Change Detection of Land Cover Using Geo-Spatial Techniques in District Hyderabad, Sindh, Pakistan

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Urban expansion worldwide is leading to significant changes in land cover, with built-up areas increasingly encroaching on agricultural and barren lands. This study utilizes geospatial techniques to analyze land cover changes in District Hyderabad, Sindh, Pakistan, from 2013 to 2023, marking a pioneering effort in this region. Landsat images from 2013, 2018, and 2023, sourced from the US Geological Survey database, were analyzed using the maximum likelihood technique of supervised image classification. Four major land cover classes—vegetation cover, built-up land, water bodies, and barren land—were identified. The analysis reveals a notable increase in built-up areas, rising from 41% in 2013 to 68% in 2023. In contrast, vegetation cover has decreased by 14%, water bodies by 6%, and barren land by 7% over the past decade. These changes indicate Hyderabad's shift from a rural to an urban landscape, driven by socioeconomic development. The findings underscore the importance of sustainable development practices that reconcile urban growth with environmental preservation. This study provides essential data for urban planning, conservation efforts, and further research on land cover dynamics.

Keywords: Land Cover, Change Detection, Image Classification, Geographic Information System, Hyderabad, Pakistan.

Introduction:

Land cover (LC) changes significantly impact biodiversity and climate at both local and regional scales [1][2][3]. Analyzing LC requires a comprehensive understanding of ecological, geological, topographical, socioeconomic, technological, and institutional factors that shape land use patterns [4]. Modifications to landscapes can have profound effects on the environment both locally and globally [5]. In recent decades, human activities have increasingly disrupted natural environments to meet growing resource demands [6]. Recognizing LC changes is essential for understanding the interactions between human populations and geographical dynamics [7].

The rapid expansion of human activities, including population growth, industrialization, and urbanization, has led to significant alterations in LC patterns worldwide [4]. In developing countries, these changes often result in the depletion of critical resources such as land cover, water bodies, and soil [8][9][10]. Monitoring and detecting LC changes is crucial for achieving environmental sustainability and improving living conditions [11][12][13].

Land use refers to human activities and their purposes, such as agriculture, habitation, and industry, while land cover denotes the physical material on the land, including vegetation, water bodies, rocks, and soil. Although land use often derives from land cover, the terms are closely related and sometimes used interchangeably [14]. Detecting changes in land use and land cover is a fundamental ecological goal for understanding landscape dynamics. Landscape characterization maps can aid in better land resource management [15]. Soil productivity supports agricultural, animal, and forest production [16], and analyzing land use and cover changes is essential for understanding global changes at various spatiotemporal scales [17].

Spatiotemporal analysis of land cover changes is vital for monitoring and modeling ecological processes and their impacts on ecosystem services [18]. Geographic Information Systems (GIS) and remote sensing technologies are key tools in monitoring land use and cover changes [19]. Remote sensing provides high temporal resolution data that enhances GIS analytical capabilities, enabling the determination of change rates and identification of contributing factors [20]. Advances in satellite imagery, drone-based data collection, and machine learning algorithms have improved the precision and efficiency of LC change detection [3][12][21].

In Pakistan, rapid population growth and urban sprawl have led to significant land-use changes, with an expected increase in the urban population to around half by 2025 (World Bank, 2021). The conversion of farmland and forests to developed land reflects broader trends in urbanization and socio-economic development [22]. Sindh, particularly Hyderabad, is affected by these changes, emphasizing the need for effective monitoring of spatiotemporal LC patterns for informed decision-making [23][24]. Despite numerous studies in India [25][26][27][28][29], research on land cover changes in Pakistan remains limited [30][31][32][33]. Notably, there are no studies focusing on Hyderabad using supervised classification methods. This study aims to address this gap by conducting a comprehensive spatiotemporal analysis of land cover changes in Hyderabad from 2013 to 2023, utilizing high-resolution remote sensing data and GIS technology.

Objectives:

The aim of this study is to map and analyze land use and land cover changes in Hyderabad over the past decade. Specific objectives include:

- To geo-visualize land cover classes in the study area.
- To detect and analyze land cover changes from 2013 to 2023.

Materials and Methods:

Study Area:

Hyderabad, Sindh: An Overview: Hyderabad, the second-largest city in the Sindh province and the eighth-largest in Pakistan, was established in 1768 [34]. The city's origins trace back to the shifting course of the Indus River in 1757, which led King Mian Ghulam Shah Kalhoro of the Kalhora dynasty to relocate the capital from Khudaabad to the newly founded Hyderabad [35]. Geographically, Hyderabad is situated at 25°23'33" N latitude and 68°22'25" E longitude, at an elevation of 13 meters above sea level [24]. Located on the eastern bank of the Indus River, the city is approximately 150 kilometers from Karachi, the provincial capital. Nearby towns include Kotri (6.7 km), Jamshoro (8.1 km), Hatri (5.0 km), and Husri [34].

Originally founded on Ganjo Takkar, or "The Bare Hill," a limestone ridge on the east bank of the Indus River [36], Hyderabad is characterized by its limestone outcrops, offering scenic views and sloping routes. The Tilak Climb, named after early 20th-century independence activist Lokmanya Tilak, is a notable landmark [37]. Hyderabad experiences a warm desert climate (Köppen BWh), with consistently hot conditions throughout the year [38]. The peak of the heat typically occurs from mid-April to late June before the monsoon season, with temperatures reaching 43°C in 2016 and 2017, approaching the historical high of 43.3°C recorded in 1973 [39].

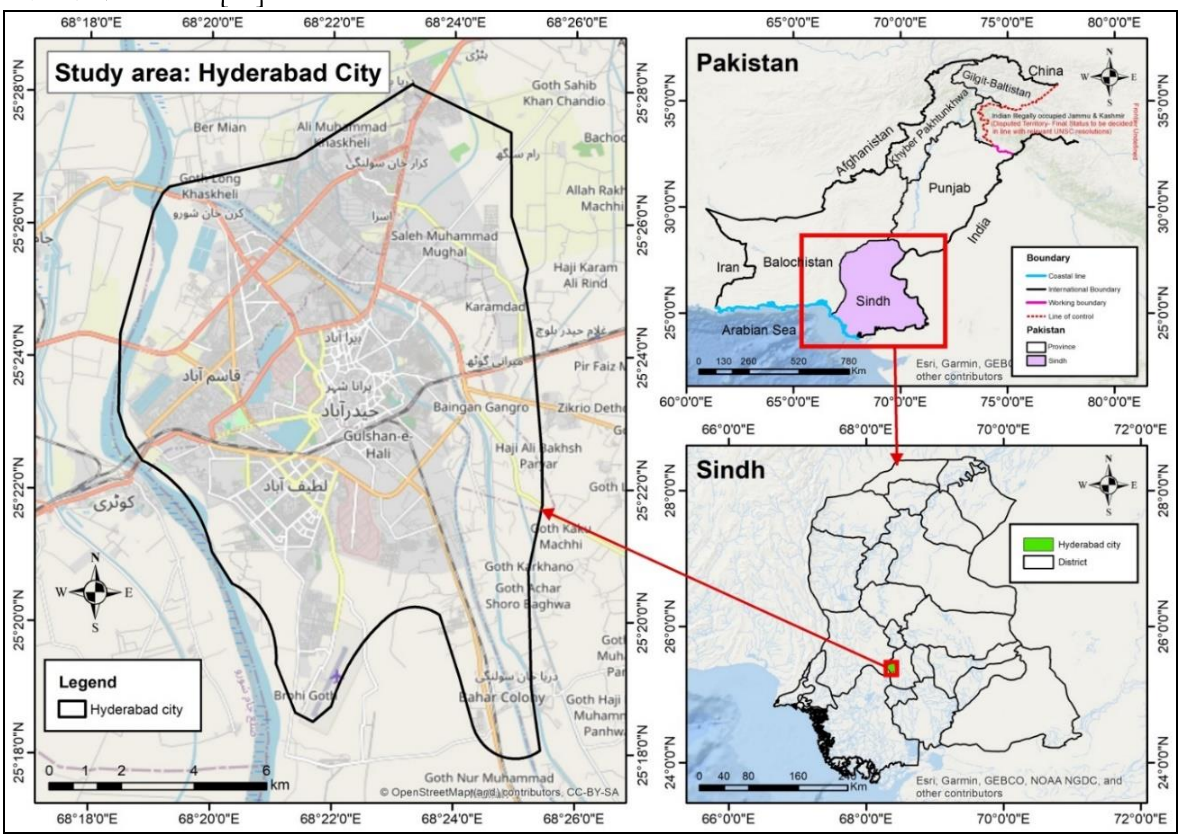

Figure 1: Geographical location of the study area

Socially and economically, Hyderabad serves as a crucial transportation hub where Pakistan's Indus Highway and National Highway intersect [40]. The city's industrial sector is diverse, encompassing textiles, sugar, soap, ice, paper, pottery, cement, mirror making, plastics, tanneries, and hosiery [26]. Hyderabad is also renowned for its decorative glass industry, which is well-known throughout Pakistan [41], and acts as a major trading center for agricultural products from surrounding regions [42].

Dataset / Data Collection:

In this study (Figure 2), Landsat 8 remote sensing datasets were acquired from the United States Geological Survey (USGS, Reston, Virginia) [43] (USGS, 2023) [44] via Earth Explorer. The Landsat 8 dataset has a spatial resolution of 30 meters and a temporal resolution of 16 days (NASA, 2023). A comprehensive description of the Landsat satellite imagery types, including acquisition times and resolutions, is provided in Table 1.

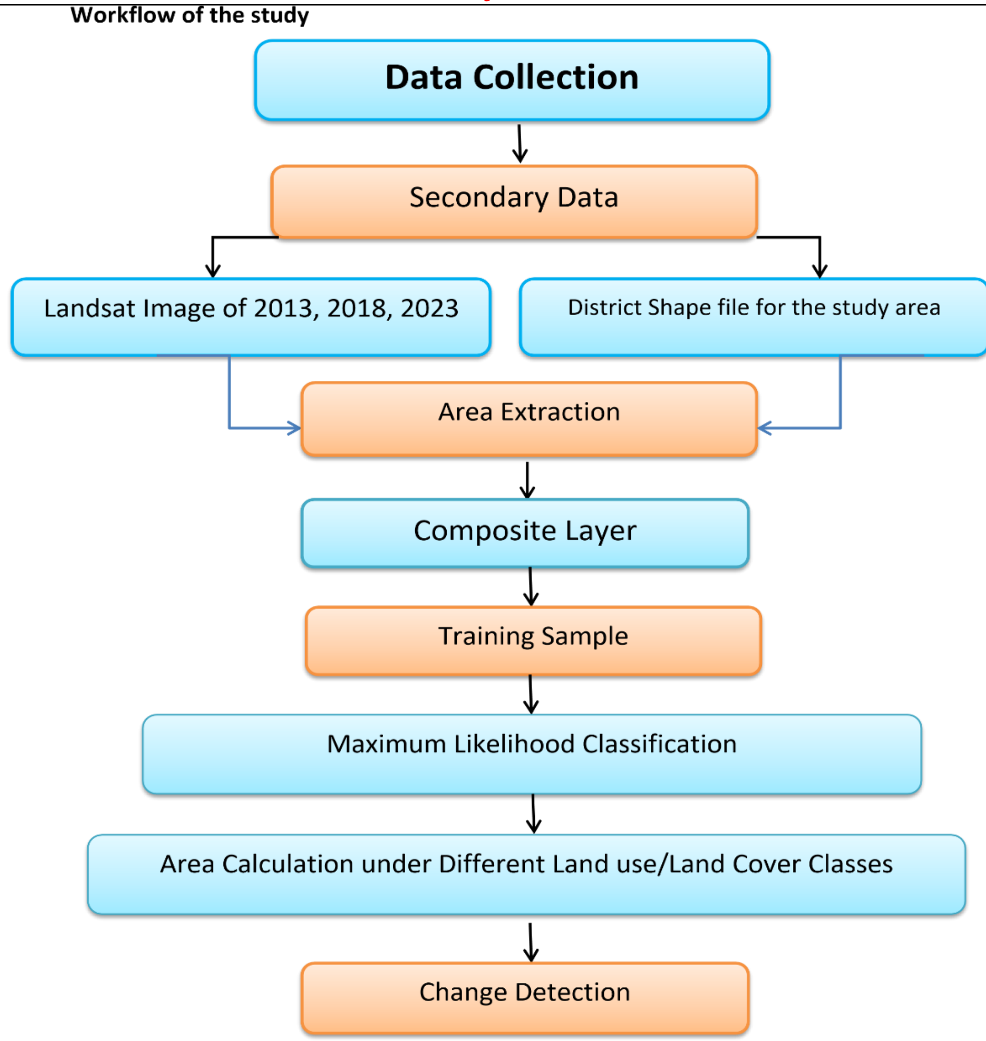

Figure 2: Research Process

Table 1: Characteristics of the Satellite Data

Landsat dataset	Description	Acquisition Time	Spatial Resolution (m)	Temporal resolution
Landsat 8 OLI (operational Landsat imager)	With 9 spectral bands, including a pan ban (3 Visible, 1 red, 1 Near infrared, 2 SWIR, 1 Panchromatic (PAN), and 1 cirrus bands)	• 12 September 2013 • 7 September 2018 • 12 September 2023	30 (except Panchromatic band); 15 (Panchromatic)	16-day repeat cycle

City boundaries were extracted using the Pakistan district Shapefile obtained from Diva GIS (Diva GIS, 2023). The study utilized three sets of images from the USGS Operational Land Imager (OLI) (NASA, 2023), with the 152nd path and the 42nd row passing through Hyderabad. These images, captured in 2013, 2018, and 2023, provide a decade-long view of spatial land-use patterns. Acquired typically in September, the images correspond with the peak of winter or spring harvests, aiding in distinguishing built-up areas from other land cover types. Landsat sensors complete an Earth observation cycle every 16 days, which allows effective monitoring of long-term land-use changes.

To ensure accuracy, all Landsat 8 images used in this study were cloud-free (NASA, 2023). This minimizes atmospheric interference, allowing the observed changes to closely reflect real-world environmental conditions and land use patterns (USGS, 2023) [44].

Image Classification:

The Anderson Level 1 classification system [45] has been extensively utilized for interpreting Landsat data, as it reduces potential misclassifications and enhances the reliability of classifying various land use categories [46]. In this study, land use and land cover (LULC) types were classified into four main categories: built-up areas, vegetation, water bodies, and barren areas [47]. Remote sensing (RS) techniques are particularly valuable for this analysis, as they allow the compilation and examination of LULC information without direct ground contact, making them ideal for developing cities.

Landsat 8 OLI datasets have been successfully used in similar studies to classify land cover into eight categories in Southeast Asia [10]. For this study, Landsat imagery was processed using both supervised and unsupervised classification methods. Specifically, an ISODATA unsupervised classification, supervised maximum likelihood classification, and iterative hybrid classification methods were employed [48][49].

Hyderabad's limited agricultural activities make the four land use categories sufficient for distinguishing LULC in urban areas. Built-up areas, characterized by impermeable surfaces like concrete and roofs, and barren areas, comprising loose soil, sand, or rocks, are particularly relevant for quantifying land use changes in the city. The terms "built-up area/impermeable surface" and "barren land" are commonly used in recent LULC studies [50][51]. Spectral reflectance was analyzed using pixel spectral curves across different bands for various land cover types [52]. Classification was performed using ArcMap 10.5, with the maximum likelihood classifier applied to detect land use changes from 2013 to 2023. Training samples were collected through visual interpretation to ensure minimal confusion between land cover types [53][46].

Area Calculation:

Classification results were converted into Shapefiles for further analysis and GIS interpretation. The surface areas of each land cover type were calculated, and the results were exported to Microsoft Excel for chart creation, allowing visualization of land cover changes in Hyderabad.

Accuracy Assessment:

An objective accuracy assessment was conducted using Ground Truth Points (GTP) obtained from the Landsat images via stratified random sampling [54]. The classified images were verified through visual interpretation using high-resolution Google Earth images, assumed to be the most accurate available data for accuracy measurement. Accuracy was assessed using an error matrix, calculating overall accuracy, kappa coefficient, producer accuracy, and user accuracy, as these metrics are widely accepted in LULC studies [55][56]. Mathematical formulas for Producer Accuracy, User Accuracy, Overall Accuracy, and Kappa Coefficient are provided below:

- **Producer Accuracy:** The probability that a reference pixel is correctly classified, calculated as the number of correct pixels of a specific land-use type divided by the total number of pixels within that land-use type [55].
- **User Accuracy:** The ratio of the number of correct pixels of a specific land-use type to the total number of pixels classified as that land-use type [55].
- **Overall Accuracy:** The ratio of the total number of accurately classified pixels to the total number of pixels in the entire study area.

$$Kappacoefficient = \frac{((TS \times TCS) - \Sigma(\text{Column Total} \times \text{Row Total}))}{(TS\text{^}2 - \Sigma(\text{Column TotalxRow Total}))} \times 100$$

$$produceraccuracy = \frac{\text{Number of Correctly Classified Pixels in each Category}}{\text{(Total Number of Reference Pixels in that Category (The Column Total)}} \times 100$$

$$\text{User Accurecy} = \frac{\text{Number of correctly classified pixels in each category}}{\text{TOTAL NUMBER OF Classified pixiels in that catogary(the row total)}} \times loo$$

$$Overall accuracy = \frac{\text{Total number of corrctly classified pixels (diagnoll)}}{\text{Total number of referannce pixels}} \times 100$$

Where,

T s = Total Sample

T c s = Total corrected samples

A Kappa Coefficient greater than 0.8 is generally considered to indicate "almost perfect" classification, suggesting that 64% to 100% of the data are reliable. In contrast, a Kappa Coefficient in the range of 0.61 to 0.79 reflects "substantial" accuracy. Values below 0.2, however, indicate "poor" classification, with at most 4% of the data deemed reliable [50].

Results, Analysis, and Discussion:

The Spatial and Temporal Trends in Land Cover:

As shown in Figure 3, the spatial land cover classification maps of Hyderabad for 2013, 2018, and 2023 are depicted in different colors. The figure also includes bar charts that clearly illustrate the areas of each land use type for these years, highlighting the temporal changes.

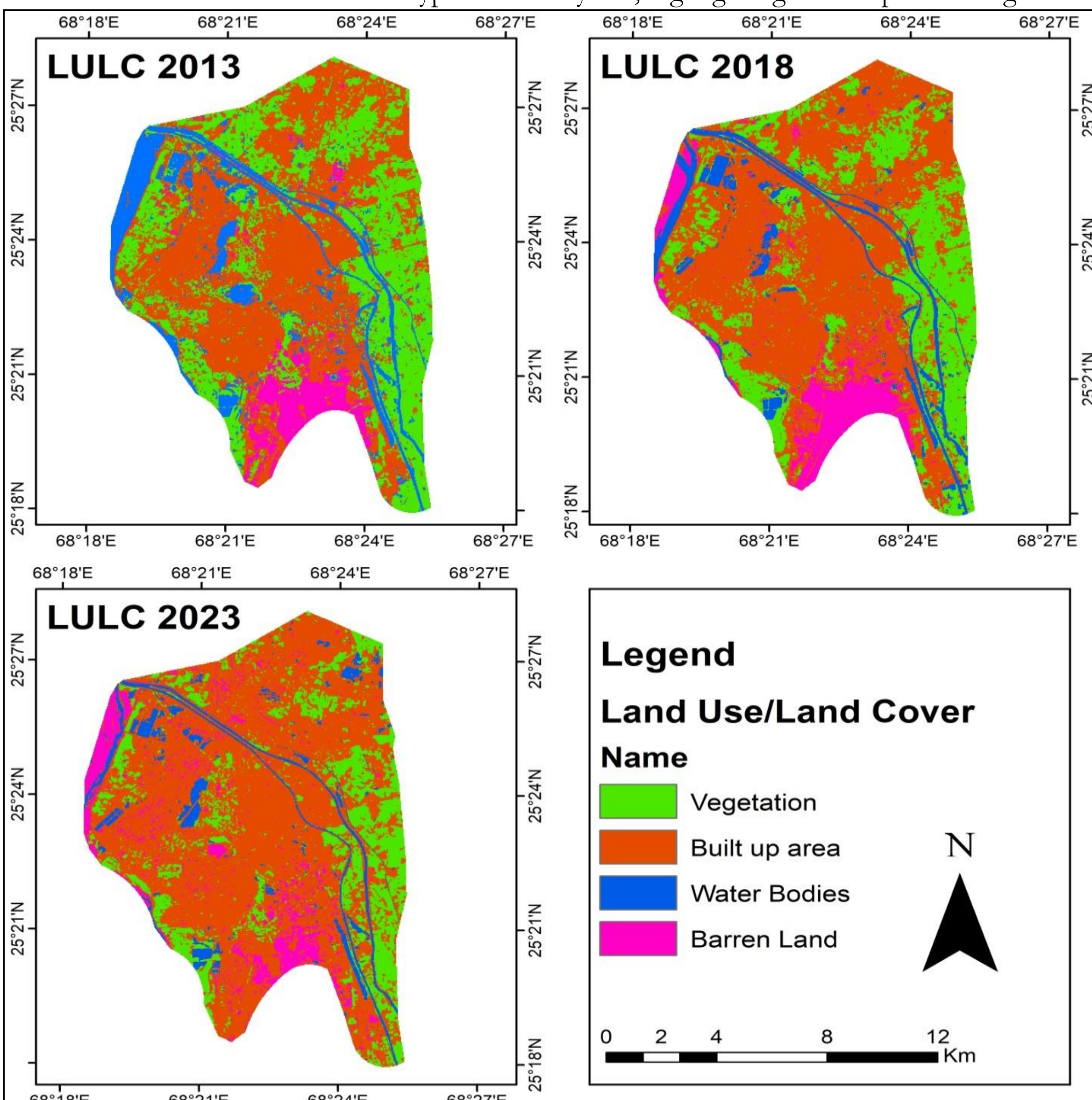

Figure 3: Spatial and Temporal Pattern of Land Cover (2013-23)

In 2013, 2018, and 2023, significant urban sprawl was observed in Northeast, Central, and West Hyderabad (Figure 3). Built-up areas emerged as the predominant land use since 2013.

Specifically, barren areas in central and northeastern Hyderabad, and vegetation in the eastern regions, were gradually replaced by built-up zones. The proportion of pixels classified as "Vegetation" and "Water Bodies" also declined over the decade. Between 2013 and 2018, built-up areas surpassed vegetation to become the dominant land use, while barren land and water bodies continued to diminish, with a slight increase in farmland pixels. By 2023, barren land pixels had become negligible, remaining only in the southernmost parts of Hyderabad. The area of built-up land increased by 68% compared to 2013, as shown in Figure 4. This expansion of built-up areas was accompanied by a significant reduction in vegetation pixels. These temporal changes provide clear evidence of urban sprawl occurring in various parts of Hyderabad, especially in the central, west-central, and northeastern regions of the city.

The spatial chart clearly illustrates changes in the four-land use and land cover types over the years. It shows a continuous increase in built-up areas, while vegetation, barren land, and water bodies have steadily decreased. Table 2 highlights the increase in built-up areas over the past decade, rising from 7,142.977 hectares in 2013 to 9,995.533 hectares in 2023. This expansion of built-up land is primarily at the expense of vegetation, water bodies, and barren land. During the same period, the area of vegetation decreased from 4,909.709 hectares to 2,802.377 hectares.

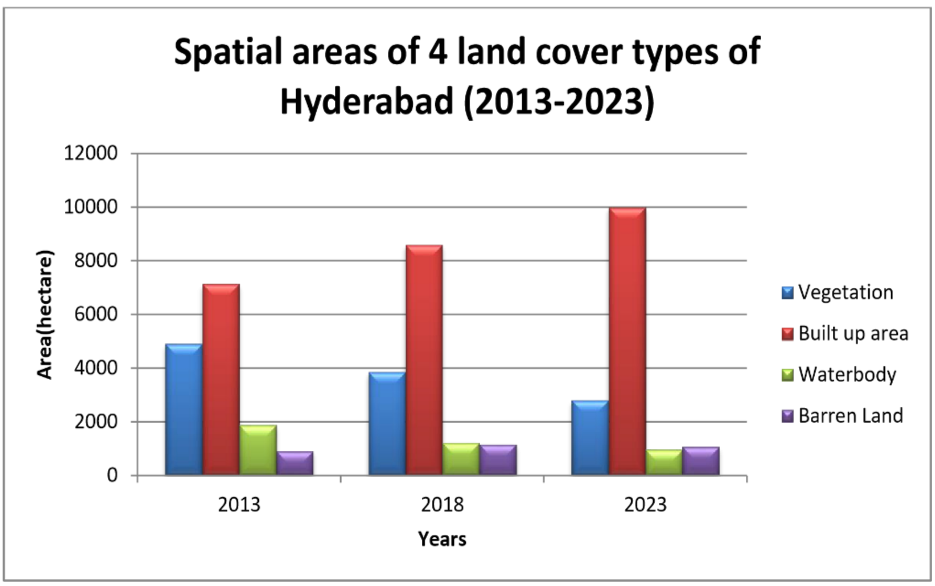

Figure 4: Areas allocated to each of the 4 key land-use types in Hyderabad in 2013, 2018, and 2023.

Table 2: Area of four different types of land cover in 2013, 2018 and 2023.

Types	Years		
	2013	2018	2023
Vegetation (hectare)	4809.709	3863.126	2802.377
Built up area (hectare)	7019.856	8602.563	9995.533
Water body (hectare)	1580.267	1223.126	1055.152
Barren land (hectare)	1360.110	1081.127	916.888
Total Area (hectare)	14769.942	14769.942	14769.942

Additionally, the area covered by water decreased from 12% to 6% between 2013 and 2023. This reduction is primarily due to the conversion of water bodies into built-up areas, with minimal conversion of other land types back to water bodies over the decade. This trend is likely driven by Hyderabad's booming real estate market and the development of infrastructure, such as a new international airport and electronic and manufacturing hubs [50]. As a result, there has been significant ecological and hydrological degradation within the city's watershed, particularly in urbanized areas [50].

The area of barren land also decreased from 14% to 7% over the past decade, mainly due to its conversion into built-up areas. There has been minimal conversion of barren land into vegetation, built-up areas, or water bodies between 2013 and 2023. Figure 5 illustrates the spatial distribution changes of built-up areas in Hyderabad from 2013 to 2023. It shows that between 2013 and 2018, urban expansion was concentrated in North, Central, and South Hyderabad. From 2018 to 2023, significant preparatory work for construction and expansion occurred in Northeast Hyderabad, leading to the completion of these developments by 2023. By then, two-thirds of the pixels in Hyderabad were classified as "built-up areas."

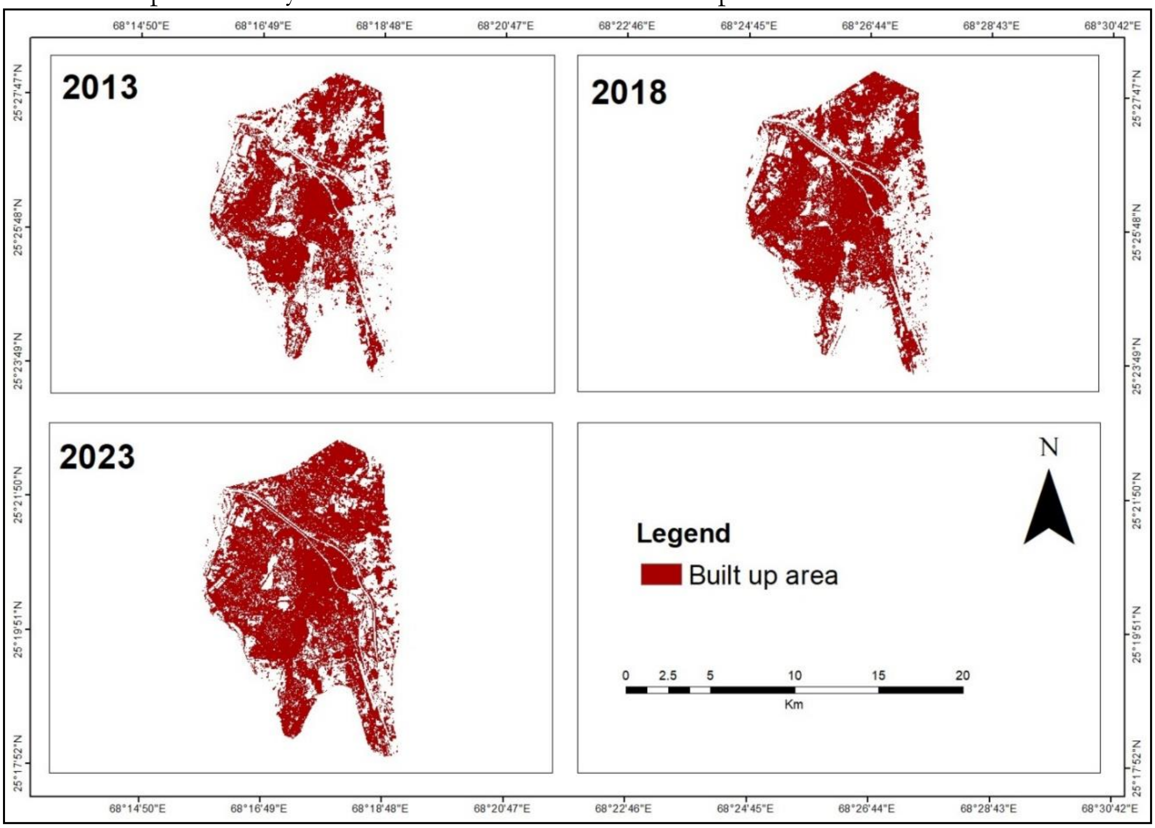

Figure 5: Spatial distribution of built-up area over the period 2013-2023

Accuracy Assessment:

Table 3 displays the Producer Accuracy and User Accuracy for each of the four land-use types across the study years, as well as the Overall Accuracy and Kappa Coefficient. The spatial retrieval framework shown in Figure 2 indicates high reliability and offers valuable insights into land-use changes over recent decades. Notably, both Producer Accuracy and User Accuracy for all land-use types consistently exceeded 80% in all years.

Table 3: Accuracy Assessment of Processed Images

Year	Metrics	Vegetation	Built Up Area	Water Body	Barren Land
2013	Producer Accuracy (PA)	90.9	100	100	85.7
	User Accuracy (UA)	100	100	90.0	85.7
	Overall Accuracy (OA)	94.2			
	Kappa Coefficient (KC)	92.3			
2018	Producer Accuracy (PA)	80.0	90.0	100	100
	User Accuracy (UA)	88.8	90.9	92.3	100
	Overall Accuracy (OA)	92.6			
	Kappa Coefficient (KC)	90.1			
2023	Producer Accuracy (PA)	93.7	100	100	87.5

	User Accuracy (UA)	100	92.3	91.6	100
	Overall Accuracy (OA)	95.6			
	Kappa Coefficient (KC)	93.8			

The accuracy was notably high for built-up areas and water bodies, with values exceeding 95% from 2013 onwards. However, in 2013, the Producer Accuracy for barren land was 85.7%, and in 2018, both Producer Accuracy and User Accuracy for vegetation were relatively lower at 80.0% and 88.8%, respectively, compared to built-up areas, water bodies, and barren land within the same year. This discrepancy may be due to the greater number of Ground Truth Points (GTPs) selected for built-up areas in the 2013 and 2018 Landsat images, while barren land, vegetation, and water bodies had fewer GTPs overall.

The Spatial and Temporal Trends in Land Cover:

The spatial classification results for land cover from 2013 to 2023 reveal significant transformations in Hyderabad's landscape. The rapid expansion of built-up areas has been accompanied by a marked decrease in vegetation, water bodies, and barren land. Several factors have contributed to this urban growth:

Urbanization and Economic Development:

Hyderabad, as the second-largest city in Sindh and a major urban center, has a rich historical and economic background with numerous commercial and industrial establishments. This has led to a high demand for residential and commercial space.

Employment and Quality of Life:

Recent years have seen Hyderabad offer improved employment opportunities, a robust education system, and better healthcare facilities, which have raised living standards and attracted rural migrants to the city.

Population Growth:

The increasing population has driven demand for new housing and infrastructure. This has led to the conversion of various land types into built-up areas as urban planning and construction projects expand across the city.

Discussion:

The land use and land cover changes observed in Hyderabad from 2013 to 2023 highlight significant urban expansion, with built-up areas increasing by 68% over the decade. This trend is consistent with patterns seen in other growing cities globally. For example:

- Saleem and Mahmood (2023) [57] reported similar urban expansion in Faisalabad, Pakistan, with agricultural land increasingly converted to built-up areas.
- Akbar et al. (2019) [58] noted substantial reductions in vegetation cover due to urban growth in Lahore.
- Gull and Mahmood (2022) [32] observed rapid increases in built-up areas in Islamabad and a persistent decline in green cover.

The reduction in vegetation from 4,909.709 hectares in 2013 to 2,802.377 hectares in 2023 aligns with broader trends of urbanization. [59] and [60] noted significant declines in vegetation due to urbanization, with Peerzado et al. highlighting a 70% reduction in vegetation in Hyderabad from 1981 to 2017. Recent studies by [38] and [23] further support these findings, indicating substantial biodiversity loss and ecological impacts from urban expansion.

The spatial distribution of urban growth, particularly in the northeastern parts of Hyderabad, aligns with observations in other cities where growth often concentrates around infrastructure developments [61] and economic hubs [62]. Our study's high classification accuracy, with overall accuracies and Kappa coefficients exceeding 90%, supports the reliability of remote sensing for monitoring urban expansion. This is consistent with [31] and [63], who demonstrated high accuracy in urban sprawl studies using Landsat and Sentinel-2 data.

The implications of these findings are significant. [59] highlighted the impact of land cover changes on urban hydrology, noting increased runoff and flood risks. [37] discussed the socio-economic impacts of urban sprawl on local communities and infrastructure. [24] explored the Urban Heat Island (UHI) effect in Hyderabad, linking urbanization to increased local temperatures. These insights underscore the need for sustainable urban planning to mitigate the adverse effects of rapid urbanization and integrate environmental considerations into development strategies.

Conclusion:

The study concludes that significant spatial and temporal changes in land use and land cover have occurred in Hyderabad over the past decade. There has been a substantial increase in built-up areas (68%) and a decline in vegetation cover (43%). The research highlights the need to better understand the mechanisms driving land cover changes and the potential social and environmental challenges posed by rapid urban growth, rural-urban migration, and industrial development. Issues such as rural-urban disparities, transportation emissions, pollution, and land misuse are likely to arise. The use of remote sensing and pixel-based classification methods offers valuable insights for impact assessments, urban planning, and environmental governance. This approach supports the integration of historical imagery and GIS data, enhancing land-use classification, monitoring change detection, and informing infrastructure decisions, marking a significant step toward technological advancement and intelligent city management.

Recommendations:

- **Mixed Land Uses:** Incorporate mixed land uses to bridge the urban-rural divide and preserve open spaces, fostering balanced and sustainable urban growth.
- **Housing Development:** Prioritize housing development away from industrial hazards while ensuring proximity to economic hubs to address housing shortages and create job opportunities.
- **Advanced Technologies:** Implement advanced technologies and building standards from developed cities to enhance infrastructure, improve urban resilience, and attract investment.
- **Environmental Data Access:** Improve access to environmental data to support sustainable urban development, health risk management, and informed community decision-making.

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