The results of the degrees of freedom test indicate rapid and unsustainable urban growth during that time period. Therefore, this study recommends the necessity of managing urban expansions through appropriate planning, taking into consideration the nature and needs of cities. These studies should serve as a basis for topics related to predicting future urban changes.

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دراسة التوسع العمراني لمدينة كربلاء (1976– 2022) باستخدام بيانات الاستشعار عن بعد ونظم المعلومات الجغرافية

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الملخص

تهدف هذه الدراسة إلى توضيح التمدد العمراني الذي طرأ على مدينة كربلاء خلال فترة الدراسة بين عامي (1976– 2022)، والتي تبرز أهميتها كونها عاصمة السياحة الدينية في البلد، حيث قامت هذه الدراسة برصد مقدار التوسع العمراني واتجاهاته في منطقة الدراسة. وذلك بالاعتماد على منهجية التحليل المكاني لمراقبة النمو العمراني في منطقة الدراسة من خلال استخدام تقنيات نظم المعلومات الجغرافية (GIS) والاستشعار عن بعد (RS). فمن خلال موقع هيئة المساحة الجيولوجية الامريكية (USGS) تم تحميل أربع مرئيات لاندسات للسنوات (1976, 1990, 2013, 2022) حيث كانت المرئيتان الاولى والثانية من قمر لاندسات (5) والمستشعر (TM) والمرئية الثالثة من قمر لاندسات (7) بالمستشعر (ETM+) والمرئية الرابعة من قمر لاندسات (8) بالمستشعر (OLI). كذلك استخدمت هذه الدراسة بعض التقنيات الكمية مثل اختبار مربع كاي لحساب درجة الحرية من اجل تقييم وتحليل انماط التوسع العمراني في منطقة الدراسة، ولقد تبين من خلال النتائج التي توصلت اليها الدراسة مقدار الزيادة الحاصلة في مساحة النمو العمراني لمدينة كربلاء حيث ازدادت هذه المساحة ضمن نطاق الدراسة الى عشرة اضعاف ما كانت عليه، حيث كانت مساحة النمو العمراني لعام 1976 هي (9.75) كم^2، وتزايدت في العام 2022 لتصبح (122) كم^2، اما نتائج اختبار درجة الحرية فأظهرت نموا عمرانيا سريعا وغير مستدام خلال تلك الفترة الزمنية، لذلك توصي هذه الدراسة بضرورة ادارة التوسعات العمرانية بالتخطيط المناسب وذلك وفقا لطبيعة المدن واحتياجاتها، إذ ينبغي أن تكون هذه الدراسات بمثابة أساس للمواضيع المتعلقة بالتنبؤ بالتغيرات الحضرية المستقبلية.

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Introduction

Cities are among the most advanced forms of human settlement, representing a historical phenomenon that has evolved alongside great civilizations. Therefore, researchers in the field of urban studies need to understand a range of spatial factors that have affected and continue to affect the urban space, whether they are natural, economic, or urban factors, to develop necessary plans to mitigate or minimize their negative impacts. Rapid changes in urban land use led to undesirable urban sprawl (Kumar *et al.*, 2007; Jarrah *et al.*, 2019), which is one of the main problems that cause a shift in urban land use and the process of managing urban expansion (Baredo and Demicheli, 2003; Nuissl and Siedentop, 2021; Creutzig *et al.*, 2019). Urban sprawl is known as the extent and level of dispersion of built-up areas in natural landscapes (Al-Sharif *et al.*, 2013; Al-Sharif *et al.*, 2014). In recent years, there has been significant development in road networks, transportation, and infrastructure, which in turn has

led to the expansion of urban areas in major cities within short periods of time. Consequently, there is a reciprocal relationship between urban expansion and land use, as it directly impacts urban development (Bhatta, 2010; Zhang and Xie, 2019).

The city of Karbala has witnessed significant urban growth, especially after 2003, due to various reasons, including its religious and touristic importance, attracting millions of visitors annually. As a result, many individuals have moved to Karbala from other areas for residential and employment purposes, and the living conditions of the city's residents have improved (Farhan *et al.*, 2018). Therefore, this expansion has become one of the most prominent features of change in Karbala, manifested in the increase in population and the expansion of the urban area, which continues to grow day by day.

Hence, techniques of integration between (GIS) and (RS) are considered among the most important and advanced technologies used to study and monitor various phenomena, including urban change (Punia and Singh, 2012; Hani Al-Tamimi *et al.*, 2022; Shalini *et al.*, 2023). These technologies enable researchers, planners, and decision-makers to understand the changes that have occurred in the study area over different time periods by building databases for the study area based on satellite imagery, aerial photographs, spatial information, and descriptive data (Basu *et al.*, 2023; Canty, 2019). By analyzing all this data and conducting necessary studies, it is possible to obtain maps that demonstrate the continuous urban changes during the specified period, as well as to identify the extent of urban expansion and the problems that arise from this expansion, such as haphazard development and congestion (Arnone *et al.*, 2016; Liu *et al.*, 2015). This contributes to proposing future solutions and recommendations. As a result of the large population increase that occurred in the city of Karbala during the time period (1976 - 2022), during which the population has increased from about 350 thousand people in 1976 to more than 1.5 million people in 2022, especially more than 65% of them are concentrated in the center. This increase has affected the change of many land uses, especially agricultural lands, which have been encroached upon to a large extent in order to accommodate population growth. Therefore, there was an urgent need to study the nature of urban expansion in the city during the research period and determine its areas, lengths, and directions to help decision makers develop methodological and future solutions. Therefore, the importance of this research (main objective) lies in monitoring and observing urban sprawl, as it is the most common type in the study area, by calculating the volume of urban growth occurring in the city of Karbala and knowing its trends during the time period (1976 - 2022) using remote sensing and GIS techniques. Also, it is possible to take this study as a tool to help planners and decision-makers when developing the correct plans for future projects.

Materials and Methods

Study Area

Karbala city is geographically located between latitudes 33°50' and 33°10' North and longitudes 44°10' and 44°12' East. It is bordered by Babil Governorate to the east and Najaf and Anbar Governorates to the south and west, as shown in Figure 1. The area of Karbala city is approximately 2,397 Km^2. The plateau occupies a large area on the western side of the city, which deprives it of the urban connection with other regions. In addition to its religious significance, there are tourist areas such as Lake Razaza, which is located more than 10 km northwest of the city, and some important archaeological sites in the governorate, such as historical shrines, Akhider Fortress, and Ain Al-Tamr, which are considered important tourist sites in the country.

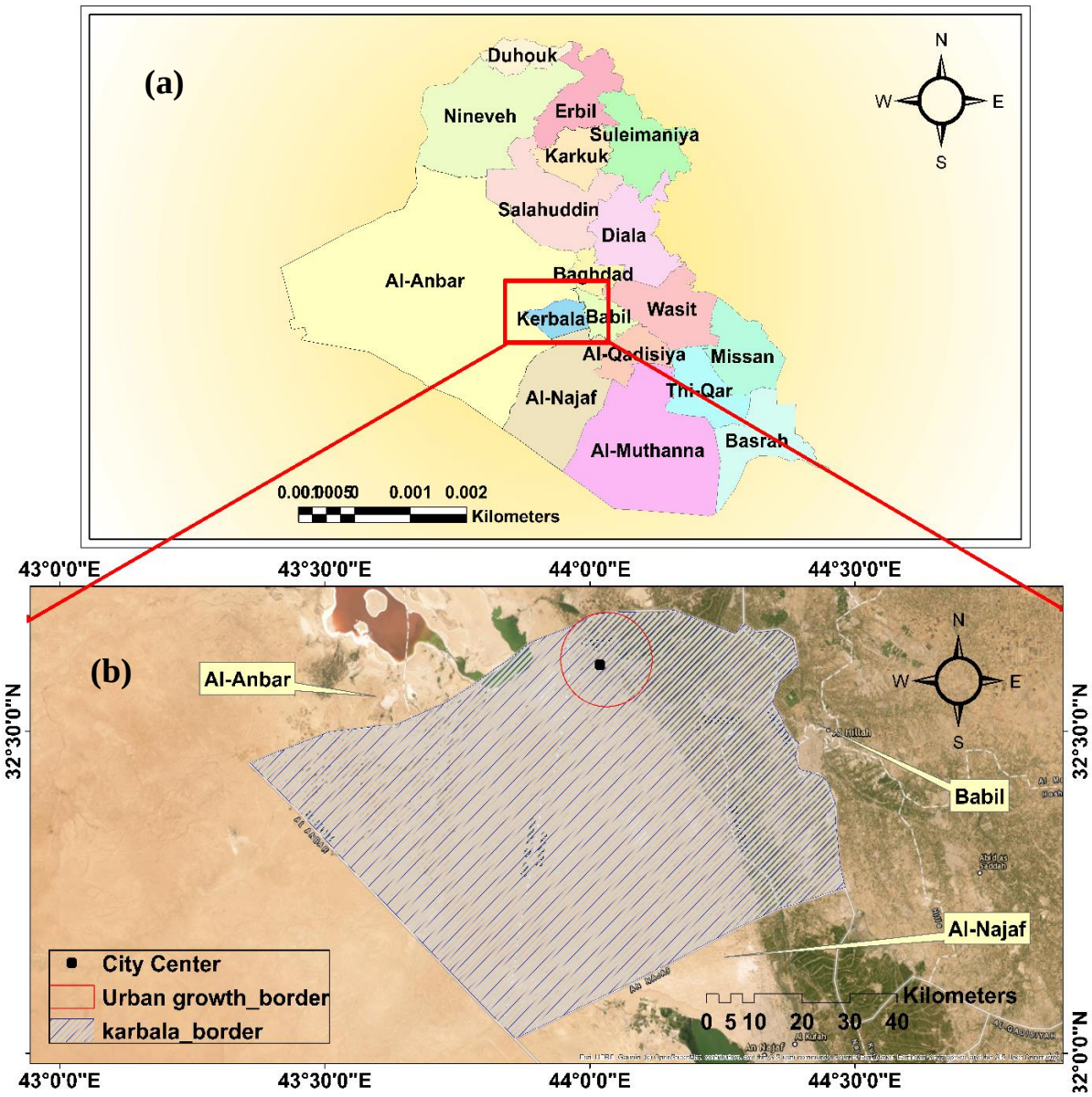


Fig. 1. Location map of the study area. a) Location of Karbala Governorate on the Iraq map b) Map showing the boundaries of urban growth in Karbala City.

Analysis Method and Approach

In this study, four satellite imagery datasets are used for the years (1976, 1990, 2013, and 2022), where these times are chosen for certain considerations, including the availability of sufficient data and information for those years. Furthermore, choosing long time periods help the study to accurately identify the trend and extent of urban expansion. The first and second images are obtained from the Landsat 5 satellite using the TM sensor, while the third image is acquired from the Landsat 7 satellite using the ETM sensor. The fourth image is obtained from the Landsat 8 satellite using the OLI sensor. All of these images are obtained with a spatial resolution of 30 meters from the website of the U.S. Geological Survey (USGS) https://earthexplorer.usgs.gov/. As for the statistical and spatial descriptive data, they are obtained from the Iraqi Survey Department. Subsequently, these satellite images are imported into the ENVI 5.3 software, where processing, correction, and image enhancement operations are performed (Cengiz *et al.*, 2022; Ramachandra *et al.*, 2013). A false composite color scheme is used to improve the visualization of the images for the purpose of classification. Afterward, the images are cropped to include only the study area without the surrounding areas. Accuracy assessment of the maps for the years 1990, 2013, and 2022 is conducted using Google Earth,

which provides high-resolution images with dates that align with the images used in this study, making them reliable and suitable for assessment, as shown in Figure 2.

After the correction and processing of the satellite images, the second phase involves exporting the data to the ArcGIS 10.8 software. The data for the study area are then converted into a spatial format (raster to polygon) to calculate the urban expansion areas for each time period (Tagil *et al.*, 2018). According to Ren *et al.* (2013), the urban area is defined within a large circle representing the urban extent along the plain strip, which represents the populated areas. A main point representing the city center is selected, and the directions of urban growth for each time period are determined from this point (Salman Aal-shamkhi *et al.*, 2017). The circle is divided into eight sections based on the major and minor directions (N, S, E, W, NE, NW, SE, SW) to calculate the lengths of urban growth and to identify the urban expansions that occurred in each direction within the study area and for different time periods. This procedure will contribute to a comprehensive understanding and effective evaluation of urban expansion patterns.

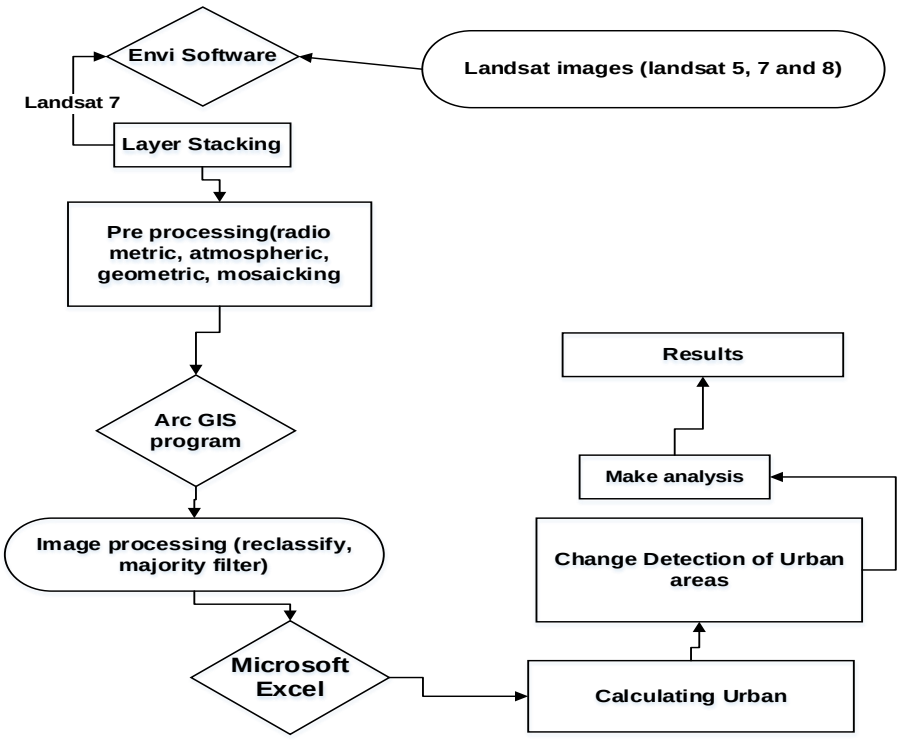


Fig. 2. Flowchart of methodology.

Results and Discussion

Analysis of Urban Growth Patterns

Before presenting the results of the current study, it is necessary to analyze the patterns of urban growth in the study area visually and quantitatively. Figure 3 shows the most important changes that occurred in the urban growth process of the city of Karbala during the time period (1976 - 2022). From the results obtained, it can be concluded that urban growth in the study area has increased significantly and in different directions for many reasons, including the large increase in the population. According to the statistics of the Iraqi Central Bureau of Statistics, the city's population was about 350 thousand people in 1976, and then it became approximately 600 thousand people in 1990. The increase continued significantly, until it reached about 1.1 million people in 2013, while in 2022 the population became about 1.5 million people. This increase in population growth, along with other accompanying factors, led to a noticeable change in urban growth patterns, while exacerbating the problem of unplanned urban growth

in the study area. Therefore, the importance of geomatics techniques such as (RS) and (GIS) is highlighted in visually demonstrating these problems.

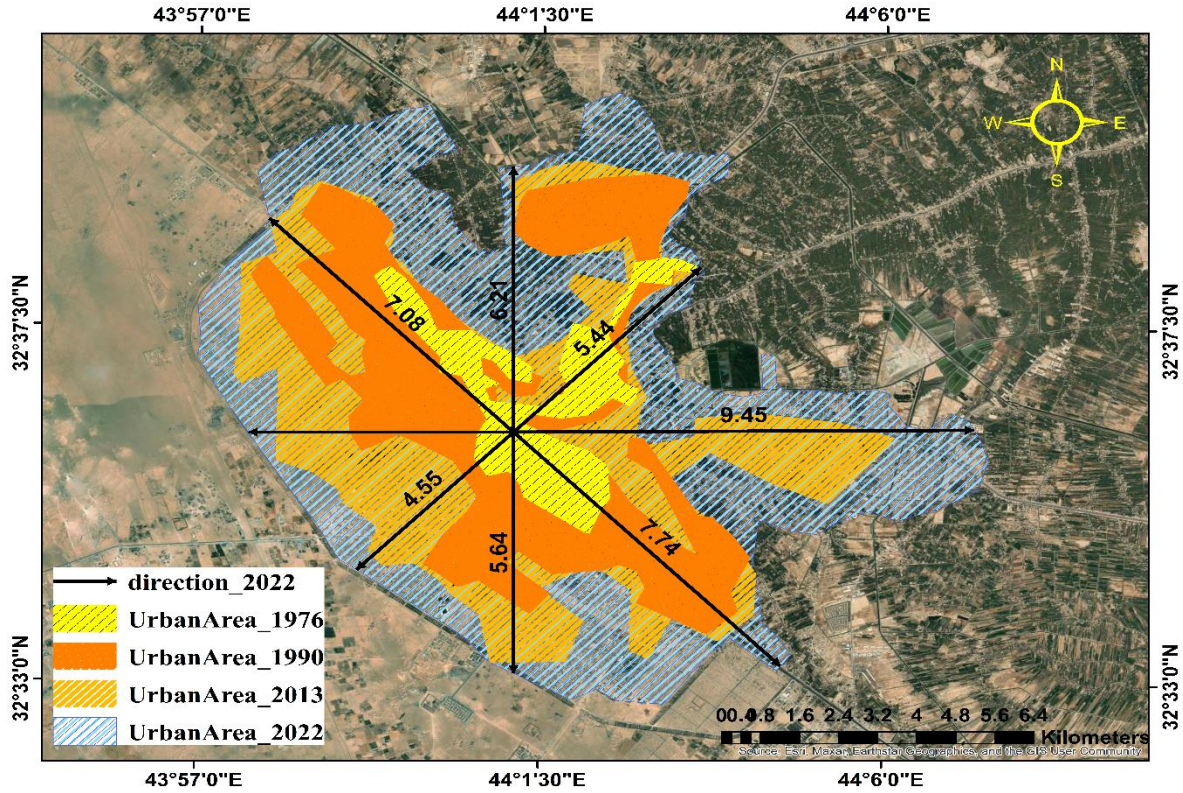


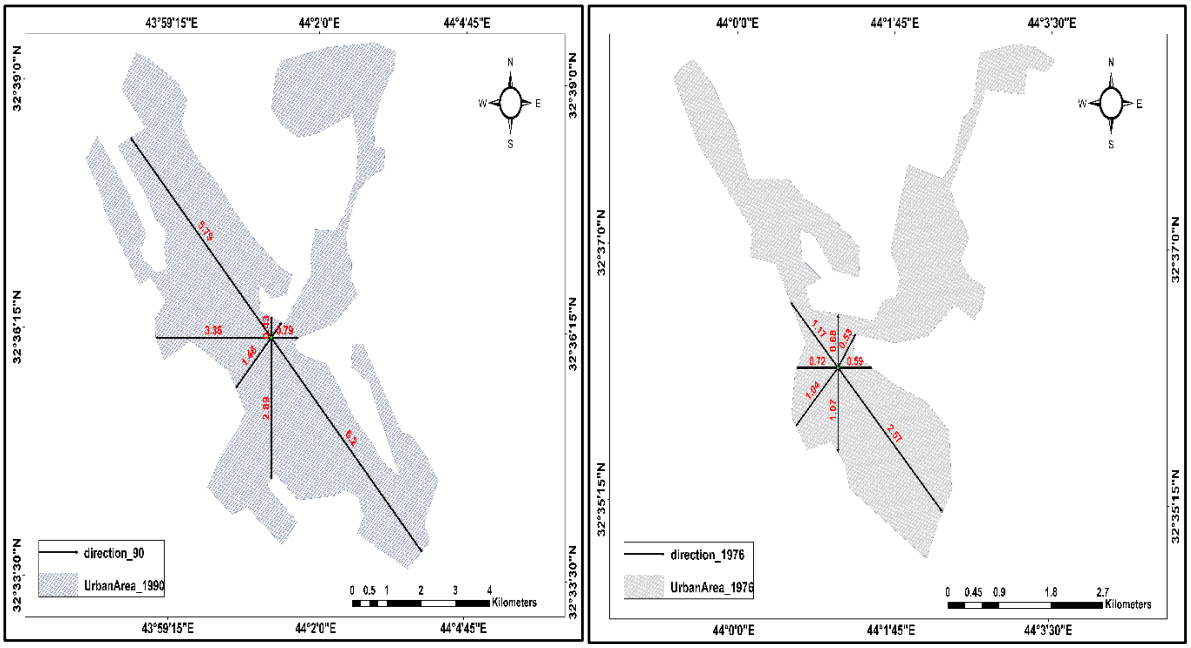
Fig. 3. Changes of urban growth in the study area.

Quantitative Analysis of Urban Changes

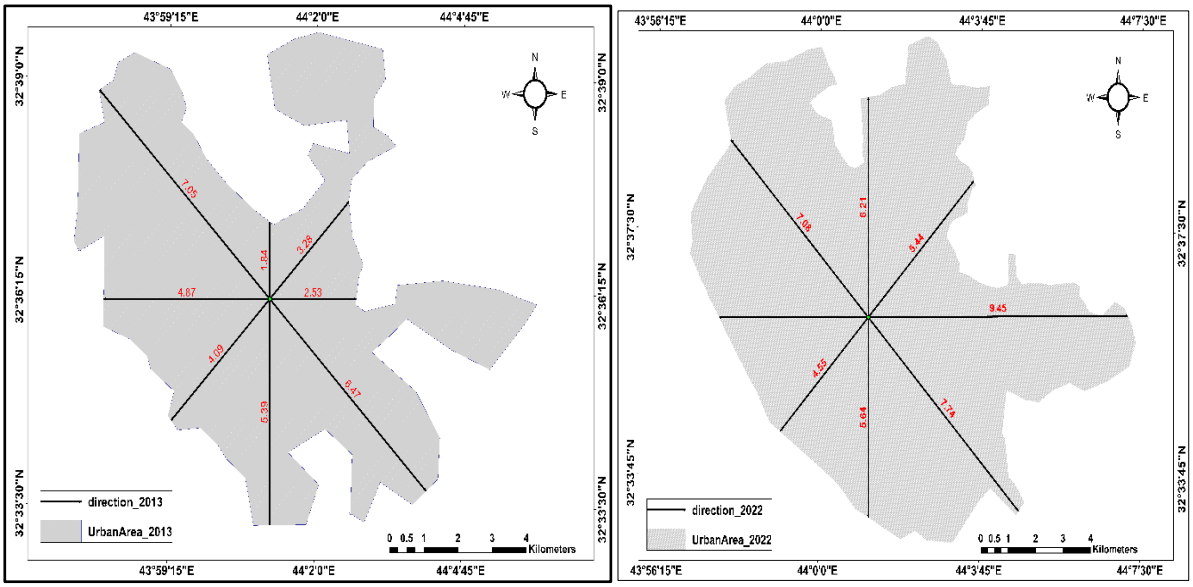
The study will present its findings here to determine the extent of urban expansion that occurred in Karbala City during the specified time period through the following points:

1. Based on the urban growth maps of the city of Karbala for the year 1976, urban growth was characterized by its concentration in the city center with relatively small variations. However, in 1990, the notice was that urban growth started to expand in almost all directions of the city. The significant increase in urban growth is evident in the years 2013 and 2022. Based on this data and results, we can observe the clear difference in urban expansion and its directions that occurred in the city of Karbala during the study period (1976-2022).
2. The study reveals the expansion that occurred in the urban mass of the city of Karbala within the specified urban scope during the study period, without considering the areas of land with other uses or those outside the specified urban scope.
3. The area of the urban mass in the city of Karbala was approximately 9.57 square kilometers in 1976. However, the urban growth area in 1990 was approximately 41.67 square kilometers, indicating that the urban mass in the study area had quadrupled during the time period (1976-1990), as shown in Figure 4.

4. The urban growth rate increased to approximately 81.39 square kilometers in 2013, indicating that the urban mass doubled during the period from 1990 to 2013, as shown in Figure 4. In 2022, the urban mass increased significantly to approximately 122 square kilometers, indicating that the urban mass has increased by half during the time period (2013-2022).



a. Growth trend in the year 1976 **b. Growth trend in the year 1990**



c. Growth trend in the year 2013 **d. Growth trend in the year 2022**

Fig. 4. The Areas of urban built-up and their directions in different time periods.

From Figure 5, it becomes evident that there is a clear increase in urban growth in the study area of Karbala City. This can be attributed to several reasons, including a significant increase in population due to the migration that occurred in Karbala province as a result of the terrorist acts that took place in the country in 2014. Additionally, the southern regions suffer from drought and unemployment, making Karbala an attractive destination for visitors and displaced people.

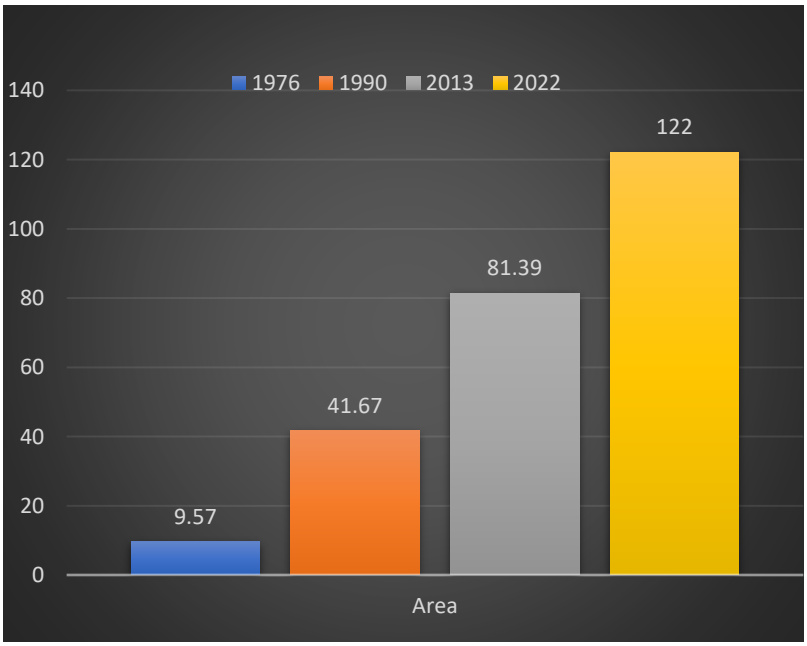


Fig. 5. Urban growth area (in km^2) for each time period in the study area.

Moreover, most of the population is concentrated in the city center due to Karbala's geographical location, with a large portion of its area allocated to the plateau and water bodies represented by Lake Razaza. Furthermore, there has been an expansion in road networks and an increase in infrastructure projects such as universities, hospitals, hotels, and government departments. The growth patterns in the study area are divided into eight directions, as mentioned earlier, including four main directions and four sub-directions. The value of urban expansion in the eight directions and during different time periods is shown in Table 1.

Table 1: Lengths of urban expansion (in km) in the area of study in the eight directions.

year	N	NW	W	SW	S	SE	E	NE	Total
1976	0.68	1.51	0.8	1.09	1.23	2.61	0.43	0.98	9.33
1990	0.74	5.94	3.41	1.51	2.78	5.94	0.88	0.46	21.66
2013	1.98	7.01	4.28	4.17	5.61	6.74	2.49	3.13	35.41
2022	5.74	7.02	5.44	4.55	5.47	7.72	9.51	5.45	50.9

When comparing the lengths of urban growth directions, it is observed that some directions have almost doubled in length in terms of growth. For example, the northwest axis had a length of approximately 1.51 km in 1976, which increased to 5.94 km in 1990, and reached 7.01 km in 2013. The same applies to the southeast axis, which had a length of 2.61 km and increased to approximately 5.94 km, and in 2013, it reached about 6.74 km, and in 2022, it increased to 7.72 km. Other axes have experienced growth, but to a lesser extent than their counterparts. The same applies to the southwest direction, where the axis length was 1.09 km and then increased to 1.51 km, and further increased to 4.17 km in 2013. The results also indicate a significant increase in the eastern axis of the city, with a length of 2.49 km in 2013, and a substantial increase in 2022 to reach 9.51 km.

Calculation of observed growth and expected theoretical growth

Table 2 shows the observed expansion of the urban mass in various directions in the study area over the time period (1976-2022). Depending on the achieved results, researchers speculate on the reasons for the urban growth trends in the city of Karbala, which are significantly and increasingly directed towards the northwest and southeast, and in recent years towards the eastern axis. This is due to the absence of natural or human obstacles that limit this expansion, as well as the low price of these lands and their proximity to the city center. Additionally, the large-scale excavation of agricultural lands and their conversion into residential areas contribute to this trend.

On the other hand, urban growth is less pronounced in the western directions, as it is believed that the unsuitability of the land in that axis for residential purposes, due to its geographic nature, specifically the predominance of the plateau, is the main reason. The same applies to the southern directions of the city, where the concentration of industrial uses and warehouses is expected to hinder population migration to those areas.

Table 2: Observed growth in the dimensions of the urban mass in the area of study in the eight directions.

Time period	N	NW	W	SW	S	SE	E	NE	Total
1976- 1990	0.06	4.43	2.61	0.42	1.55	3.33	0.45	-0.52	12.33
1990-2013	1.24	1.07	0.87	2.66	2.83	0.8	1.61	2.67	13.75
2013-2022	3.76	0.01	1.16	0.38	-0.14	0.98	7.02	2.32	15.49
Total	5.06	5.51	4.64	3.46	4.24	5.11	9.08	4.47	41.57

Afterwards, the expected theoretical growth in the length of the urban mass in the area of study is calculated in different directions, as shown in Table 3. This is done to gain a broader understanding of the urban growth process in the study area by comparing the observed values with the theoretically expected values. The following relationship is used to calculate the expected growth values for the lengths of urban growth (Bhatta *et al.*, 2010).

$$Ge = (Gr * Gc)/Gt \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where,

Ge: is expected growth; *Gr*: is expected growth in row total; *Gc*: is expected growth in column total, and *Gt*: is expected growth total.

Table 3: Theoretically expected growth in the lengths of the urban mass in the area of study in the eight directions.

Time period	N	NW	W	SW	S	SE	E	NE
1976- 1990	1.50	1.63	1.38	1.03	1.26	1.52	2.69	1.33
1990-2013	1.67	1.82	1.53	1.14	1.40	1.69	3.00	1.48
2013-2022	1.89	2.05	1.73	1.29	1.58	1.90	3.38	1.67

Afterwards, it is possible to determine and quantify the extent of urban expansion in the study area through expected growth values minus observed growth values. Positive values resulting from this subtraction indicate significant urban growth, while negative values show that there is little or limited growth. From Table 4, it is evident that there is significant urban growth in the eastern regions, which was relatively slow previously. There is also rapid urban growth in the northwest and southeast regions in the earlier time periods, followed by a slowdown in recent years due to various reasons. In the western regions, there is urban growth, but it is slower compared to other directions.

Table 4: The difference between observed and expected growth in the lengths of the urban mass in the area of study in the eight directions.

Time period	N	NW	W	SW	S	SE	E	NE
1976- 1990	-1.44	2.80	1.23	-0.61	0.29	1.81	-2.24	-1.85
1990-2013	-0.43	-0.75	-0.66	1.52	1.43	-0.89	-1.39	1.19
2013-2022	1.87	-2.04	-0.57	-0.91	-1.72	-0.92	3.64	0.65

Calculation of Chi-Square

To assess the degree of freedom for urban growth in the area of study, the Chi-square test is used. This test can indicate the sustainability of urban growth based on the degree of freedom, where higher values of the degree of freedom suggest unsustainable urban expansion. The (*Df*) is calculated for each time period as a whole or for each direction using the following relationship (Almeida *et al.*, 2005):

$$Df = \frac{\sum(Gs-Ge)\text{^}2}{Ge} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where:

Df: is the Degree of Freedom; *Gs*: is observed growth in the Time Period, and *Ge*: is expected growth in the Same Time Period.

From Table 5, it can be observed that urban growth in the city of Karbala, in general, has been unbalanced for the time period (1976-2022). The high degrees of freedom do not indicate a regular pattern of urban growth and its connection to other areas. Instead, they suggest that the growth is uneven and unsustainable, varying from one region to another and across different time periods (Bhatta *et al.,* 2010).

Table 5: The degrees of freedom for urban growth in each time period.

Time	Freedom degree
1976-1990	14.31
1990-2013	6.25
2013-2022	11.21

From Table (6), it can be observed that the urban expansion in the northwest and east directions of the study area is uneven and disjointed. On the other hand, in other directions such as the west direction, the degrees of freedom are low. After determining the degrees of freedom for the study area, they can be utilized to understand future urban expansion and develop appropriate plans for achieving sustainable urban development.

Table 6: The degrees of freedom for urban expansion in each direction.

NE	N	NW	W	SW	S	SE	E	NE
3.79	3.36	7.13	1.58	3.01	3.39	3.09	6.42	**3.79**

Conclusion

This study demonstrates the great potential of remote sensing methods and geographic information systems in studying urban development plans in Karbala City. It also shows that these methods have the ability to be combined with quantitative methods and statistical tests to obtain an accurate assessment of urban expansion trends in different regions. Through the results of the study, it is clear that there are significant changes in the sizes, shapes, and locations of all urban areas during the specific study period in Karbala. It is also noted that the results of the chi-square test confirm that the urban growth in the study area is unbalanced and unsustainable. Therefore, these results highlight the urgent need for effective and sustainable urban planning to limit the rapid expansion of the phenomenon of urban sprawl.

Recommendations

Based on the findings, the study provides a set of recommendations that can be summarized as follows:

1. Achieve integration between (RS and GIS) techniques in guiding and controlling the directions of urban growth in cities in a balanced and studied manner, through legislation that limits the increasing urban expansion.
2. Benefit from studies that focus on detecting urban expansions and consider them as important tools in the decision-making process and the development of future strategic expansion plans in the city.
3. The study recommends conducting further research on urban change detection and its application to other cities, using geomatics applications, to study this phenomenon and its environmental impact in the study area.
4. Emphasize the concept of sustainability by monitoring and observing the effects of urban expansion on the natural environment in cities, such as preserving vegetation cover, regulating water usage, and reducing air pollution.

These recommendations aim to promote more balanced and sustainable urban development practices in the study area and beyond.

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