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Evaluation of Land Cover Changes in Karbala Governorate Using Remote Sensing and GIS Techniques

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ABSTRACT

Evaluating the land cover changes is a critical issue for the process of environmental sustainability strategies. This study evaluates the land cover changes in Karbala Governorate during the last two decades (2001-2021) using Landsat Images based on the supervised maximum likelihood classification (MLC) method. Land cover is classified into four categories using supervised classification and two satellite imageries; Landsat 7 for the date 2001, and Landsat 8 for the date 2021. The results show a noticeable increase in the urban category associated with a decrease in the water cover. Additionally, a significant expansion occurred in the urban category at the expense of agricultural lands and the groves category. This expansion has resulted in the unplanned growth of settlements and the difficulties that go with it. The escalating urbanization in this particular region is associated with several prominent adverse outcomes.

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تقييم التغيرات في الغطاء الأرضي في محافظة كربلاء باستخدام تقنيات الاستشعار عن بعد ونظم المعلومات الجغرافية

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الملخص

يعد تقييم التغيرات في الغطاء الأرضي مسألة بالغة الأهمية لعملية استراتيجيات الاستدامة البيئية. تهدف هذه الدراسة الى تقييم تغيرات الغطاء الأرضي في محافظة كربلاء خلال العقدين الأخيرين (2001–2021) باستخدام صور Landsat بناء على طريقة تصنيف الاحتمالية القصوى الخاضعة للإشراف (MLC). تم تصنيف الغطاء الأرضي إلى أربع فئات باستخدام التصنيف الخاضع للإشراف الاعتماد على صورتين عبر الأقمار الصناعية؛ لاندسات 7 لتاريخ 2001، ولاندسات 8 لتاريخ 2021. وتظهر النتائج ارتفاعا ملحوظا في الفئة الحضرية مرتبطا بانخفاض الغطاء المائي. بالإضافة إلى ذلك، حدث توسع كبير في الفئة العمرانية على حساب الأراضي الزراعية وفئة البساتين. وقد أدى هذا التوسع إلى النمو غير المخطط له للمستوطنات والصعوبات التي تصاحبه. يرتبط التحضر المتصاعد في هذه المنطقة بالذات بالعديد من النتائج السلبية البارزة.

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Introduction

One of the best methods for analyzing changes in land use and land cover is the use of remote sensing (RS) techniques and geographic information systems (GIS), as it prepares a vast amount of data that can be processed for analysis, interpretation, and classification quickly, accurately, and with the ability to be updated over time (Aboelnour and Engel, 2018). The phrase "land use" refers to the description of the land's usage, including whether it is utilized for agricultural, residential, industrial, or other purposes (James et al., 2022). When human operations are not being carried out on a piece of land, it is said to have a certain state or cover known as the land cover. Examples of this are natural pastures, rock detecting areas, and riverbeds (Abood and Mahmoud, 2018). Earth's surface land use change detection through human activities for proper urban management is generally referred to as LULC change detection (Twisa and Buchroithner, 2019). Land cover change is undoubtedly influenced by population density expansion and economic development resulting in a discernible pattern in the LULC over time (Wiatkowska et al., 2021). The rising urbanization rate in most emerging nations is currently one of the most pressing global issues; yet, this transformation has important implications for future environmental and urban planning processes (Mansur et al., 2022; Tang et al., 2023) .

Landsat data have improved global monitoring by allowing for frequent revisits (Gonçalves et al., 2015). According to the growth of vegetation and the appearance of welts on the bare soil, the classification of satellite images influences how area classifications for a given area vary over time. All of the chosen satellite images (Landsat 7 ETM+ and Landsat 8 OLI) in this study belong to the same season over time to prevent finding erroneous changes in the land cover caused by vegetation phenology (Weil et al., 2018). The urban area of most cities throughout the world grew over the twentieth century as a result of population growth and people relocating from rural areas to more developed places. Rapid urban sprawl has a major impact on city administration and development around the world (Theodorou, 2022). Metropolitan areas are seeing substantial urbanization and demographic expansion, while rural settlements, commonly referred to as villages, are likewise encountering accelerated growth and population increase. Once villages have grown into cities, they are rapidly approaching the threshold of being a city. Iraq has had multiple conflicts in the past, all of which impacted the country's economic, urban, and human recession (Hassan, 2023). This resulted in a massive urban sprawl and an expansion in the uses of built land. Overshot is the maximal capacities for city management in the emerging nations. As a result, it appears that urban planning has a critical rule for managing cities' ability to accommodate population growth rates (Carneiro et al., 2021) .

Remote sensing uses satellite or aerial images to generate a variety of spatial data including metropolitan areas, land use types, vegetated regions, water bodies, and other information about a region's utilities and infrastructures (Wu et al., 2023). GIS, on the other hand, offers efficient and useful ways to produce, store, analyze, and display data from remote sensing (Dawson, 2019). When compared to previous methodologies, satellite remote sensing exhibits the potential to serve as a significant tool for monitoring land-use changes with enhanced temporal resolution and reduced financial burden (Zhu et al., 2022). This study aims to use the MLC method to discover changes in land use from 2001 to 2021 that affect each pixel of Karbala Governorate.

Materials and Methods

Study area

Karbala Governorate is selected as a study area, with a total area of around 5,034 km^2. It is located in central Iraq, west of the Euphrates River, about 100 kilometers southwest of Baghdad, in the Mesopotamian zone, between (44° and 40° E) and (33° and 31° N). Anbar Governorate borders it at north and west, Najaf Governorate at south, and Babil Governorate at east as shown in Figure (1). Karbala, an Iraqi city, has been significantly influenced by Islamic factors that have played a pivotal role in shaping its urban and demographic structure as well as the organization of land utilization. The temperature in the study area varies significantly between winter and summer seasons, also between day and night throughout the year, reaching maximum temperatures of roughly (45-50) °C. Annual rainfall ranges between 100 and 180 mm (Britannica, 1993; Al-Ansari, 2021). The majority of the rain falls between December and April (National Bureau of Statistics, 2020).

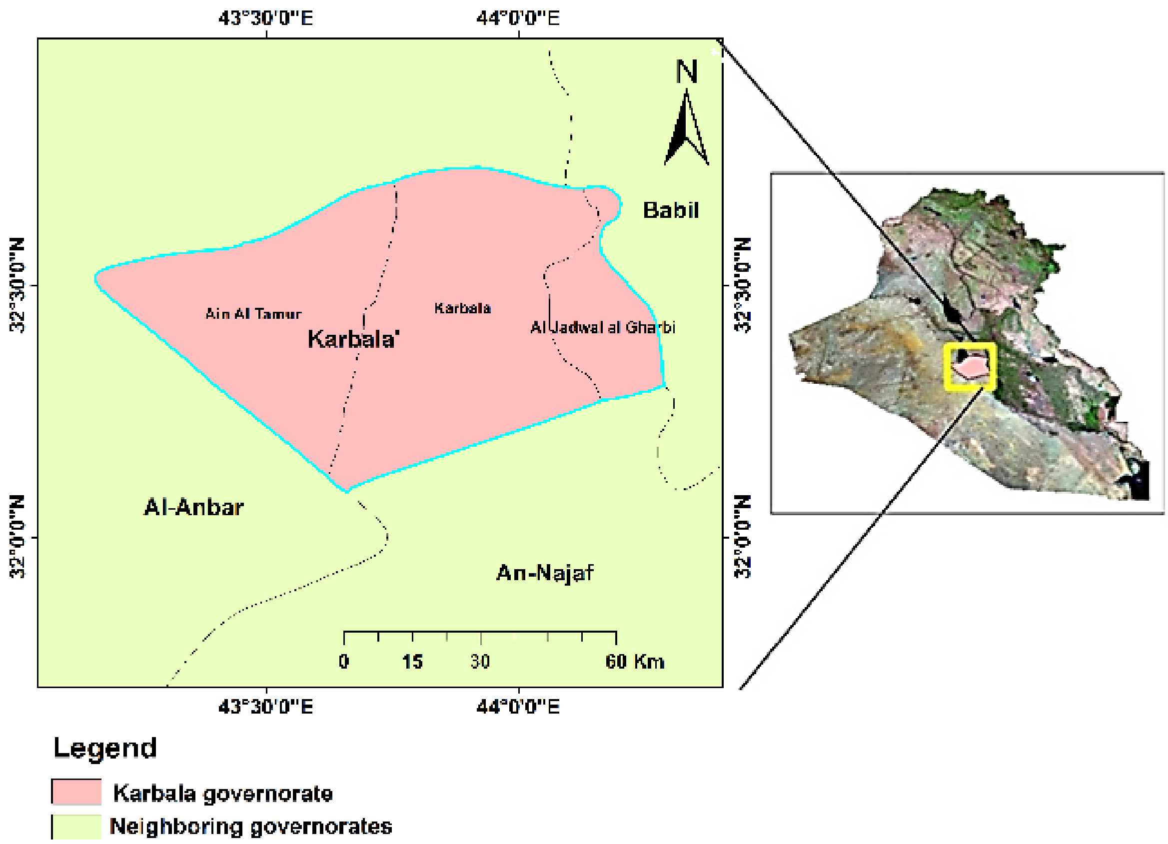

Fig. 1. Location of the study area.

Dataset

In April 1999, Landsat 7 was launched from California. The Enhanced Thematic Mapper Plus (ETM+) sensor is located on the board satellite. Landsat 7 includes a 15-meter spatial resolution panchromatic band; the temporal resolution is 16 days. The ETM+ sensor, an upgraded version of the Thematic Mapper equipment on board Landsat 4 and 5, is carried by Landsat 7. The Landsat 7 products are 256-gray-level, 8-bit images. As shown in Table (1), there are eight spectral bands on the ETM+ including a pan and thermal band. The thermal imaging functionality of this sensor is regulated by two distinct bands, namely band 6-1 and band 6-2. In band 6-1, the acquisition process operates at a low gain, whereas in band 6-2, the acquisition process operates at a high gain. In comparison to other thermal sensors on other satellites, the Landsat 7 ETM+ has a high spatial resolution accuracy. Landsat 8 satellite images are considered one of the vital resources for agriculture, hydrology, coastal resources, land use and mapping, environmental monitoring, and geology applications. The Landsat 8 satellite, launched by the United States of America in 2013; it offers academics access to regularly updated, multi-band imagery at no cost. The Landsat 8 satellite collects data in 11 spectral bands as indicated in Table (2), utilizing two distinct sensors known as the Operational Land Imager (OLI) and the Thermal Infrared Sensor (TIRS) (US Geological Survey, 2015). Landsat images are used in this study as shown in Table (3).

Table 1: Landsat 7 spectral bands with a spatial resolution (US Geological Survey, 2015).

Bands	Wavelength (micrometres')	Resolution (meters)
Band 1- Blue	0.45 – 0.52	30
Band 2- Green	0.52 – 0.60	30
Band 3- Red	0.63 – 0.69	30
Band 4- Near Infrared (NIR)	0.77 – 0.90	30
Band 5- Shortwave Near Infrared (SWIR) 1	1.55 – 1.75	30
Band 6- Thermal	10.40 – 12.50	60 (30)
Band 7- Shortwave Near Infrared (SWIR) 2	2.09 – 2.35	30
Band 8- Panchromatic	52 - 90	15

Table 2: Landsat 8 Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) spectral bands with a spatial resolution (US Geological Survey, 2015).

Bands	Wavelength (micrometres')	Resolution (meters)
Band 1- Blue	0.43 – 0.45	30
Band 2- Green	0.45 – 0.51	30
Band 3- Red	0.53 – 0.59	30
Band 4- Near Infrared (NIR)	0.64 – 0.67	30
Band 5- Shortwave Near Infrared (SWIR) 1	0.85 – 0.88	30
Band 6- Thermal	1.57 – 1.65	30
Band 7- Shortwave Near Infrared (SWIR) 2	2.11 – 2.29	30
Band 8- Panchromatic	0.50 – 0.68	15
Band 9 - Cirrus	1.36 – 1.38	30
Band 10- Thermal Infrared (TIRS) 1	0.50 – 0.68	100
Band 11- Thermal Infrared (TIRS) 2	11.50 – 12.51	100

Table 3: Landsat image specification.

Satellite	Path/Row	Date	Resolution (m)
Landsat 7 ETM+	169-38	3/2001	30
Landsat 7 ETM+	169-37	3/2001	30
Landsat 8 OLI	169-38	3/2021	30
Landsat 8 OLI	169-37	3/2021	30

Methodology

The US Geological Survey (USGS) Earth Explorer website provided the Landsat images https://earthexplorer.usgs.gov/. Landsat 7 satellite imaging data for 2001 is chosen, while Landsat 8 satellite imagery data for 2021. Several software programs are used to classify satellite images, the most famous of which are ArcGIS, ENVI and ERDAS IMAGINE. They give the same accuracy and quality in classification because they rely on the same classification algorithms. To evaluate the land cover changes, an MLC classification comparison is implemented using ArcGIS10.5. One of the most used techniques for estimating changes in land cover is comparing classifications. This method looks at various land cover maps and counts the pixels that shift from one land category to another (Weng, 2001). The result is quantifiable data on each category's overall changes between 2001 and 2021.

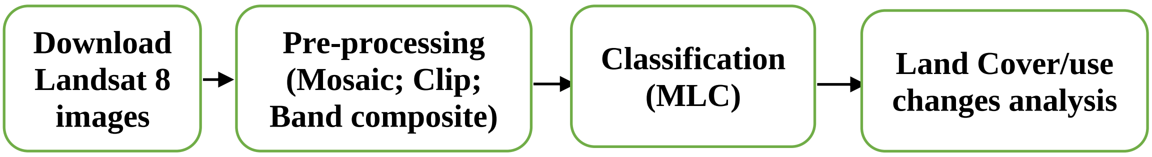

Fig. 2. The study steps flowchart.

The downloading of landsat satellite images is done through the official website of the US Geological Survey. Where the range of the chosen date is specified, then the appropriate scene is downloaded, which usually free of clouds. Pre-processing includes mosaic first, which means merging more than one scene to cover the study area. Then comes the clipping step, through which the merged scenes are reduced to the amount of the study area. After preparing the landsat image using the previous steps, the MLC algorithm classifies the image into several categories. Then the land cover categories are reduced and identified.

Maximum Likelihood Classification (MLC)

The MLC assumes that a normal distribution can describe each class in each band. The Bayes theorem asserts a posteriori distribution P(i), i.e., the probability that a pixel with a feature vector belongs to class (i). Maximum likelihood is a supervised classification approach developed on the Bayes theorem. This classification is based on Bayes' classification; the conditional probabilities are as follows (Trauth et al., 2006) :

$$\boldsymbol{P(CiV\dashv), i = 1 \ldots\ldots o\ oN} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where, i = 1. .... N; N represents the number of classes, and V is the measurement vector. If there is a complete set of conditional probabilities $P(Ci|V)$ for a pixel, then we could label the pixel.

The spectral signatures are created by selecting training sites to identify similar areas. The training sites are collected from the images by selecting the region of interest using ArcGIS software. The image was classified into four classes: urban area, vegetation, barren soil, and water bodies.

Results and Discussion

This study applies the MLC Supervised method to classify Landsat images using ArcGIS 10 software. The training sites are collected, and four signatures are selected: water, urban area, barren soil, and vegetation. There are more than 40 training sites collected for each class. The urban area is considered residential buildings, highways, industries, commercial buildings, …. etc. Figures (3 and 4) show the land covers obtained using the MLC method on Landsat image. Table (4) illustrates each class's land cover changes from 2001 to 2021. The urban area has increased by 2% from the study area. At the same time, the water class lost about 5.2%. The barren soil area is decreased by about 4% (from 74% to 69%). The vegetation cover is increased by 8% (from 9% to 17%). The area and percentage for each class is computed, also change detection results is illistrated in Table (4). Finally, the error matrix using MLC methods for the years 2001 and 2021 are shown in Tables (5 and 6) respectively.

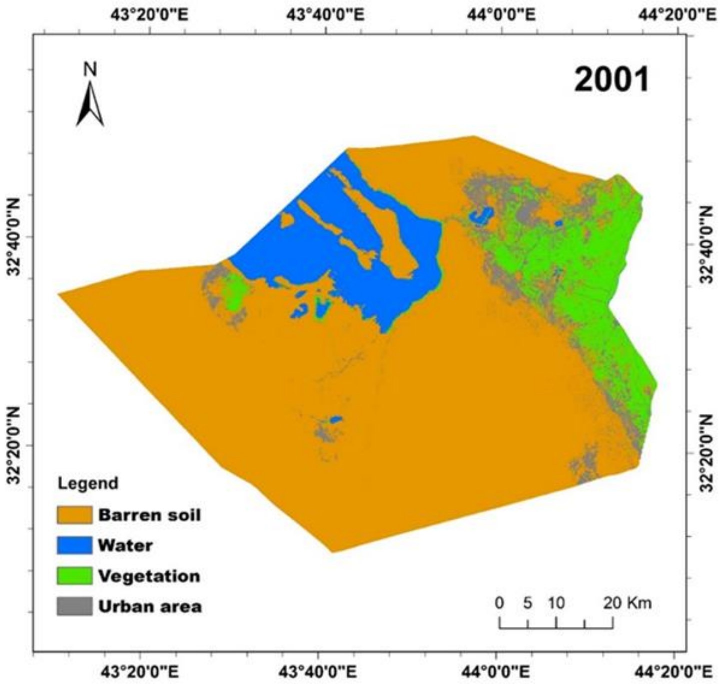

Fig. 3. MLC results for Karbala Governorate for March 2001.

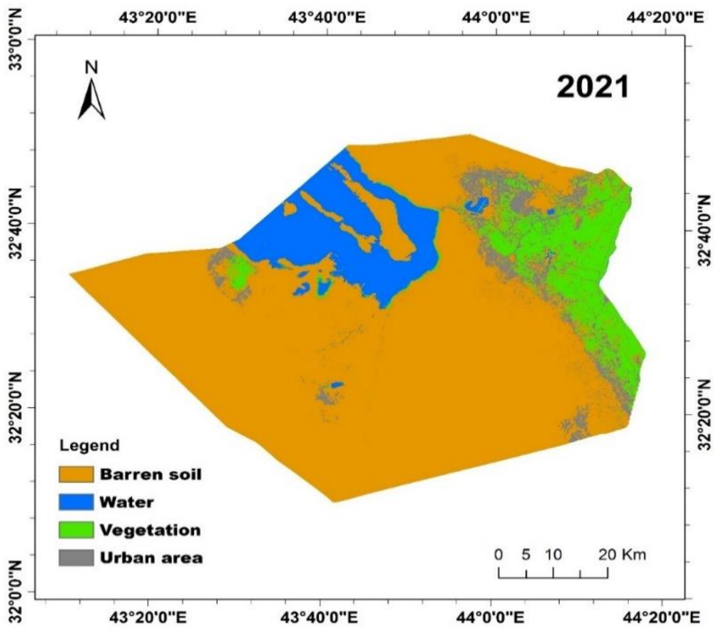

Fig.4. MLC results for Karbala Governorate for March 2021.

Table 4: The area and percentage change in the land cover classes during 2001–2021.

Land cover classes	2001		2021		Change 2001-2021	
	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
Vegetation	451.6	9.1%	857.4	17.2%	405.8	8.10%
Water cover	543.2	10.9%	281.7	5.7%	-261.5	-5.20%
Urban area	287.2	5.8%	377.4	7.8%	90.2	2.00%
Barren soil	3702.7	74.3%	3468.2	69.6%	-234.5	-4.70%

Table 5: The Error matrix for the year 2001.

Class	Vegetation	Water	Urban	Barren soil	Total
Vegetation	34	0	0	0	34
Water Cover	0	39	0	0	39
Urban area	5	1	33	4	43
Barren soil	1	0	7	35	44
Total	40	40	40	40	160
Overall accuracy = 88%					

Table 6: The Error matrix for the year 2021.

Class	Vegetation	Water	Urban	Barren soil	Total
Vegetation	36	0	0	0	36
Water Cover	0	39	0	0	39
Urban area	3	0	35	3	41
Barren soil	2	1	5	37	44
Total	40	40	40	40	160
Overall accuracy = 90%					

Conclusion

The present study is carried out in a prominent religious city in Iraq (Karbala Governorate), employing Landsat images and GIS techniques. The creation of accurate LULC maps and change statistics is a crucial strategy that plays a pivotal role in effectively monitoring the progression of urban expansion through time. This study extracted four land cover categories: urban area, vegetation, water, and bare soil. The results reveal that Karbala Governorate's environment had altered noticeably between 2001 and 2021, where the urban area and vegetation cover have grown by more than 90.2 km^2 (2%) and 405.8 km^2 (8%) respectively in 2021. On contrast, the water cover and barren soil decreased by more than 261.5 km^2 (5.2%) and 234.5 km^2 (4.7%) respectively in 2021.

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