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Assessing Land Use Change in the Hub Dam Watershed of Karachi, Pakistan through GIS and Remote Sensing

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Abstract:

Geographic information systems (GIS and Remote sensing are two technologies that allow for the detection and long-term monitoring of changes in land use, which is essential for resource management, land use planning, and environmental monitoring. In recent years, mapping and analyzing land use change using remote sensing and GIS has gained popularity due to its ability to deliver precise and timely information for decision-making. The purpose of this study was to use RS and GIS methods to compare and analyze Karachi's LULCC. This study describe the trend of land use change in Karachi from 1992 to 2022 Using GIS in tandem with supervised classification and visual interpretation, this can better understand the spatial distribution of different LULC shifts, which is important for three reasons understanding the factors at play in LULC shifts. This study employed digital image processing techniques to assess LULC and to track their changes over time in this study. According to the data, the amount of forested and arid land decreased significantly between 1992 and 2022 as urban and agricultural areas, as well as water, expanded. A significant rise in water levels did not occur. In spite of this, the major water supply reservoir for the city dropped by 19.5% throughout the research period. The transformation of forested and barren terrain into urban territory has resulted in the growth of slums, which is one of the most significant negative effects associated with rapid urban development.

Keywords **—GIS; Remote Sensing; Karachi; Hub Water dam**

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I. INTRODUCTION

A potent technique for comprehending the dynamics of land cover changes through time is land use change mapping and analysis employing remote sensing and geographic information systems (GIS). In remote sensing, information about the Earth's surface is collected and analysed using satellite or airborne sensors, whereas in geographic information systems (GIS), geographical data is organized, examined, and visualized using software. Combining these two technologies allows for the detection and long-term monitoring of changes in land use, which is essential for resource management, land use planning, and environmental monitoring. The identification of patterns and trends in land use changes, such as urban growth, deforestation, and agricultural land use changes, is made possible by this method. Given the speed at which land use is changing and the need for sustainable development, mapping and analyzing land use change using remote sensing and GIS has gained importance in recent years. In order to plan and manage land use effectively, it is a crucial tool for governments, organizations, and scholars. This method offers priceless insights into the reasons for and effects of changes in land use, allowing for better resource management, biodiversity preservation, and community sustainability.

In recent years, mapping and analyzing land use change using remote sensing and GIS has gained popularity. By delivering precise and timely information for decision-making, the integration of remote sensing and GIS has transformed the process of detecting and analyzing changes in land use. We will look at the most recent developments in the mapping and analysis of land use change using remote sensing and GIS in this literature review.

Using remote sensing and GIS, Chen et al. (2019) carried out research on the analysis and detection of land use change. In the Chinese province of Zhejiang, land use changes between 2013 and 2018 were identified using Landsat 8 satellite images. The findings demonstrated that remote sensing and GIS can successfully identify and track changes in land use in the study area. Ali et al. (2018) used remote sensing and GIS to examine the change in land use in the Nilgiri Biosphere Reserve in India. They examined the variations in land use between 1990 and 2015 using GIS and Landsat satellite images. The findings indicated that the effects of urbanization, agricultural development, and forest degradation had a substantial impact on the land use pattern in the research area. Using remote sensing and GIS, Bhattacharya et al. (2019) studied the detection of land use change in Kolkata, India. To assess the changes in land use between 1990 and 2015, they employed GIS and Landsat satellite images. According to the report, urban land usage increased significantly, which resulted in a decline in the use of agricultural land and the amount of greenery. Using remote sensing and GIS, Zhang et al. (2020) carried out a study on the analysis and detection of land use change in the Jiangsu Province, China. To assess the changes in land use between 2005 and 2015, they employed GIS and Landsat satellite images. According to the findings, urban land usage increased significantly while rural land use decreased.

With the aid of remote sensing and GIS, Shiferaw et al. (2020) studied the mapping and analysis of land use change in Ethiopia's Upper Blue Nile Basin. To assess the changes in land use between 1985 and 2015, they employed GIS and Landsat satellite images. The findings demonstrated a large increase in agricultural land usage, which resulted in a reduction in areas of woodland and grassland. Nonetheless, remote sensing and GIS-based mapping and analysis of land use change is a crucial tool for regulating and observing land use changes. Decision-making information can be accurate and fast with the use of remote sensing and GIS integration. The studies that were looked at in this literature review show how useful remote sensing and GIS are for identifying and assessing changes in land use across the globe.

The study's objective was to compare and analyze the LULCC of Karachi utilizing RS and GIS techniques. The following goals were achieved in order to attain this goal: (1) To identify and outline several LULC categories and the pattern of land use change in Karachi from 1992 to 2022 (2) to combine GIS with supervised classification and visual interpretation to explore the spatial distribution of various LULC changes, and (3) to pinpoint the main factors that are driving LULC change and the extent of their involvement.

II. STUDY AREA

The Hub Dam watershed is a region in Pakistan's Karachi that is about 3,400 square kilometers in size. The Hub River, which originates in the Balochistan province and flows through the Lasbela region before joining the Arabian Sea, is the main source of water for the watershed. The Hub Dam, which was constructed on the Hub River in 1981, is a significant supply of water for Karachi and the territories around it.

The Hub Dam is an essential supply of water for Karachi's expanding population and has a storage capacity of about 857,000 acre-feet of water. Many farmers' lives are supported by the irrigation water provided by the dam's catchment area to the nearby agricultural regions. Many bird and mammal species as well as other types of flora and wildlife can be found in the Hub Dam basin. Many animals, such as leopards, foxes, and hyenas, have a home in the nearby hills and mountains. Also, the watershed is home to a number of significant wetlands that serve as crucial nesting grounds for migrating birds. However the Hub Dam watershed faces a number of difficulties, including a lack of water, deforestation, and soil erosion. The region's agriculture and economy could be severely harmed by floods and droughts that could affect the watershed.

A number of projects have been launched to conserve and safeguard the Hub Dam watershed in order to address these issues. They include the preparation of water management plans to ensure sustainable use of the watershed's resources, the planting of trees to stop deforestation, the building of check dams to stop soil erosion, and others. Overall, Karachi and its environs benefit greatly from the Hub Dam watershed's economic, social, and ecological stability. To maintain the sustainable management and conservation of this crucial resource for future generations, continued efforts are required (fig 1.)

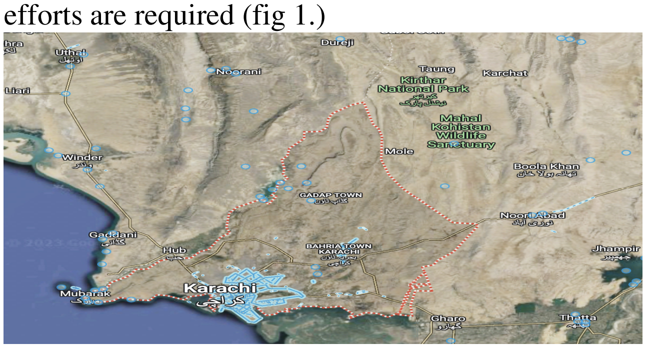

Figure 1 location map of Karachi

III. METHODS

Data acquisition

Two multispectral satellite photos of the city were obtained during two Epochs—1992 and 2022—in order to analyze LULC changes in a city like Karachi. The SUPARCO, an Earth Science Data Interface, and United States Geological Survey (USGS)respectively, provided 1992 and 2022 photos (LANDSAT) for the month of October. Table 1 provides details of the satellite data that was gathered for change analysis.

Table 1Satellite data information

Data	Source	Spectral resolution/bands	Resolution (m)	Bands/color	Year of acquisition
Landsat 5 TM imagery	USGS glovis	Band 2 (green) 510–620 nm USGS glovis	30	Multi-spectral	1992
		Band 3 (red) 630–700 nm			
		Band 4 (near IR) 710–1000 nm			
SPOT 5 imagery	SUPARCO	Band 2 (green) 510–620 nm	10	Multi-spectral	2012
		Band 3 (red) 630–700 nm			
		Band 4 (near IR) 710–1000 nm			

Aerial pictures, topographic maps, and ground truth data were also obtained to supplement the high-resolution images. Image classification and accuracy assessment relied on ground truth data in the form of reference data points obtained via Global Positioning System (GPS) from January to December 2022 for 2022 image analysis.

Image classification and pre-processing

Satellite image pre-processing is a crucial step in the change detection process as it helps establish a direct correlation between the collected data and biophysical phenomena (Abd El-Kawya et al. 2011). Distortions in remotely sensed data due to the acquisition system and platform movements require geometric correction. To achieve this, the satellite data was imported into ERDAS 2021 software and underwent geo-referencing, mosaicking, and subletting based on the Area of Interest (AOI). The per-pixel signatures were assigned to all the satellite data, and the land area was divided into five classes based on the Digital Number (DN) value of the landscape elements. The different classes included Barrenarea, Water, Agriculture, Forest, and Built-up area (Table 2).

Table 2Classes delineated on the basis of supervised classification.

Water body	River, reservoirs, lakes, ponds and open water
Agricultural area	Fallow lands and crop fields
Built up area	Mixed urban, roads, transportation, industrial, commercial, Residential
Barren area	Terrain with bare soil and a lack of vegetation, caused by human activity.
Forest area	Uneven forest cover

There are a number of stages required to generate precise land cover maps using satellite images. To begin, we give each group its own name and color so that we can easily tell them apart. Then, polygons are created around these representative sites to create training samples for each land cover type. Using the pixels contained by these polygons, spectral signatures are recorded for each land cover type. If you want to do accurate mapping, you need to make sure the spectral signatures are good. After applying the maximum likelihood algorithm to the images, a supervised classification is carried out with the analyst hand-picking example pixels to represent each target category.

Urban surfaces are a complicated mixture of elements including buildings, grass, roads, soil, trees, and water, thus even with our method, misclassifications might occur in places with mixed pixels. Classification accuracy can be enhanced by employing post-classification refinement to deal with this matter. In order to improve classification precision and provide superior land cover maps, visual interpretation is a crucial technique. Results generated utilizing the supervised algorithm can be vastly improved with the help of local knowledge, reference data, and visual analysis.

Accuracy assessment

In order for individual classifications to be relevant in change detection, accuracy assessment is essential. The area's various land cover classes are represented using the stratified random approach, and the correctness of the representation is evaluated on a scale of one hundred points based on ground truth data and human interpretation. Using error matrices, we may statistically evaluate how well our classifications match up to the original reference data. In addition, the degree of classification accuracy is evaluated using a nonparametric Kappa test.

Land cover/use change detection

Post-classification change detection methods like the overlay approach and the two-way cross-matrix are used to identify shifts in land use/cover. Quantitative conversions from one land cover category to another and their related area across the evaluated period on a pixel-to-pixel basis are calculated using cross-tabulation analysis. The research results in a new thematic layer with numerous permutations of "from-to" transition types. This technique has been demonstrated to be useful in identifying the specific location, nature, and rate of change in urban settings.

IV. RESULTS AND DISCUSSIONS

The error/confusion matrix was used to create accurate land use/cover maps for 1992 and 2022, as illustrated in Figures 2 and 3. Classification accuracy on a pixel-by-pixel basis is typically evaluated using this method (Lu and Weng 2007). The Kappa statistics/index was also computed for each mapped category. The generated land use/cover maps for both periods achieved a kappa value of 0.89 in their classifications. Overall, this was acceptable for further investigation and anomaly detection (Lea and Curtis 2010). According to the image classification outcomes, Karachi has an area of 89,958 acres (ha). Table 3 provides a summary of the percentage of each class area that will have changed between 1992 and 2022.

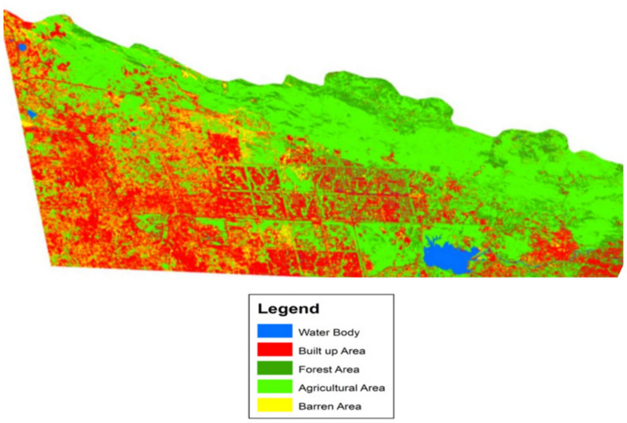

Figure 2Land cover map of Karachi in 1992

Table 3Area statistics and percentage of the land use/cover units in 1992–2022

Land use and Land cover categories	1992		2022		1992-2022 changed area (%)	Annual Change
	Area (ha)	Area %	Area (ha)	Area %		
Water body	1325	1.21	1739	2.29	+24.5	+0.58
Built up area	18,370	24.2	61,320	70.29	+313.34	1-.67
Forest Area	13,334	18.50	8120	9.2	-70.24	-4.5
Agriculture Area	15,446	21.3	31000	37.23	+210.5	13.0
Barren Area	57,924	67.24	2177	-99.24	5.6	

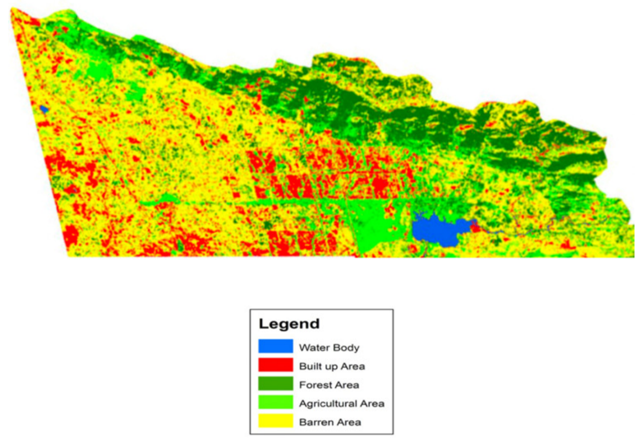

Figure 3land cover map of Karachi in 2022

Comparing the percentages of land assigned to each LULC category in 1992 and 2022, we find that Barren Area accounted for 67.24% (57,924 ha) of all LULC categories in 1992. Due to a drastic change, the area devoted to this category will be only 1.87 percent, or 2,177 hectares, in 2022. Forest Area was the other category that saw a decrease in population over the study period. Whereas 18.50% (13,334 ha) of the land was classified as such in 1992, by 2022 only 7.20% will be (8120 ha). The overall share was raised for the other three categories of people. Specifically, Build Up Area saw a significant increase. Its percentage will have risen from 24.2% (18,370 hectares) in 1992 to 70.29% (61,320 ha) in 2022. Also, by 2022, the percentage of land dedicated to agriculture will have risen from the 21.3% (15,446 ha) it was in 1992 to the 37.23% (29,000 ha) it is projected to be then. Not much of a difference was observed between the beginning and end of the study session, however the Water class did increase. From 1.57 percent (1,325 hectares) of the total area in 1992 to 2.29 percent (1,739 hectares) in 2022.

Specifically, from 1992 and 2022, the study found that the total inhabited area increased by more than 233%. (Table 2). This number represented the extreme pressure that the category of built up surface was putting on the other two categories of land cover, especially agricultural fields. Continuous growth of built-up surfaces in the various parts of the city is a result of the rapid building sites of industrial units, commercial and residential units,pavements and road networks, leisure and port facilities, and other impervious surfaces. In 2011, Chigbu et al. used medium-resolution satellite images to analyse land-use and cover changes in the Aba Urban region of Nigeria. According to the findings, the percentage of land covered by buildings rose from 21.7 to 36.5%. Tahir et al. (2013) conducted research on LULCC in the urban region of Mekelle, Ethiopia, and found an increase of 200 percent.

Population and industrial expansion during this time period may help explain the observed alterations in urban areas. Simultaneously, the geometric centre of a city and its distance from main highways were revealed to have a strong association with urban expansion, demonstrating that roads were a key factor in urbanisation. The ecosystem near Karachi Motorway was severely impacted by urbanisation, primarily due to deforestation and habitat loss. Based on the data collected for this study, it can be concluded that forest cover has decreased by almost 57% during the course of the last 20 years, between 1992 and 2022. Wild and accidental fires in the summer, when there is no rain for months and temperatures climb to 45 °C, transform hundreds of hectares into cinders, explaining in large part the loss of forest to scant vegetation.

Converting forested areas into farmable ones was also a major factor. According to the statistics provided, most of the forested lands were converted to agricultural use, but some were relocated to gardens in the vicinity. Soil erosion, high temperatures, and dust storms are all potential outcomes of continued deforestation in the area. These unfavourable effects would cause climate shifts, and the subsequent ripple effect would contribute to a future acceleration of global warming. Half of the forest cover was unaltered during the research period, while 8 percent was degraded, indicating a general tendency towards degradation of forest to sparse vegetation, most notably along the western edges, where much of the conserved forest was severely damaged. Stone quarries, cultivation, wood cutting for fuel and fodder consumption by the villagers, and the facto cement industry that borders the western periphery have all contributed to the transformation of the dense forest that existed along the western margin in 1992 into sparse vegetation by 2022, the results show. According to reports, the city's ongoing devastation of its forests has resulted in a considerable financial loss. The annual decline rate for wood biomass is between 4% and 6%, making it the second highest in the world. Modern geospatial approaches such as remote sensing and GIS were used by Tripathi and Kumar (2022) to examine LULC dynamics in Takula Block (Uttarakand), where they found that forest cover has reduced by 6.28 percent between 1999 and 2005. Comparable research of land use and land cover shifts in Rize, Turkey was conducted by Reis (2008) utilising remote sensing and GIS. According to a change detection comparison of the LULCC, the amount of farmable land rose by 36.2% between 1973 and 2002. Classified maps showed that the percentage of the city that belongs to the Water class has been growing at a rapid clip. In 1992, 1325 ha of the study area was covered by water, but by 2022, that number will have climbed to 1739 ha. It's possible that the Monsoon Season's precipitation levels are to blame for this variation. In particular, throughout this time frame, there has been a substantial reduction in the size of Rawal Lake, from 594 to 478 hectares. Rawal Lake's overall area has increased by 19.5%, representing a major shift. Butt et al. (2015) performed a similar change detection analysis on the Rawal watershed and found comparable outcomes. Rapid deforestation and urbanisation, leading to progressive land use change, are two of the biggest challenges facing the watershed right now. The water regime entering Rawal Lake is being negatively impacted by the rising population and rising number of housing complexes in the watershed area. Many factors, including tree cutting for high-value domestic uses (heating, cooking timber, etc.), forest disease, and inefficient forest management, are speeding up the rate of deforestation in the watershed region. Due to population growth in the central area, affluent people were forced to leave their homes on unoccupied lots, reducing the total area covered by wilderness. Because of this, new neighbourhoods have sprung up on the fringes of the city. Over the study period, the Barren class showed a declining trend (Table 2). This research found that the area shrank from 1992 to 2022, with the 20-year decline accounting for 96.63 percent of the total change. Using GIS and remote sensing, Tahir et al. (2013) assessed the LULCC in Mekelle, Ethiopia. The percentage of bare land in the area decreased by 92.86 percentage points, and all of the local farm boys were transformed into something else.

It's believed that agriculture would be hit particularly hard by climate change because temperature and precipitation are direct inputs to agricultural products. Agricultural output, forest nutrient cycles, and other ecologically significant processes may be affected by climate change, as has been hypothesised. Hydrological fluxes of nutrients, for instance, will be influenced by changes in precipitation, which may have knock-on effects on production, decomposition, and nutrient uptake. Changes in hydrologic fluxes, decomposition, and rapid physiologic development may also result from increases in temperature, ultimately resulting in lower yields and premature maturation(Bonan 2008; Johnson et al. 2000). Intense precipitation is the primary cause of the ongoing devastation of forest and farmland. A longer growing season may be possible if there is an increase in precipitation. More water for irrigation has been made possible by an increase in precipitation in some parts of Pakistan. Conversely, opposite effects were seen in some locations, where fertile soils were washed away by extreme flooding brought on by above-average rainfall, or where drying and storing of crops was hampered. As compared to other biomes, however, woody biomass has the second-fastest rate of decline. It fluctuates annually between 4% and 6%. (UNEP 2004). Forest cover has decreased as a result of natural and anthropogenic climate change. As average temperatures rose and precipitation fell over time, the effects of these two factors on the forest's size were shown using a regression analysis.

V. CONCLUSION

In this investigation, we used digital image processing methods to evaluate LULC and to detect their evolution over time. By analysis, we learn that between 1992 and 2022, urban and agricultural regions, as well as water, expanded, leading to a significant decrease in forest and arid terrain. There wasn't much of a jump in water levels. Yet, within the time frame of the study, the city's primary water supply reservoir saw a reduction of 19.5%. Major negative impacts connected with rapid urban development include the expansion of slums, which have been generated by the conversion of forest and barren land to urban territory. Growth in both population and GDP are major factors in the demand for more urban space.

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