Exp. Theo. NANOTECHNOLOGY 10 (2026) 741-754 https://doi.org/10.56053/10.2.741

Assessment of urban expansion with land use and land cover vegetation for al-refaie district, dhi qar governorate using GIS techniques

Ameer Z. Gatea[1], Sundus A. Abdullah[1,], Bassim Mohammed Hashim[2]*

[1]Department of Remote Sensing and GIS, College of Science, University of Baghdad, Iraq.
[2]Scientific Research Commission, Baghdad, Iraq.
[*]) Email: sundusalbakri70@gmail.com

Received 1/2/2026, *Received in revised form* 2/3/2026, *Accepted* 21/3/2026, *Published* 15/4/2026

Al-Refaie district in Dhi Qar Governorate has witnessed a remarkable development in land use over the years, as it has been affected by the various economic and social transformations in the region. The study used Landsat 5 TM and Landsat 8 OLI images and Geographic Information Systems (GIS) techniques to analyze changes in Land Use/Land Cover (LULC) and calculate the Normalized Difference Vegetation-Index (NDVI) and the Normalized Difference Water-Index (NDWI) indices for 1990, 2000, 2013, and 2024. Based on the principles of urban planning and sustainable city expansion, this data is examined and its function in planning and designing residential areas and communities in the Al-Refaie district is examined. According to the findings, Al-Refaie's urban areas grew dramatically between 1990 and 2024, growing from roughly 21 km² to 65 km². In contrast, changes in LULC and human activity had a detrimental impact on agricultural land and water resources, causing agricultural lands to decrease from 540 km² in 1990 to 343 km² in 2024 and water to shrink from 304 km² in 1990 to 73 km² in 2024. Water and agricultural regions have decreased in favor of urban areas due to ongoing urban expansion. Land usage in Al-Refaie has been greatly impacted by demographic shifts, as is visible in both urban and residential regions. Decision-makers can effectively examine future patterns of urban expansion in keeping with the anticipated population growth in Iraq in the upcoming years by using long-term urban planning, which is based on land use and cost analysis.

Keywords: LULC; NDVI; NDWI; Landsat; Al-Refaie district

1. INTRODUCTION

Dhi Qar is one of Iraq's southern provinces, and its administrative capital is Nasiriya. The city is formerly a part of a historically affluent region because of its advantageous location for trade and culture. The land use and cover (LULC) has rapidly changed both spatially temporally and also climatically as a result of anthropogenic activities and expanding urban populations, due to the scarcity of water and the repercussions for food and social security [1]. Climate change would make natural disasters like floods and droughts worse, and both short-term and long-term processes exhibit these effects [2]. Rapid urbanization is a phenomenon that is seen all around the world. In developing countries like Iraq, the rate of urbanization is accelerating [3]. One of the major cities in Iraq is Al-Refaie District, which is also the district center and is administratively connected to the Dhi Qar Governorate. It is roughly 80 kilometers north of Nasiriyah, the capital of the Dhi Qar Governorate, and 300 kilometers south of Baghdad, the capital of Iraq. It is situated in the center of five governorates in Iraq, Amara, Kut, Diwaniya, Samawa, and Nasiriya, all of which are very near to one another. Similar to what happened in Iraq, cities are haphazardly expanding into areas that are vulnerable, which impacts agricultural production and lands, as well as animal productivity and bird migration. The requirement for food, housing, and water has increased due to rapid population growth, particularly in urban areas. This has made the annual depletion of degraded and desertification-prone agricultural land necessary. Emerging-nation cities usually face unique urban growth that deviates from regional objectives and regulations [4]. Rapid urbanization is a phenomenon that is seen all around the world. Similar to what happened in Iraq: cities are haphazardly expanding into areas that are vulnerable, which impacts agricultural production and lands, as well as animal productivity and bird migration. The requirement for food, housing, and water has increased due to rapid population growth, particularly in urban areas. This has made the annual depletion of degraded and desertification-prone agricultural land necessary [5][6]. Satellite remote sensing data is now regarded as the most reliable source of information for identifying changes in LULC due to its wide range. Long-term monitoring, vegetation cover, surface water body extraction, and LULC category analysis at the global and regional levels are all done using Landsat imagery [7]. Landsat images are vital for land use analysis, and they are utilized in numerous other fields. It has been shown that the LULC changes have both direct and indirect effects on the different environmental parameters [8].

The normalized difference water index (NDWI) is used to examine the water bodies while, an effective technique for calculating and recording shifts in the utilization of green land is the NDVI. It is based on the red (R) and near-infrared (NIR) bands [9]. The analysis of these criteria is vital to understanding the impact of urban expansion on the local environment and directing urban development efforts in a way that ensures a balance between population growth and conservation of natural resources [10]. Urban growth presents major obstacles for cities in emerging nations, frequently clashing with regional objectives and policies. Urban management and the local environment are impacted by changes brought about by rapid and perhaps unanticipated urban growth. In order to accommodate the demands of the expanding population, urban areas had to rapidly expand at that time due to the rapid urban growth that is linked to a significant increase in population [11]. Following the conclusion of the first decade of the twentieth century, Al-Refaie had significant demographic shifts due to social and economic advancements as well as the rise of the planning element that gave the city its planned growth character [12]. The lack of participation from certain specialists in the planning process, such as geographers who can ascertain the future urban expansion directions of the city, created certain challenges that followed city planning [13]. Nanotechnology is a multidisciplinary field of science and engineering that involves the design, characterization, production, and application of materials at the nanoscale, typically ranging from 1 to 100 nanometers. The study and manipulation of materials at the molecular, atomic, or even subatomic scale is known as nanotechnology. Environmental nanotechnology uses nanoscale pieces to remove or reduce pollutants from soil using a variety of physical, chemical, and biological remediation techniques [14]. In an attempt to create engineered materials that can overcome many of the difficulties associated with contaminant remediation, various studies have concentrated on applying the concepts of nanotechnology and combining them with surface modification, both chemically and physically [15].

In this study, examine the urban growth and its effects on vegetation cover in Al-Refaie city over than thirty years. The study assesses the temporal and spatial patterns of vegetation changes and urbanization using satellite imagery and remote sensing data, offering vital information to policymakers, environmentalists, and urban planners. Tao et.al., 2022 [16], studied LULC in the cities of Baghdad, Erbil, and Basra from 1990 to 2020 using Landsat 5 TM and Operational Land Imager (OLI). According to the findings, in Baghdad, the amount of barren area has increased, indicating the local climate and its impact on subsistence. Anthropogenic activities have an impact on Basra city, and throughout the past 30 years, the majority of Basra has been transformed into built-up territory. Erbil had more agricultural area during the study period. Saud et al., 2023 [7], investigated LULC in Al Hillah city using remote sensing and GIS techniques. The findings show that changes occurred in water and agricultural land, and the urban area grew by 20.5 km^2 from 1990 to 2022. The current study aims to assess the urban expansion in Al-Refaie city by analyzing the changes based on analysis of NDVI and NDWI using Landsat 5 TM and Landsat 8 OLI images for 1990, 2000, 2013, and 2024.

2. EXPERIMENTAL

2.1 Study area

The district of Al-Refaie in the Dhi Qar Governorate serves as the study area. It is situated in the southern region of Iraq, more precisely south of the floodplains. Latitude (31°) north and longitude (46°) east are where the city is situated. Wasit Governorate borders it on the north, Basra and Muthanna Governorates border it on the south, and Missan Governorate borders it on the east [25]. Its western border is represented by the Qadisiya province, which is an area with a significant concentration of oil industry. The district, which is roughly 80 km from the governorate's capital, Nasiriya, is regarded as the region's administrative hub. Given the abundance of oil resources in the area, including the Zubair and Gharraf fields, as shown in Figure 1. Among others, Al-Refaie is a key location for the oil fields in southern Iraq. The area of the study area is approximately 3553 km^2. Evaporation rates in Al-Refaie region are accelerated by the region's defining characteristics, which include intense sunshine, high temperatures, dry winds, low humidity, and little to no rainfall [26-30].

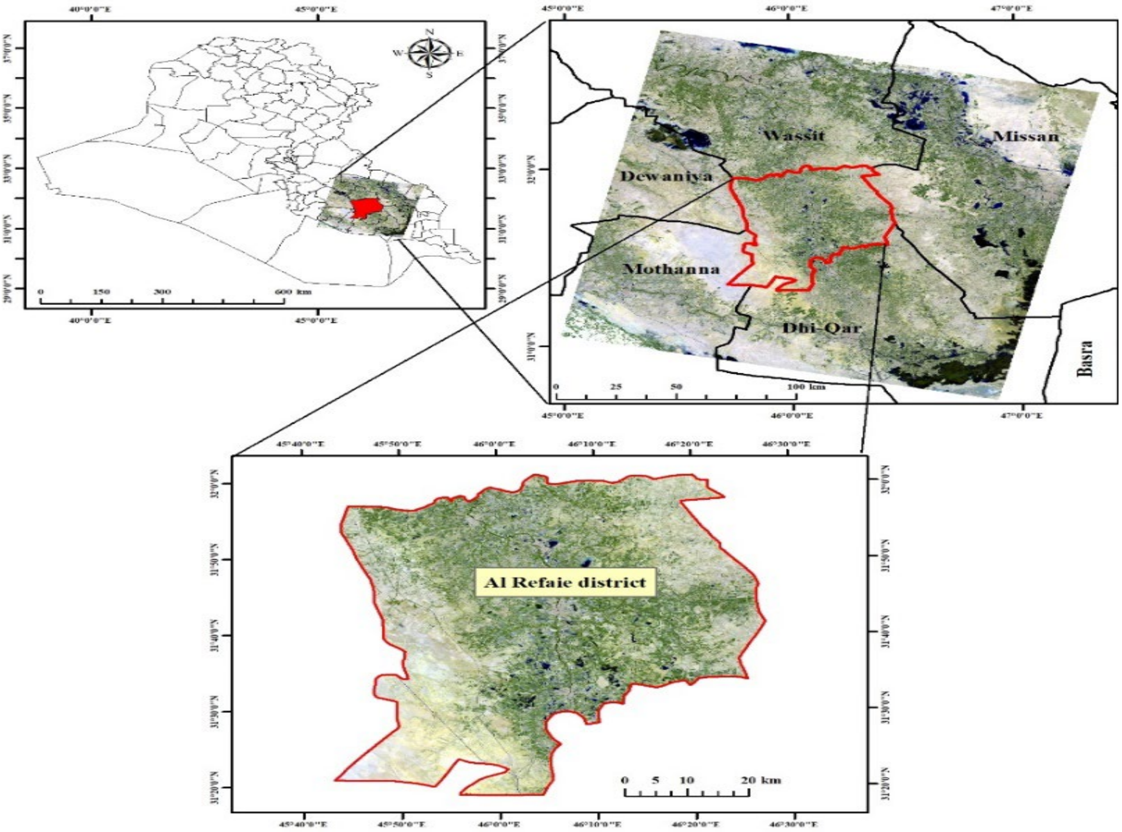

Figure 1 Location of Al-Refaie district in Dhi Qar governorate.

2.2 Data Sources

Used Landsat 5 TM and Landsat 8 OLI images for Al-Refaie city in March and April, when the weather is clear and cloudless. These images are acquired from the US Geological Survey website (www.earthexplorer.usgs.gov) [17]. Landsat 5 TM images taken on March 14, 1990, and March 9, 2000. While Landsat 8 OLI images are acquired in April 14, 2013, and April 4, 2024. In order to maintain consistency with Landsat 9 images, these images feature 30-meter resolution bands. The image bands for Landsat 5 TM, Landsat 8 OLI, and Landsat 9 OLI-2, shown in Tables 1 and 2, respectively [16].

Table 1 Landsat5 TM bands details [7].

Band No.	Wavelength (μm)	Resolution (m)	Bands
1	0.45-0.52	30	Blue
2	0.52-0.60	30	Green
3	0.63-0.69	30	Red
4	0.77-0.90	30	NIR
5	1.55-1.75	30	MIR
6	10.40-12.5	120	Thermal
7	2.09-2.35	30	MIR

Table 2 Landsat 8 OLI and Landsat 9 OLI-2 TM bands details [11].

Band No.	Wavelength (μm)	Resolution (m)	Bands
1	0.43-0.45	30	Coastal
2	0.45-0.51	30	Blue
3	0.53-0.59	30	Green
4	0.63-0.67	30	Red
5	0.85-0.88	30	NIR
6	1.57-1.65	30	SWIR1
7	2.11-2.29	30	SWIR2
8	0.50-0.68	15	Pan
9	1.36-1.38	30	Cirrus
10	10.60-10.19	100	TIRS1
11	10.50-12.51	100	TIRS2

2.3 Normalized Difference Vegetation Index (NDVI)

A popular remote sensing metric for determining the amount and condition of vegetation in a particular area is the Normalized Difference Vegetation Index, or NDVI [21]. By computing the difference between the red and near infrared (NIR) light reflected from the Earth's surface, it is obtained from satellite or aerial imagery [7].
This formula is used to determine the NDVI: [10, 31]

$$NDVI = \frac{(NIR - RED)}{(NIR + RED)} \quad (1)$$

In Landsat 4-7, the NDVI is computed as (Band 4-Band 3) / (Band 4-Band 3).
In Landsat 8-9, the NDVI is computed as (Band 5 – Band 4) / (Band 5 + Band 4) [16].

2.4 Normalized Difference Water Index (NDWI)

Changes in the water content of bodies of water are tracked using the NDWI. Since water bodies absorb a lot of light in the visible to infrared electromagnetic range, NDWI uses the green and near-infrared bands to highlight them. It is sensitive to built-up land and may result in an overestimation of water bodies [15]. The index is proposed by McFeeters (1996). Values description: Index values greater than 0.5 are frequently used to indicate water bodies. Vegetation usually corresponds to significantly smaller values, while built-up areas often correspond to values between 0 and 0.2 [11]. The green and near-infrared (NIR) bands of the electromagnetic spectrum's reflectance values are used to compute NDWI. The formula for calculating NDWI is: [4]

$$NDWI = \frac{(\mathrm{NIR} - \mathrm{SWIR})}{(\mathrm{NIR} + \mathrm{SWIR})} \quad (2)$$

2.5 Classification techniques

A procedure called "classification" is used to create a good collection of land cover information by classifying each pixel in the image or the original remotely sensed satellite data according to its kind. Since there are no specified classes, unsupervised categorization is employed. Each spectral group is distinct due to the different geographical features and the classification, which is impacted by the nature of the researched place (rural or urban) [6]. Each species has distinct reflectance and diffusion properties that determine its classification. Maps of land cover are frequently created using contemporary classification techniques, such as supervised and unsupervised approaches [12,32].

2.6 Methodology

There are numerous crucial steps in the process for examining changes in land use and urban growth. Data from satellite imagery is first gathered and analyzed. In order to evaluate changes in land cover, the following phase concentrated on computing a number of indices. In order to identify these changes, LULC classifications are also established. Calculating population density and projecting future growth rates are part of the last step. Starting in 1990, the study period lasted 34 years, with a focus on the Al-Refaie district in Dhi Qar Governorate. The satellite image is processed and interpreted using ArcGIS 10.8 software, enabling the creation of LULC maps that demonstrated the changes in land cover over time. Figure 2 represent a diagram for the methodology steps of this work. Landsat 5 TM bands details are as illustrated in Table 1 and Landsat 8-9 OLI-2 bands details are as illustrated in Table 2.

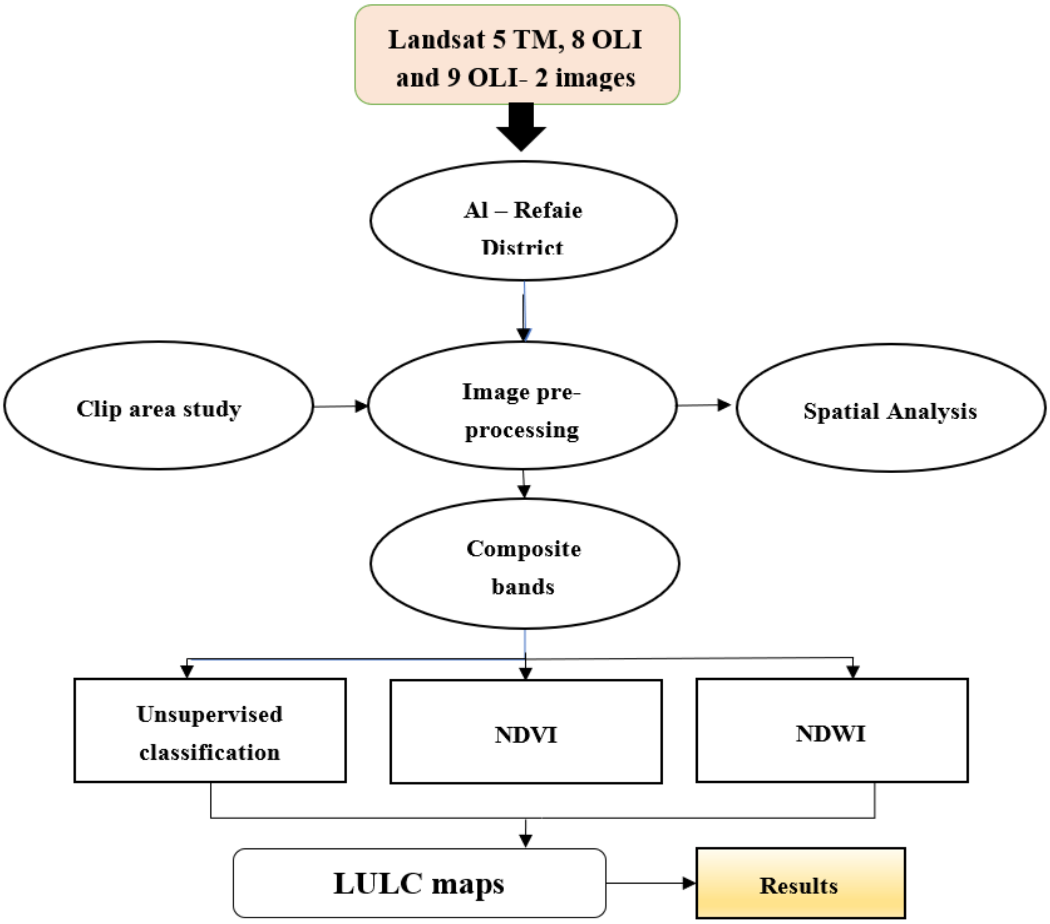

Figure 2 Flowchart for the methodology steps of the current study.

3. RESULTS AND DISCUSSION

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn.

3.1 NDVI

Figure 3 shows the values of the NDVI for Al-Refaie district in Dhi Qar Governorate in the years 1990, 2000, 2013 and 2024. The results in Figure 3 showed that the highest value of the NDVI in 1990 is 0.45, and is concentrated in the eastern part of the district. In 2000, the highest value of the NDVI is 0.48, and the green areas are concentrated in the northeastern and eastern parts and slightly in the southwestern side of Al-Refaie District, as shown in Figure 3b. The central marshlands are suffering from drought due to the marsh drainage measures in the 1990s. Figure 3c showed that the highest value of the NDVI is 0.52, where the vegetation is distributed in the middle and east of the region, especially in the central marshlands, which recovered during that period due to the rehabilitation measures of the marshes and wetlands in Iraq [29]. Despite the rehabilitation measures of the marshes in recent years, the highest value of the vegetation cover index is recorded in 2024, which is 0.66 and is concentrated in the middle and north of Al-Refaie district, as shown in Figure 3d.

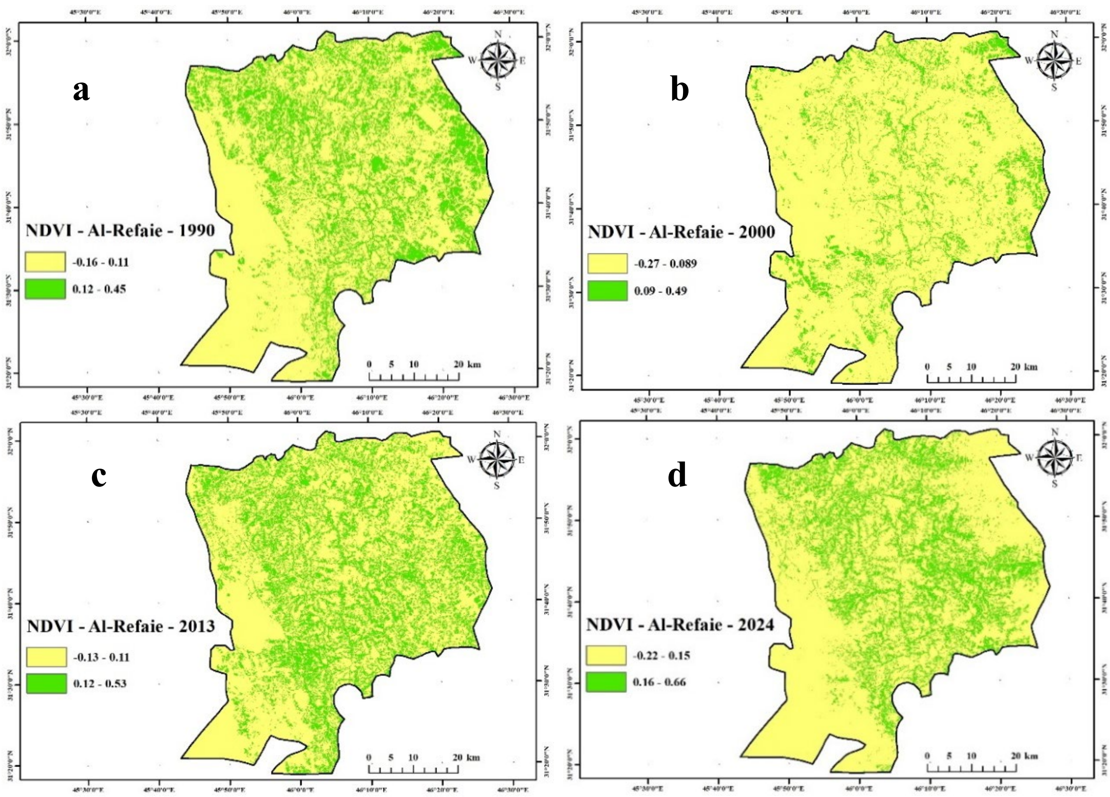

Figure 3 NDVI of Al Refaie district in (a) 1990; (b) 2000; (c) 2013; and (d) 2024.

3.2 NDWI

Figure 4 shows the NDWI values in Al-Refaie district between 1990 and 2024. The result showed that the highest water index value recorded in 1990 is 0.13 and is concentrated in the marshes west of Al-Refaie District as shown in Figure 4b. In 2000, the highest NDWI value is 0.28 due to the drying procedures. After the rehabilitation procedures of the marshes and wetlands in the twenty-first century, the NDWI value in 2013 recorded a value of 0.11 and spread in different areas of Al-Refaie District as shown in Figure 4c. In 2024, the NDWI recorded 0.25 as shown in Figure 4d.

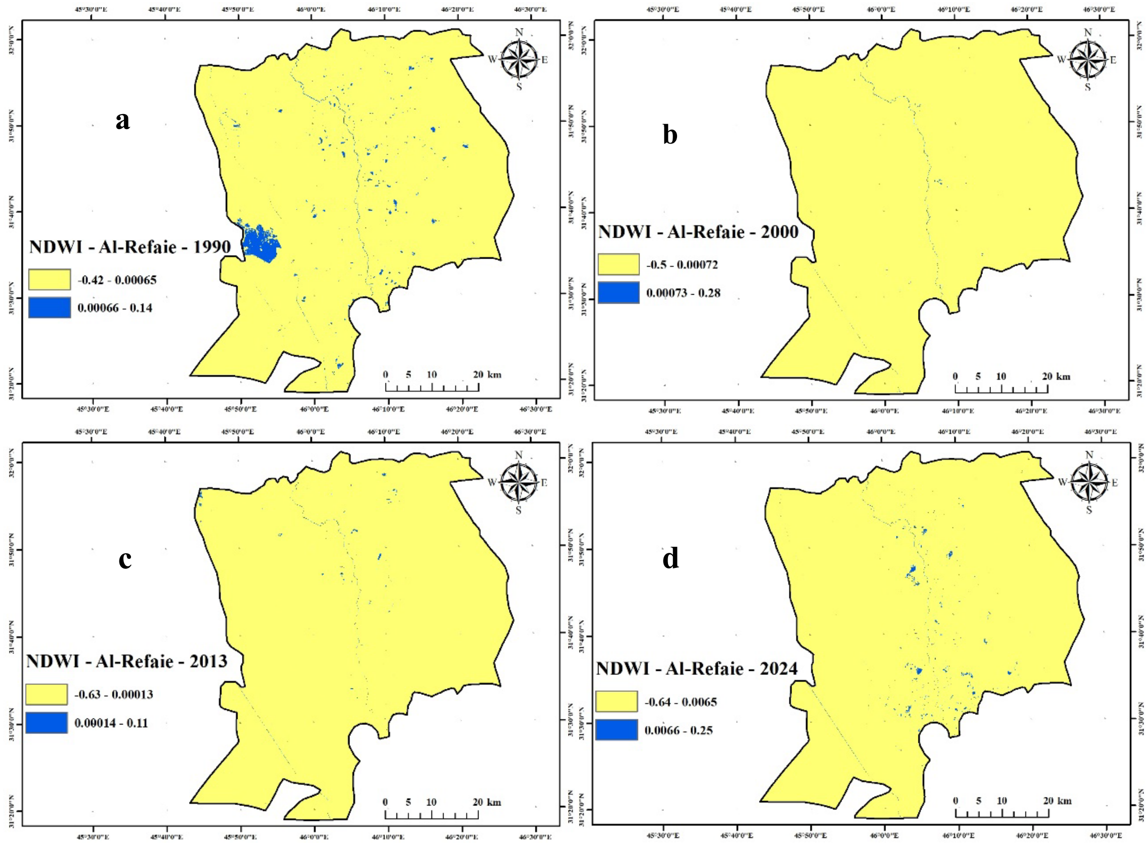

Figure 4 NDWI of Al-Refaie district in (a) 1990; (b) 2000; (c) 2013; and (d) 2024.

3.3 LULC

Figure 5 shows the analysis of land use and pollution in Al-Refaie district for the years 1990, 2000, 2013 and 2024. In Figure 5a, in 1990, the area of water and wetlands recorded at 304 km^2, and the vegetation areas clearly visible and formed an area of 540.4 km^2. On the other hand, the barren area recorded the highest value, amounting to 2663.2 km^2, which covered vast areas in the north, south and west of Al-Refaie district. The urban area amounted to about 21.6 km^2 and concentrated in the center of Al-Refaie district on both sides of the river. In addition, the area of the military zone is 17 km^2. As for the area of petroleum sites, it is 5.7 km^2, which included the Gharraf oil field. In 2000, the study of LULC in Al-Refaie district shown in Figure 5b showed a significant decrease in the area of water areas and marshes due to drying, as the area of water areas amounted to 196.5 km^2. The vegetation area decreased to 469.3 km^2. The area of barren areas increased to 2848.4 km^2 due to the drying of marshes and the lack of green spaces. The urban area increased to 28.8 km^2, while the area of military areas is 17 km^2. In addition to a slight increase in the area of petroleum sites, which recorded 5.8 km^2 [30].

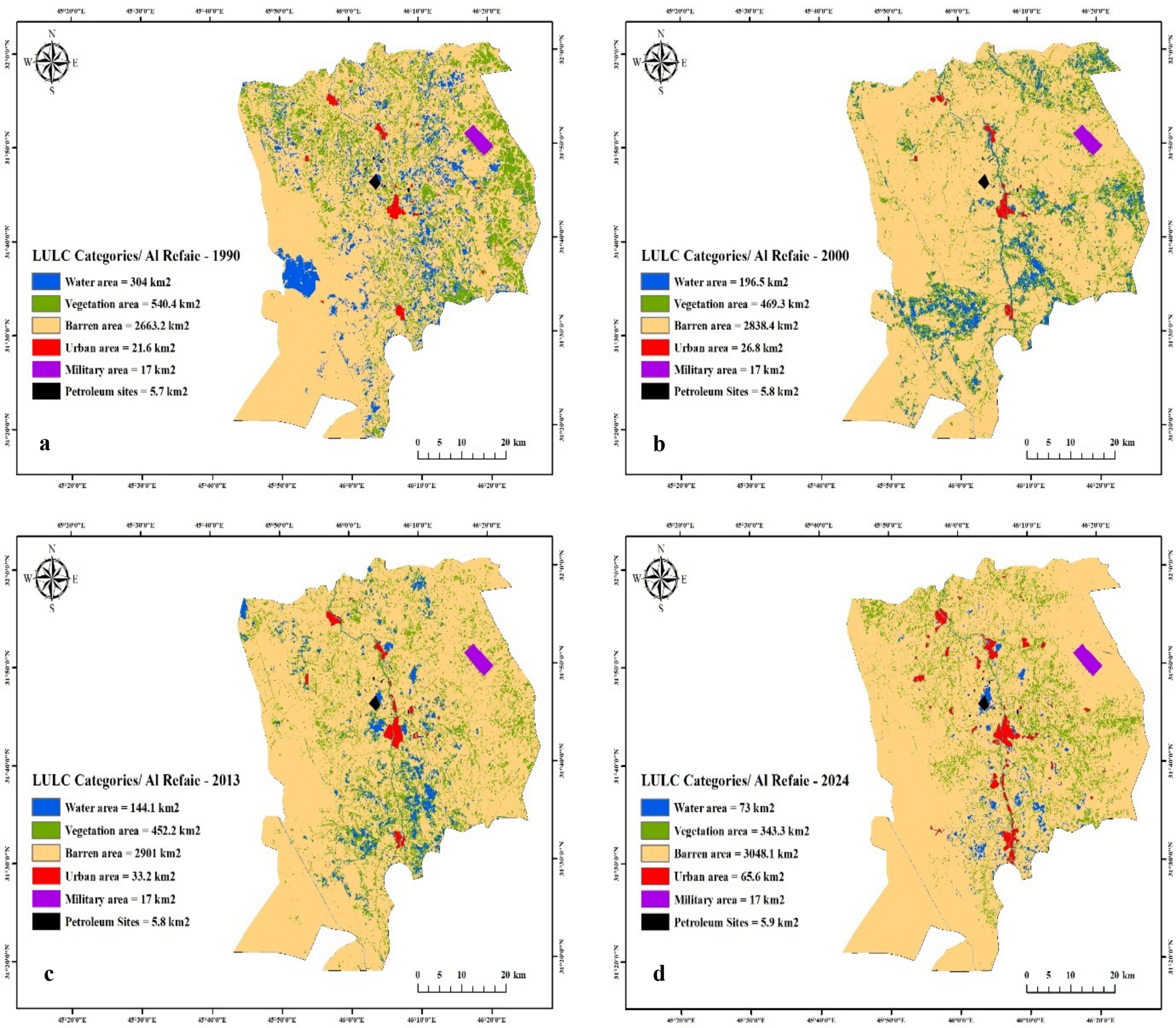

Figure 5 LULC analysis of Al-Refaie district.

Figure 5c shows the LULC analysis of Al-Refaie district in 2013. Figure 5c shows the land use analysis of Al-Refaie district in 2013. It showed a decrease in the area of water and wetlands to 144.1 km^2. There is also a slight decrease in the area of green and agricultural areas to 452.2 km^2. In addition, the area of barren lands increased to 2901 km2. The area of urban areas increased due to the increase in population and urban expansion in Al-Refaie city, reaching 33.2 km^2. The area of military areas remained the same at 17 km^2, as did the area of petroleum sites, which amounted to about 5.8 km^2. Figure 5d shows the land use in Al-Refaie city in 2024, showing a significant decrease in the water percentage to 73 km^2, as well as a decrease in the area of agricultural land to 343.3 km^2. The percentage of barren land increased due to the decrease in the percentage of water and agricultural land, reaching about 3048.1 km^2. The main reason for the decrease in water areas and vegetation cover and the increase in dry marshes and barren areas is due to the drought that has affected Iraq since 2019, due to high temperatures and evaporation, especially in the marshlands in southern Iraq [31]. The decrease in rainfall also greatly affected the drying up of marsh waters and the decrease in green areas. Differences between land use classifications during the study years as illustrated in Table 3.

Table 3 The variations among the LULC categories during 1990, 2000, 2013 and 2024.

Category	Area (km^2)		Difference (km^2)	Area (km^2)		Difference (km^2)	Area (km^2)		Difference (km^2)
	1990	2000		2000	2013		2013	2024	
Water	**304**	**196.5**	**-107.5**	**196.5**	**144.1**	**-52.4**	**144.1**	**73**	**-71.1**
Vegetation	**540.4**	**469.3**	**-71.1**	**469.3**	**452.2**	**-17.1**	**452.2**	**343.3**	**-108.9**
Barren	**2663.2**	**2838.4**	**175.2**	**2838.4**	**2901**	**62.6**	**2901**	**3048.1**	**147.1**
Urban	**21.6**	**26.8**	**5.2**	**26.8**	**33.2**	**6.4**	**33.2**	**65.6**	**32.4**
Military	**17**	**17**	**0**	**17**	**17**	**0**	**17**	**17**	**0**
Petroleum	**5.7**	**5.8**	**0.1**	**5.8**	**5.8**	**0**	**5.8**	**5.9**	**0.1**

3.4 Accuracy Assessment

Table 4 The accuracy assessment of the LULC categories of Al-Refaie district in 1990.

Category	Water	Vegetation	Barren	Urban	Military	Petroleum	Row total	User Accuracy
Water	10	0	0	0	0	0	10	1
Vegetation	0	12	0	0	0	0	12	1
Barren	2	4	69	1	1	2	75	0.9
Urban	0	0	0	0	1	0	1	0
Military	0	0	0	0	2	2	2	1
Petroleum	0	0	0	0	0	0	0	0
Total	12	16	68	1	1	2	100	0
Produce Accuracy	0.83	0.75	1	1	1	1	0	

Overall accuracy: 87 % Kappa coefficient: 0.813

Table 5 The accuracy assessment of the LULC categories of Al-Refaie district in 2000.

Category	Water	Vegetation	Barren	Urban	Military	Petroleum	Row total	User Accuracy
Water	6	0	0	0	0	0	6	1
Vegetation	0	10	0	0	0	0	10	1
Barren	0	4	78	0	0	0	84	0.94
Urban	0	0	0	1	0	0	0	1
Military	0	0	0	0	0	0	0	0
Petroleum	0	0	0	0	0	0	0	0
Total	6	14	78	1	1	0	100	0
Produce Accuracy	1	0.71	1	0	0	0	0	

Overall accuracy: 95 % Kappa coefficient: 0.843

Table 6 The accuracy assessment of the LULC categories of Al-Refaie district in 2013.

Category	Water	Vegetation	Barren	Urban	Military	Petroleum	Row total	User Accuracy
Water	**6**	**0**	**0**	**0**	**0**	**0**	**6**	**1**
Vegetation	**0**	**12**	**1**	**0**	**0**	**0**	**13**	**0.9**
Barren	**0**	**0**	**69**	**2**	**2**	**0**	**73**	**0.8**
Urban	**0**	**0**	**0**	**1**	**0**	**0**	**0**	**0**
Military	**0**	**0**	**0**	**0**	**2**	**0**	**2**	**0**
Petroleum	**0**	**0**	**0**	**0**	**0**	**6**	**6**	
Total	**7**	**16**	**73**	**2**	**2**	**0**	**100**	**0**
Produce Accuracy	**0**	**12**	**1**	**0**	**0**	**13**	**0**	

Overall accuracy: 92%   Kappa coefficient: 0.739

Table 7 The accuracy assessment of the LULC categories of Al-Refaie district in 2024.

Category	Water	Vegetation	Barren	Urban	Military	Petroleum	Row total	User Accuracy
Water	**3**	**0**	**0**	**0**	**0**	**0**	**3**	**1**
Vegetation	**1**	**14**	**1**	**2**	**0**	**0**	**18**	**0.8**
Barren	**0**	**4**	**65**	**2**	**2**	**0**	**73**	**0.8**
Urban	**0**	**0**	**0**	**4**	**0**	**0**	**4**	**0**
Military	**0**	**0**	**0**	**0**	**2**	**0**	**2**	**2**
Petroleum	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Total	**4**	**18**	**66**	**8**	**4**	**0**	**100**	**0**
Produce Accuracy	**0.75**	**0.8**	**0.9**	**0**	**0**	**0**	**0.88**	

Overall accuracy: 90%   Kappa coefficient: 0.714

Figure 6 and 7 shows the comparison of LULC of Al-Refaie district obtained using Landsat 5 TM and Landsat 8 OLI in 1990, 2000, 2013, and 2024.

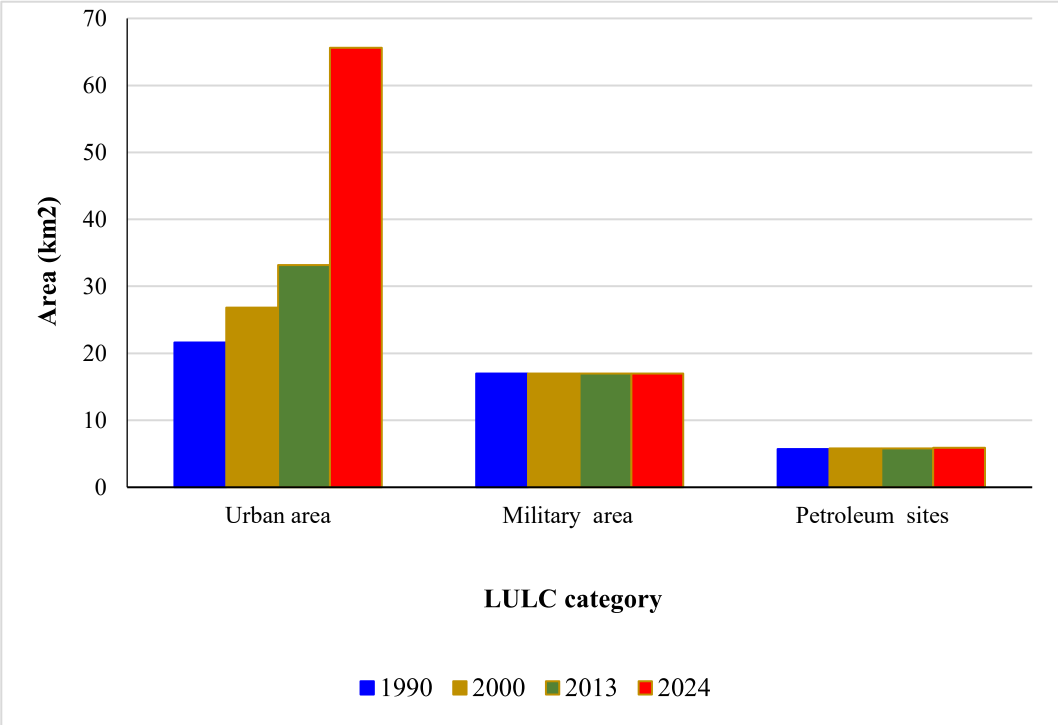

Figure 6 LULC analysis (water area, vegetation area and barren area) for Al-Refaie district in 1990, 2000, 2013, and 2024.

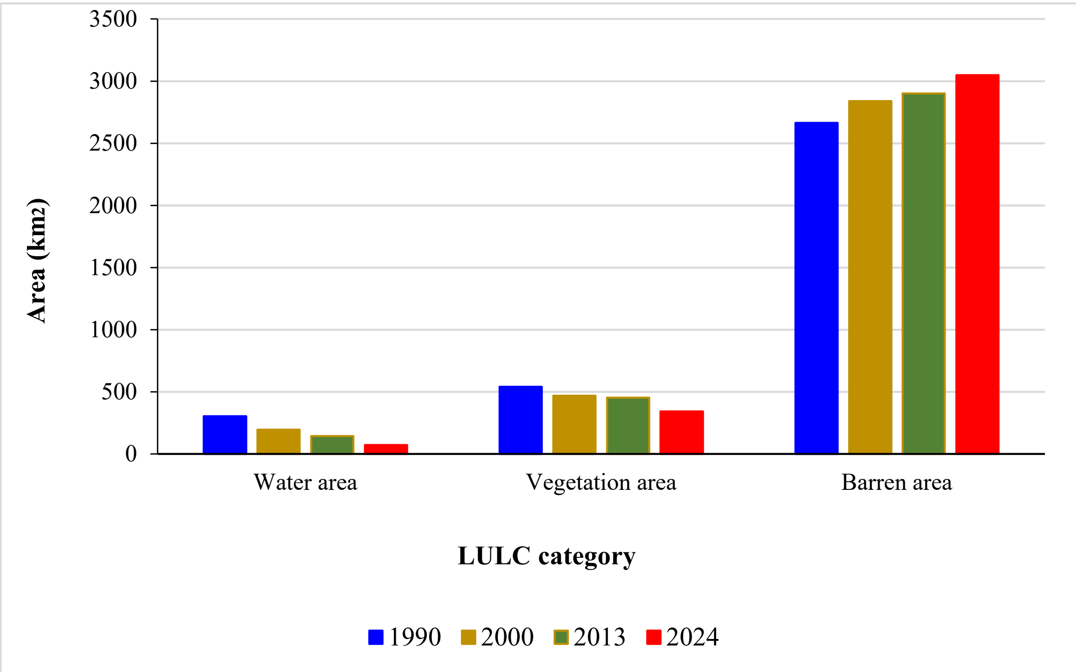

Figure 7 LULC analysis (urban area, military area and petroleum sites) for Al-Refaie district in 1990, 2000, 2013, and 2024.

4. CONCLUSIONS

The study showed how changes in vegetation, water cover, and land use can be studied using data from remote sensing. Understanding changes in land use and existing locations, as well as forecasting future changes, is accomplished with the help of this satellite data. According to the findings, this study categorized land use and changes in land use in Al-Refaie city from 1990 to 2024, showing how various areas have altered. Rapid urban development is a defining characteristic of Al-Refaie city during this time, as urban areas grew dramatically over 34 years. A notable reduction in water areas, particularly in marshes and tiny bodies of water, which were impacted by industrial and environmental changes, sometimes resulting in an increasing in arid regions and water scarcity. Significant swings in the vegetation were caused by the loss of green spaces and water resource shortage, which deteriorated the vegetation and increased its reliance on groundwater and irrigation. According to the findings, green and agricultural areas suffered due to the city's urbanization and population growth between 1990 and 2024. The local ecology deteriorated because of the growth of residential and industrial districts at the expense of agricultural fields and vegetation cover. This suggests that in order to maintain environmental balance, quick action is required to safeguard natural resources and guide growth in a sustainable way. We suggest creating sustainable development plans for Al-Refaie city based on these findings, with an emphasis on restoring water areas and growing green spaces. As the city's population grows and land usage changes, it is also necessary to reevaluate its core services.

References

[1] F. Dkhilalli, S. M. Borchani, M. Rasheed, R. Barille, K. Guidara, M. Megdiche, J. Mater. Sci. Mater. Electron, 29(8) (2018) 6297 https://doi.org/10.1007/s10854-018-8609-z
[2] M. Bayatavrkeshi, M.A. Imteaz, O. Kisi, M. Farahani, M. Ghabaei, A.S. Al-Janabi, B.M. Hashim, B. Al-Ramadan, Z.Y. Yaseen, PLoS One 18 (2023) e0290698 https://doi.org/10.1371/journal.pone.0290698
[3] B. Hashim, A.N. Alnaemi, B.A. Hussain, S.A. Abduljabbar, Z.H. Doost, Z.M. Yaseen, Phys. Chem. Earth 135 (2024) 103647 https://doi.org/10.1016/j.pce.2024.103647
[4] A. Boumezoued, K. Guergouri, Régis Barillé, Rechem Djamil, Mourad Zaabat, M. Rasheed, J. Alloys Compd. 791 (2019) 550 https://doi.org/10.1016/j.jallcom.2019.03.251
[5] S. Huang, C.W. Chen, Ecol. Model. 189 (2005) 49 https://doi.org/10.1016/j.ecolmodel.2005.03.020
[6] Z. Ali, Muhaimeed, Iraqi J. Agric. Sci. 47 (2016) 846
[7] S N. Ben Azaza et al., Opt. Mater., 96 (2019) 109328 https://doi.org/10.1016/j.optmat.2019.109328
[8] M. Rasheed, SuhaShihab, O. Alabdali, H. H. Hassan, J. Phys. Conf. Ser., 1879 (2021) 032113 https://doi.org/10.1088/1742-6596/1879/3/032113
[9] S. Al-Maliki, T.I.M. Ibrahim, G. Jakab, M. Masoudi, J.S. Makki, Z. Vekerdy, Water 14 (2022) 1523 https://doi.org/10.3390/w14091523
[10] Areej Adnan Hateef, Essebti Dhahri, M. Rasheed, Habiba Kadhim, Z. Abbas, N. Hassan, Physics and Chemistry of Solid State, 25 (2024) 801 https://doi.org/10.15330/pcss.25.4.801-810
[11] S.S. Saud, S.A. Abdullah, B.M. Hashim, IOP Conf. Ser. Earth Environ. Sci. 1202 (2023) 012013 https://doi.org/10.1088/1755-1315/1202/1/012013
[12] A. I. A. Ali, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY 10 (2026) 239 https://doi.org/10.56053/10.s.239
[13] M. Ali, F.K.M. Al-Ramahi, Iraqi J. Sci. 61 (2020) 2142 https://doi.org/10.24996/ijs.2020.61.8.29
[14] K.J. Stasicka, Z. (Stasicka), Environ. Pollut. 107 (2000) 263 https://doi.org/10.1016/S0269-7491(99)00160-2.
[15] Z. S. Ahmed, M. RASHEED, H. S. Ahmed, Experimental and Theoretical NANOTECHNOLOGY 10 (2026) 343 https://doi.org/10.56053/10.s.343

[16] Z. S. Ahmed, M. RASHEED, H. S. Ahmed, Experimental and Theoretical NANOTECHNOLOGY 10 (2026) 329 https://doi.org/10.56053/10.s.329.
[17] Halder, Z.Y. Yaseen, Environ. Sci. Pollut. Res. 11 (2022) 123 https://doi.org/10.1007/s11356-022-24153-8
[18] A. I. A. Ali, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY 10 (2026) 277 https://doi.org/10.56053/10.s.277
[19] S.A. Abdullah, K.H. Abbas, A.H. Harif, R.F. Alaa, H. Salman, IOP Conf. Ser. Earth Environ. Sci. 1202 (2023) 012015 https://doi.org/10.1088/1755-1315/1202/1/012015
[20] A. Khaleefah, M. RASHEED, Experimental and Theoretical NANOTECHNOLOGY 10 (2026) 289 https://doi.org/10.56053/10.s.289
[21] A.A. Salman, F.K. Al-Ramahi, Iraqi J. Sci. 63 (2022) 5589 https://doi.org/10.24996/ijs.2022.63.12.43
[22] A. Raghdi, M. Heraiz, M. Rasheed, A. Keziz, Journal of the Indian Chemical Society, 101 (2024) 101413 https://doi.org/10.1016/j.jics.2024.101413
[23] S. Vigneshwaran, S. Vasantha Kumar, Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XLII-4/W9 (2018) 165 https://doi.org/10.5194/isprs-archives-XLII-4-W9-165-2018
[24] F.G.M. Faisal, H.M. Ali, G.S. Mohammed, S.H. Saeed, Iraqi J. Sci. 62 (2021) 3779 https://doi.org/10.24996/ijs.62.10.36
[25] S. S. Batros, M. Rasheed, H. K. Aity, A. A. Hatef, T. Saidani, Materials Chemistry and Physics, 355 (2026) 132243 https://doi.org/10.1016/j.matchemphys.2026.132243
[26] M. RASHEED, A. Khaleefah, Materials Chemistry and Physics, 353 (2026) 132112 https://doi.org/10.1016/j.matchemphys.2026.132112
[27] K. Salman, B.A. Al-Razaq, Iraqi J. Phys. 21 (2023) 60 https://doi.org/10.30723/ijp.v21i2.1117
[28] J H. K. Aity, M. Rasheed, E. Dhahri, A. A. Hateef, T. Saidani, Journal of Materials Science, 61 (2026) 6226 https://doi.org/10.1007/s10853-026-12241-w
[29] T. Saidani, S. Mokhtari, M. Rasheed, H. Lahmar, M. Trari, Journal of the Indian Chemical Society, 103 (2026) 102499 https://doi.org/10.1016/j.jics.2026.102499
[30] A.A. Salman, F.K. Mashee, A. Ramahi, I.M. Abdulameer, D.H.M., Exp. Theor. Nanotechnol. 9 (2025) 123 https://doi.org/10.56053/9.S.123
[31] A.K. Rahman, L.S. Chen, M.I. Al-Khalidi, Exp. Theo. NANOTECHNOLOGY 10 (2026) 115 https://doi.org/10.56053/10.1.109
[32] S.M. Kareem, J.T. Wallace, D.R. Singh, Exp. Theo. NANOTECHNOLOGY 10 (2026) 298 https://doi.org/10.56053/10.S.357