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Analyzing Land Use and Land Cover Dynamics Using Geospatial Approaches: A Case Study of District Lahore, Pakistan

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Abstract: Present study focuses on the city of Lahore due to the substantial impacts of LULC on land-atmosphere climatic interactions. This study aims to find and interpret the variations in land use patterns in Lahore during 20 years (2003, 2013, and 2023) with a ten-year interval. For in-depth analysis, four different classes- built-up, barren land, vegetation cover and water bodies were determined. Several pre- and post-processing procedures were carried out to improve the accuracy of the results after Landsat 7, Landsat 8, and Sentinel 2 satellite imageries had been utilized. The methodology included supervised classification using the maximum likelihood algorithm along with change detection to evaluate and interpret the LULC alterations. The extent of change is demonstrated by quantitative data showing that the built-up area increased from 308.6491261 sq. km in 2003 to 336.9702759 sq. km in 2023. On the other hand, there was a drop of 1099.13587 sq. km in barren land and a decrease of 10.47416794 sq. km in water bodies. Despite a notable increase between 2003 and 2013, vegetation cover decreased by 328.4721624 sq. km by 2023. This study offers important insights for sustainable urban development and land management policy in addition to improving our understanding of the dynamics of land use and land cover in Lahore.

Keywords; GIS, Remote sensing, land use, land cover, change detection, management, Lahore.

Introduction

Land use and Land Cover Change (LULCC) has been a significant concern in policies aimed at conserving natural resources and monitoring the environment. Land use (LU) is the result of interactions between a society's cultural background, its physical requirements and circumstances, and the inherent potential of the land. The term land use refers to human activity and various land uses, such as modifications to the rock and soil, natural vegetation, manufactured cover, water bodies, and other land-based features (Omran, 2012). The enormous pressures of population growth and agriculture are making land a precious resource. Therefore, to properly plan for the use of natural resources and their management and to fulfill the growing demand for basic human requirements and welfare, land use changes must be studied. Satellite imagery is used for the identification of topographical data on the Earth's surface (Ulbricht & Heckendorff, 1998).

Change detection is the process of detecting changes in an object's or phenomenon's condition by observing it at various intervals (Singh, 1989). An essential tool for assessing land use change is the Geographic Information System (GIS), along with remote sensing technology. Resolved remote sensing data at various time intervals facilitates the analysis of both the rate of change and the reasons driving it (Ramachandra & Kumar, 2004). Compared to traditional survey methods, the combination of GIS and remote sensing technology allows for the easier and faster detection of changes in land use (Da Costa & Cintra, 1999). On a local, regional, and global level, land use changes are taking place quickly. Land change is influenced by anthropogenic activities such as mining, agriculture, construction, and deforestation.

There are various methods for classifying images. Prakash & Gupta (1998) created a land use map for change detection investigations of an Indian coal-mining district using a combination method of color composite band subtraction, band division, and supervised classification. A study of satellite image data from the drought (2001) and post-drought (2006) periods to evaluate changes in land use and vegetation cover in Lahore, the second-biggest city in Pakistan and a major center of culture, commerce, and politics, is situated in the Punjab area of Pakistan. Numerous reasons, such as population increase, migration from rural to urban areas, industrialization, and economic activity, have contributed to the city's rapid urban expansion. Lahore's LULC patterns change along with the city's infrastructure, offering an exceptional opportunity to study the complex interactions between human cultures and the environment. Shah (2022) found significant urban expansion and land use changes, with a notable increase in built-up areas and a decrease in agricultural land. This trend was attributed to population growth and economic development.

The urban population of Lahore is rapidly increasing, leading to notable changes in land use that impact vegetation, water supplies, soil quality, and animal feed. As a result, these changes harm the environment and contribute to a decrease in the availability of different products. Therefore, the purpose of this study is to examine the changes in land use that have taken place in Lahore during the past twenty years by using GIS and Remote Sensing techniques.

Material and Methods

Study Area

Lahore is one of the most populous and historically significant cities in Pakistan, which is also the capital of the Punjab province. It is located between latitude 31° 34' 55.3620" N and longitude 74° 19' 45.7536" E. Lahore is bordered to the east by Wagah, to the south by Kasur district, and to the west and north by Sheikhupura district. The Ravi River flows on the northern side of Lahore. Total area of Lahore is 1,774 square kilometers (Fig. 1).

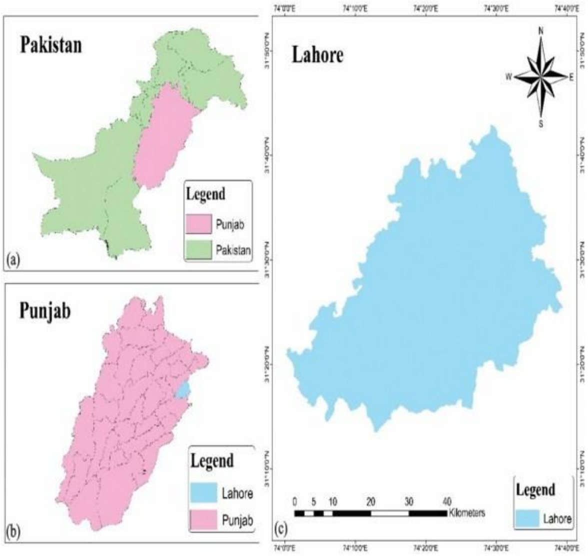

Fig 1. The study area location map (a) displays the Pakistan boundary line (b) denotes the study area province boundary (c) the study area district Lahore

Data Acquisition and Processing

A comprehensive dataset was created from multiple sources to facilitate an in-depth analysis. The land use and land cover of Lahore were determined using satellite imagery taken over a 20-year period of Sentinel 2, Landsat 7 ETM+, and Landsat 8 OLI (Table 1). In May of 2003, 2013, and 2023, Sentinel-2 images were obtained for free using https://www.copernicus.eu/en, and Landsat images were obtained for free from https://earthexplorer.usgs. gov/.

Table 1. Satellite datasets used along with their sources.

S. No	Satellite	Date	Source
1	Landsat 7 ETM+	May, 2003	USGS
2	Landsat 8 OLI	May, 2013	USGS
3	Sentinel 2	May, 2023	Copernicus

Composite Bands

Since each satellite image has unique band characteristics, this research employed Landsat 7, Landsat 8, and Sentinel 2 images for the present study.

For Landsat 7, we selected bands 4, 3, and 2.

For Landsat 8, we used bands 5, 4, and 3.

For sentinel 2 bands 8, 4, and 3 are utilized.

Significant information and color contrast are provided by this combination, which facilitates the differentiation of various LULC features.

Area of Interest

The Lahore district shape file was superimposed on the raster satellite data after it was opened in Erdas Imagine. Using Erdas Imagine's subset image tool, the region of interest inside the Lahore boundary was separated from the rest of the image.

Image Processing

Satellite images are collected in layers, either band 7 or band 11 images, and each band is of black and white color. The layer stacking function in Erdas Imagine is utilized to convert the image into a multispectral one. The digital map of Lahore is superimposed over the satellite image using the Erdas Imagine subset command to remove the interest area from the remaining portion of the image. The image's band arrangement is changed to produce a natural-colored image. For natural color, the band arrangement is 3, 2, and 1, respectively.

Image Classification

Features such as vegetation, metropolitan areas, water bodies, barren ground, etc. are unrecognizable from one another in unclassified images. Because these images' features are merged from various bands that lack attribute tables. We used Erdas Imagine's supervised classification tool to convert images into their corresponding characteristics. Our satellite images are classified so that we can obtain changes in land use.

The following categorization scheme as shown in Table 2 was used to oversee the classification of satellite data.

Table 2. Satellite datasets used along with their sources.

Land Class	Description
Vegetation	Gardens, parks, and cultivable lands.
Urban area	Roads, buildings, and pavements etc.
Barren land	Harvested, fallow, and uncultivable land.
Water bodies	Rivers, canals, and ponds.

Supervised Classification

Every year, a supervised classification algorithm was used to classify satellite images. The steps involved in a supervised classification operation are as follows:

- Identifying signatures
- Evaluating signatures
- Performing a supervised classification

Using AOI (Area of Interest) tools, several representative sign signatures were gathered for each feature in the image. After defining the signatures, a classification decision rule-that is, executing a supervised classification command over a raster image using the corresponding signatures - is used to sort the image's pixels into classes based on the signatures. There is a raster image in the output file. This image's attribute table contains the class name and class color. To determine the area covered by each class, we have created an area column using the edit tool.

Results and Discussion

Land Use Distribution

For several planning and management tasks concerning the earth's surface, knowledge of land cover is crucial. We used RS and GIS analysis to examine changes in land use. Unique and practical information about changes in land use is provided by the integration of GIS and RS techniques. However, the accuracy of the analysis's findings relies on the expertise of those who made the decisions to isolate certain pixels representing various land use features. The class area was determined by using the classified image of each year, i.e., 2003, 2013, 2023 (Table 3; Figs. 2, 3, 4). Four land use classes were applied to these images. There were four categories of land use: vegetation, urban areas, water bodies, and barren areas. A total of 1774 square kilometers area was classified.

Table 3. Land use distribution for the years 2003, 2013, 2023.

Sr. No	Land Use Classes	Area (sq.km)		
		2003	2013	2023
1	Vegetation	148.749054	316.462949	328.4721624
2	Urban area	308.6491261	314.13595	336.9702759
3	Barren land	1296.792774	1125.779011	1099.13587
4	Water bodies	20.47684918	18.316907	10.47416794

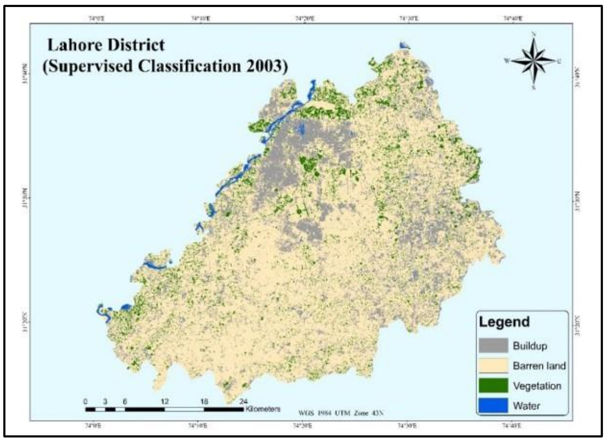

Fig. 2 Supervised classification of Lahore (2003).

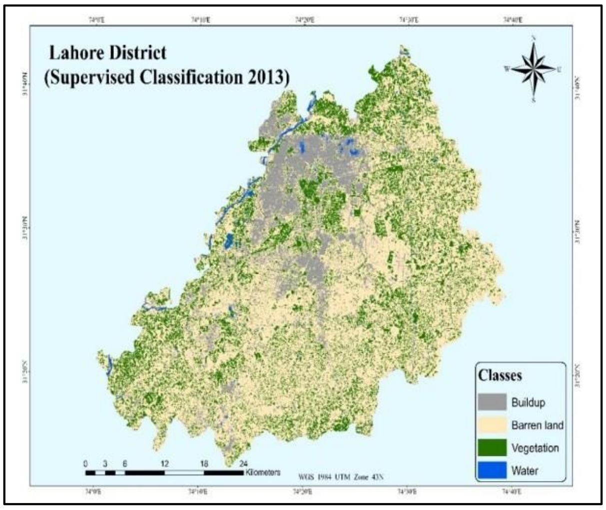

Fig. 3 Supervised classification of Lahore (2013).

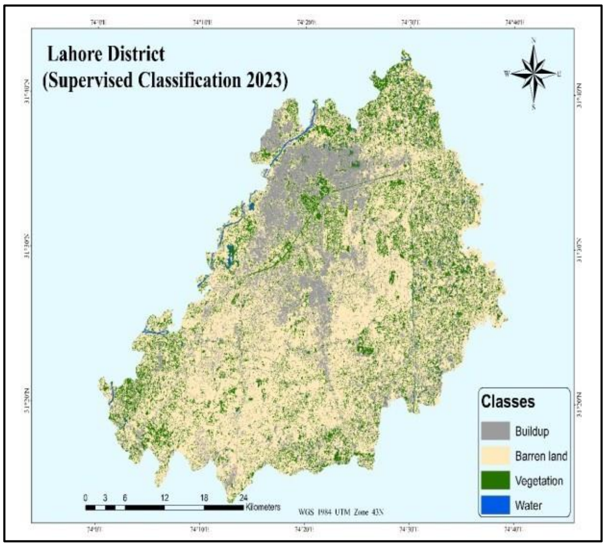

Fig. 4. Supervised classification of Lahore (2023).

Change Detection

Diverse trends of change patterns have been found during this phase of an extensive analysis. Land Use and Land Cover (LULC) was divided into four main classes: vegetation, water bodies, barren land, and built-up areas. This research data indicates that while barren land shows a falling tendency, built-up areas and vegetation are expanding positively. After being measured at 308.6491261 sq. km in 2003, the total built-up area increased gradually, reaching 314.13595 sq. km in 2013 (Figs. 5, 6) and then increasing to 336.9702759 sq. km by 2023. On the other hand, the area of barren land decreased from 1296.792774 sq.km in 2003 to 1125.779011 sq.km in 2013 and then to 1099.13587 sq.km in 2023 (Figs. 7, 8. Water bodies, which were first recorded as 20.47684918 sq. km in 2003, saw a series of contractions, with a loss of 18.31690689 sq. km in 2013 and a further decrease of 10.47416794 sq. km by 2023. The vegetation area increased significantly from 148.749054 sq. km in 2003 to 316.462949 sq. km in 2013. Nevertheless, a subsequent decrease occurred, resulting in the vegetation area being reduced to 328.4721624 sq.km in 2023 (Fig. 9).

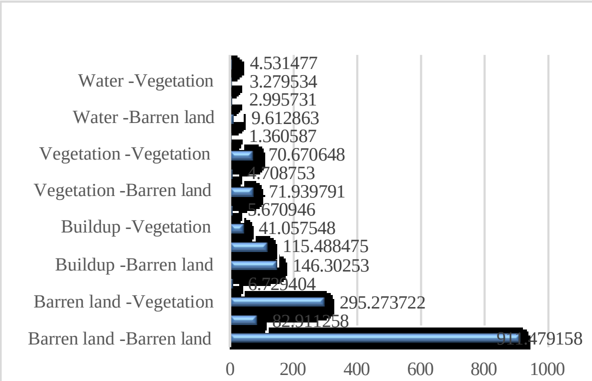

Fig. 5 Change detection during 2003-2013.

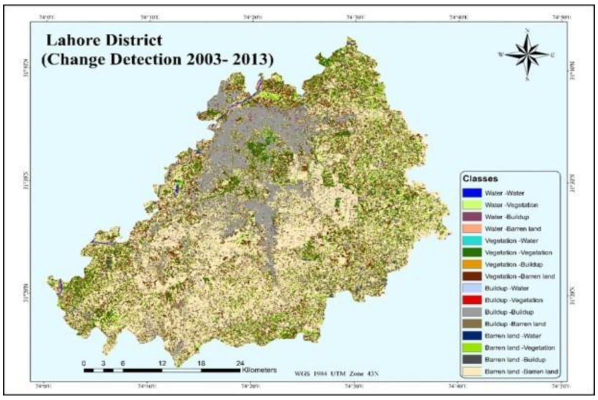

Fig. 6 Change detection during 2003-2013.

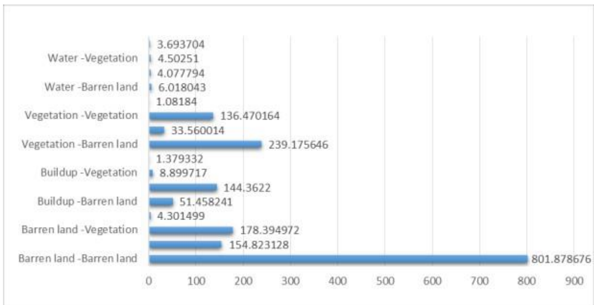

Fig. 7 Change detection in the area of the classes during (2013-2023)

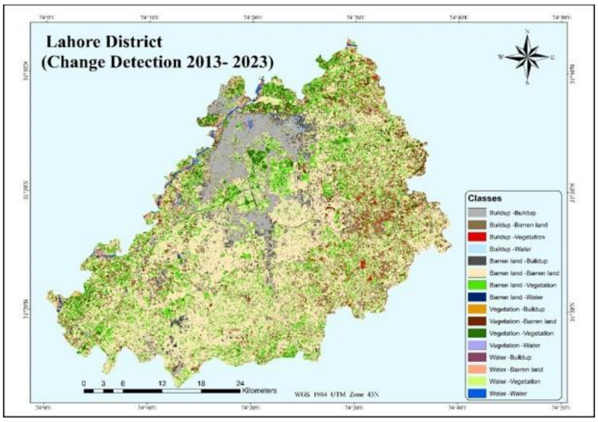

Fig. 8. Change detection during 2013-2023.

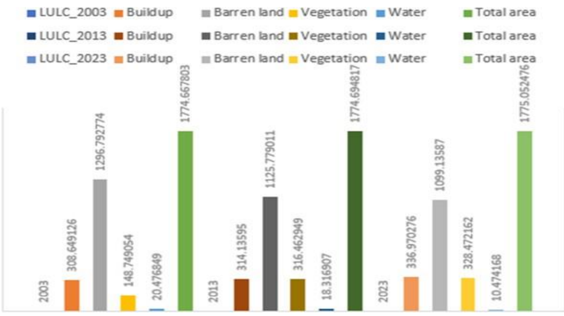

Fig. 9 Change in the area of the classes during 2003-2023.

The impact of both natural and human-induced changes on the urban environment and human health is a growing concern in today's world (Han et al., 2015). For this reason, research on land-use and land-cover dynamics is essential to the effective planning, use, and management of natural resources (Rawat & Kumar, 2015). Complex multi-factorial ecological studies are not suitable for using conventional methods for gathering population data, conducting surveys, and assessing environmental samples (Mashala et al., 2023). More sophisticated methods like satellite Remote Sensing (RS) and Geographic Information Systems (GIS) are needed for many of those challenges that arise frequently in environmental research, including the processing of multidisciplinary data. Applications for GIS and RS are numerous in the domains of agriculture, environment, and combined eco-environmental evaluation (Behera et al., n.d., Qian, 2016). Numerous studies have concentrated on the detrimental effects of LULC alterations on an area's ecological features (Yulianto et al., 2019).

This study highlights the usefulness of Remote Sensing (RS) and Geographic Information System (GIS) methods for collecting and evaluating spatial-temporal data. The main objective is to build a thorough geographic database that outlines the Land Use and Land Cover (LULC) dynamics in the Lahore metropolitan city. This study attempts to clarify various tendencies in LULC change patterns during the given period through an in-depth analysis. LULC were carefully identified into four main classes: vegetation, water bodies, barren land, and built-up areas. The spatial-temporal data were collected, processed, and interpreted by the study using GIS and RS methodologies. This cutting-edge technology made it easier to build a solid spatial database for Lahore, which allowed for a more in-depth investigation of land dynamics.

The analysis revealed remarkable patterns in LULC dynamics. Notably, vegetation and built-up areas show positive expansion, whereas barren land shows a tendency toward decline. The overall built-up area began at 308.6491261 square kilometers in 2003 and increased gradually to 314.13595 square kilometers in 2013 and 336.9702759 square kilometers by 2023. The extent of barren land, on the other hand, decreased from 1296.792774 sq. km in 2003 to 1125.779011 sq. km in 2013, and then decreased further to 1099.13587 sq. km in 2023. Water bodies, which initially measured at 20.47684918 sq. km in 2003, began to decline over time. By 2013, they were reduced to 18.31690689 sq. km, and by 2023, it decreased to 10.47416794 sq. km. Between 2003 and 2013, the vegetation area increased significantly from 148.749054 sq. km to 316.462949 sq. km. But then there was a decline, and in 2023 the vegetation area was only 328.4721624 sq.km.

The patterns that have been observed are indicative of the intricate relationship between urbanization, environmental management, and climate change in Lahore. The decrease in bare land could be due to either more urbanization or changes in land-use policies, whereas the growth of built-up areas indicates rapid urban development. The need for conservation measures is highlighted by the diminishing water bodies, which raise questions about the sustainability of water resources. The irregular patterns of vegetation draw attention to how susceptible green spaces are to changing urban environments. Comprehending these processes is crucial for well-informed urban planning, sustainable development, and preservation of the environment. The use of GIS and RS in this work highlights their critical significance in promoting evidence-based decision-making for urban management and policy development, as well as demonstrating their effectiveness in capturing dynamic LULC changes.

Conclusion

Digital image processing techniques were employed in his study to assess the LULC and detect its changes. The investigation revealed that between 2003 and 2023, there was a notable growth in urban areas, which led to a corresponding decrease in the amount of vegetation and barren terrain. It was a negligible increase in the water bodies. The study area's environment has been severely degraded by the conversion of arid land and vegetation into urban areas; the main unfavorable effect of this has been the slum growth that comes with rapid urban development.

The study found that integrated driving variables have a significant impact on land use and land cover at both the regional and national levels. Rapid and extensive changes in the Land Use and Land Cover (LULC) have occurred in the Lahore district of Pakistan. The Department of Urban Planning and Design would benefit from this research for the creation of sustainable land. Future studies may intend to expand the analysis to other urban areas in the region and investigate the effectiveness of different land use policies and initiatives in reducing environmental deterioration. These findings will offer essential knowledge for policymakers and urban planners who are working to tackle the complex problems of urban growth and environmental sustainability in fast- developing areas.

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