Concrete Expansion: Urban Growth Estimation Through Geoinformatics, A Case Study of Karachi

Sumaiya Bano, Shahnawaz
Federal Urdu University of Arts, Science and Technology, Gulshan Campus, Karachi
***Correspondance:** sumiahmed564@gmail.com

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Karachi, once the capital of Pakistan and currently the capital of Sindh province, is the country's largest city and the 12th most populous city globally. It plays a crucial role in the national economy, contributing 60-70% of the country's total revenue. However, the city faces significant challenges due to rapid urban sprawl—a prevalent issue in developing countries. The uncontrolled expansion of Karachi's urban area, often described as the "concrete jungle," presents considerable risks due to inadequate management and lack of long-term planning. This uncontrolled growth has led to increased population density, resource deficits, management challenges, and ecological pressures. Remote sensing and GIS technologies are now being employed for change detection and urban expansion analysis. Satellite data, including both current and historical images in various spatial resolutions, facilitate this analysis. In this study, change detection techniques are used to assess Karachi's urban growth through historical maps, employing Landsat 7 ETM+ images from 2002 and Landsat 8 OLI images from 2022. This analysis, based on satellite images and measurements, reveals that Karachi's population has grown at an annual rate of approximately 4%, driven by high natural increase and substantial migration from other regions. The population increased from 9.34 million in 1998 to 15 million in the 2017 census. Over the past 20 to 25 years, Karachi has expanded at a rate of about 15% annually, adding approximately 2 square kilometers per year to accommodate its growing population, resulting in a notably high population density.

Keywords: RS; GIS; Urban Growth; Urbanization; Change Detection.

Introduction:

Karachi, the capital of Sindh province, is located on the Arabian Sea (Figure 1). The city functions as a major transport hub, hosting Pakistan's two largest seaports—Port of Karachi and Port Bin Qasim—as well as the busiest airport in the country. Although the region around Karachi has been inhabited for thousands of years, the city itself was officially established in 1729 as the fortified village of Kolachi [1].

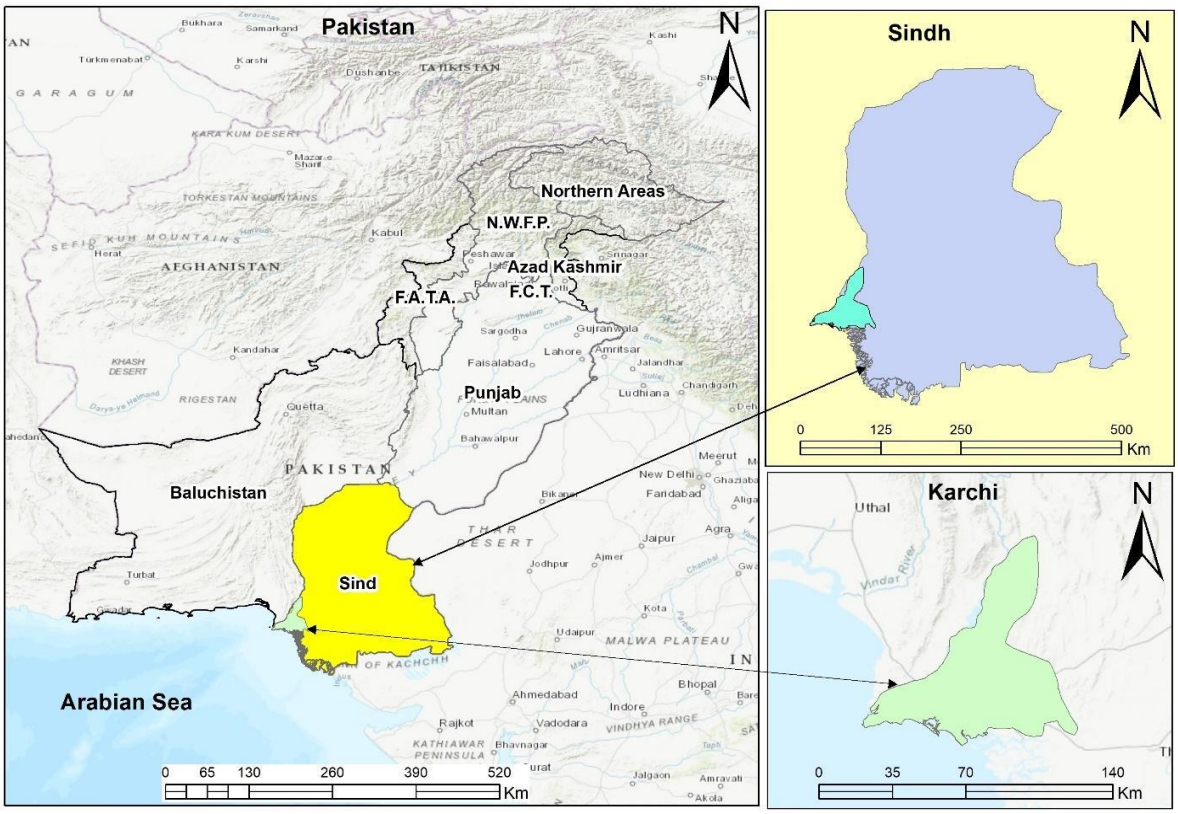

Figure 1: Study Area; Karachi

Karachi extends across coastal plains interspersed with rocky formations, hills, and coastal marshes. Mangrove forests thrive in the brackish waters surrounding Karachi Harbour and extend southeastward towards the expansive Indus River Delta. To the west of the city lies Cape Monze, also known locally as Ras Muari, notable for its sea cliffs, rocky sandstone formations, and pristine beaches [2].

As one of the world's fastest-growing cities, Karachi is home to a diverse range of communities representing nearly every ethnic group in Pakistan. Serving as the heart of the Pakistani economy and intersected by the Indus River, the city has undergone remarkable expansion in recent decades. Karachi has rapidly ascended to become the second most populous city globally, following Shanghai.

Urbanization:

As urbanization progressed, a growing share of the global population moved to cities. In 1800, only 3% of the world's population lived in urban areas. A significant milestone was reached in 2008 when the number of urban residents surpassed those in rural areas. This trend is especially pronounced in less developed regions, where increasing urbanization reflects the migration from rural to urban areas as cities and their infrastructures expand [3].

Several factors drive this migration. First, the reliance on land as a primary means of production has decreased, with many shifting away from agriculture. As a result, cities, which offer diverse job opportunities, become more appealing. Second, the division of labor in urban areas leads to a wide array of products and services, improving residents' quality of life. Finally,

advancements in education within cities foster a more educated populace, focusing more on human capital—knowledge and creativity—rather than traditional labor-based capital [4].

Urban Growth Models:

In the United States, urban sociologists have developed three principal models of urban growth. The concentric zone model illustrates a city expanding outward from a central point, featuring distinct zones such as the Central Business District (CBD), transitional areas, residential neighborhoods, and suburbs. Historically, this model was evident in cities like Chicago but has become less prominent as transportation systems have evolved. The sector model, an updated variation, divides the city into sectors that radiate from the center, influenced by transportation advancements like railways and highways. This model better reflects the layout of contemporary cities, such as Chicago and Calgary [5]. The multiple nuclei model posits that cities can have several centers or nuclei, each specializing in different activities. While a city may start with a single central business district (CBD), it can develop additional business districts, as observed in cities like Mumbai and Shanghai. Each nucleus serves distinct functions, such as clusters of fast-food restaurants or retail centers, attracting consumers based on the concentration of similar land uses in surrounding areas [6].

History of Karachi:

Karachi began as a modest fishing village before attracting a group of traders in the early 18th century. The settlement grew rapidly and had gained considerable importance by the time it was captured by the British in 1839. The British formally annexed Karachi and the province of Sindh in 1842 [7].

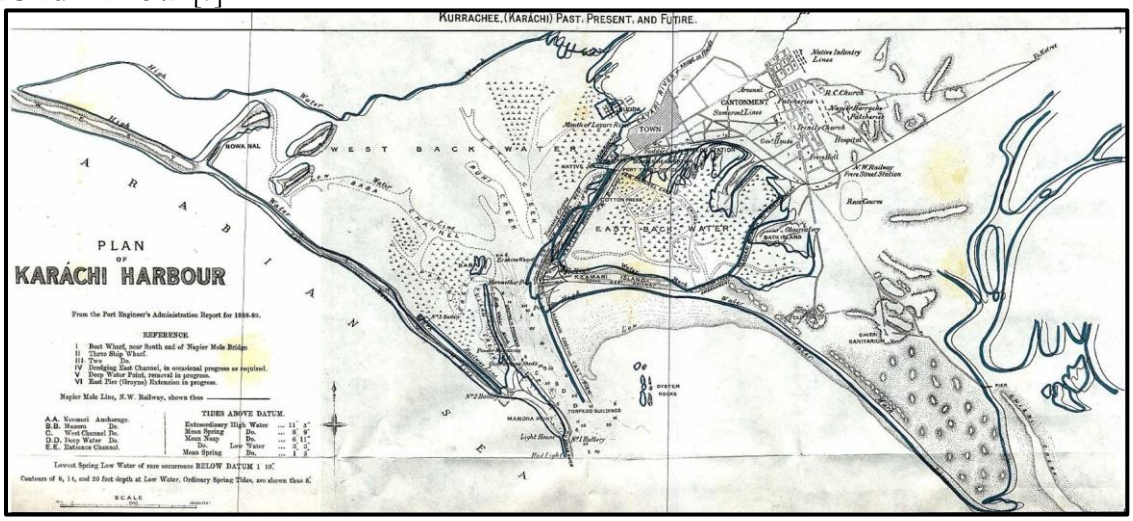

Figure 2: Karachi Harbour 1890 (Source: A**rifhasan.org**)

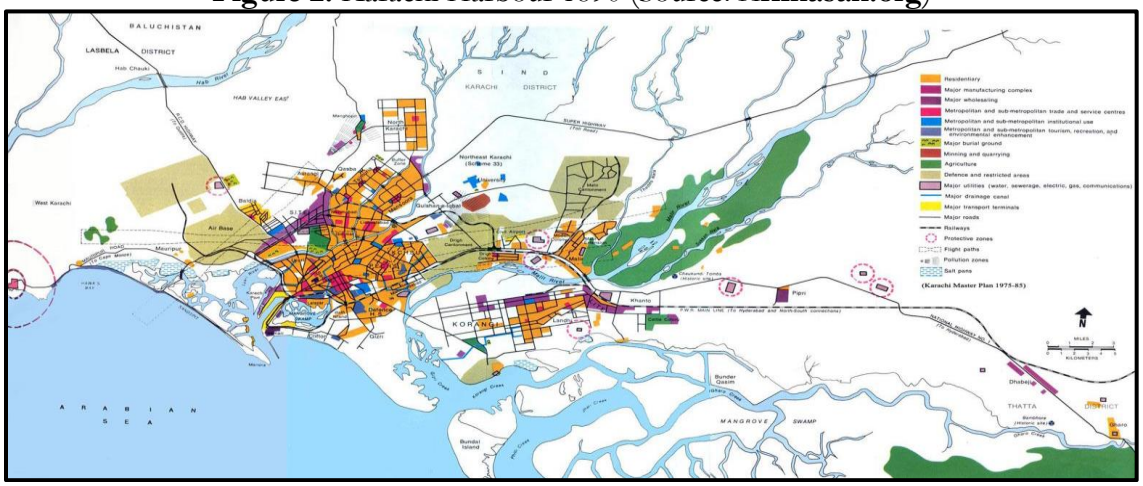

Figure 3: Karachi-Landuse-1974-Karachi-Master-Plan-75-85(Arifhasan.org)

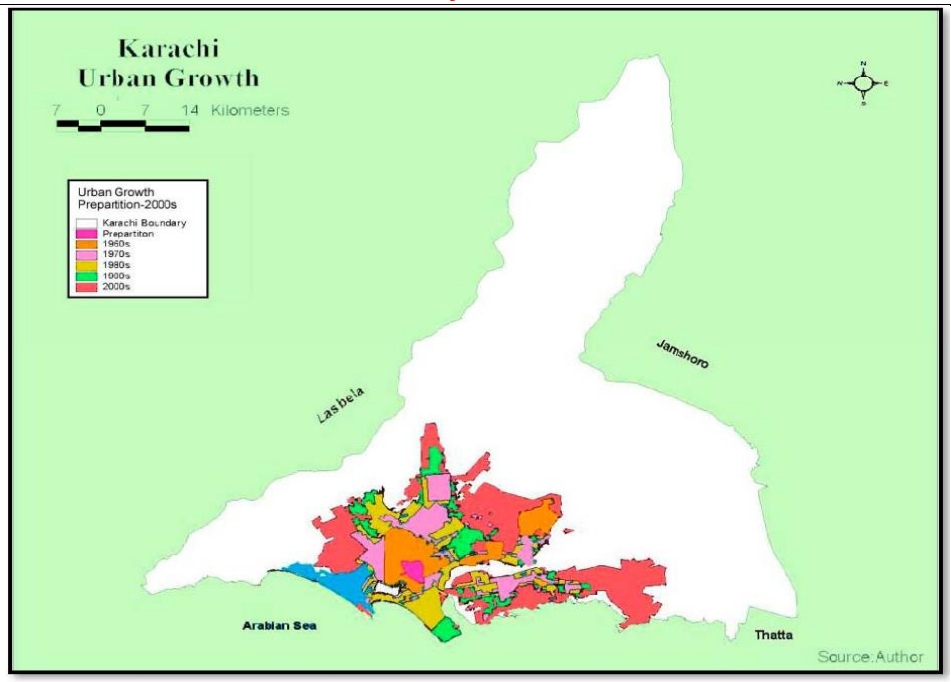

Figure 4: Karachi Urban Growth [8]

Karachi evolved from a small fishing village into a significant military and commercial hub under British rule. It became a principal port for the Indus River region and developed into a full-fledged seaport with a well-managed harbor by 1873. When Pakistan was created in 1947, Karachi was not only the capital and premier port of the new nation but also a center for industry, business, and administration. Although the capital was permanently moved to Islamabad in 1969, Karachi retained its status as Pakistan's business and industrial hub (Figure 2 & 3). This economic prominence led to a substantial population increase, as a large influx of job-seeking immigrants from rural areas nearly doubled the city's size in the last two decades of the 20th century. With the city's infrastructure already strained, about one-third of these new arrivals settled in urban shantytowns lacking basic amenities such as power, running water, and sanitation. Addressing the delivery of basic city services has remained a challenge for Karachi into the 21st century (Figure 4) [9].

The economy of Sindh, the second-largest of Pakistan's provinces, is significantly influenced by Karachi, the provincial capital and the country's largest city and economic hub [10]. Karachi remains a crucial financial and industrial center, handling much of Pakistan's overseas trade and serving as a key player in the economy of Central Asia. It contributes substantially to Pakistan's GDP and houses a large portion of the nation's white-collar workforce. Karachi's population continues to grow, and the recent economic boom in Pakistan has further revitalized the city's economy [11].

Literature Review:

The rapid urbanization occurring globally, particularly in developing nations like India, presents significant challenges. This process involves the irreversible loss of productive agricultural lands, forests, surface water bodies, and groundwater resources, largely driven by unchecked population growth. Such urbanization results in critical issues including food scarcity, informal settlements, environmental pollution, disruption of ecological systems, and rising unemployment. The unchecked development of low-density human settlements leads to urban sprawl, characterized by a fragmented and disorganized expansion. Urban sprawl reflects poor city planning and often results from land-use/land-cover changes. This type of sprawl occurs when the growth of urbanized areas significantly outstrips population growth within a given period, resulting in extensive low-density impervious surfaces [12].

Over the past two centuries, urbanization has surged dramatically. In 1800, only 2% of the global population lived in cities, a number that increased to 12% by 1900. Recent studies reveal that by 2008, over 50% of the world's population resided in urban areas, with projections indicating this figure will rise to 75% by 2030. It is expected that global urban land use will expand by an additional 430,000 square kilometers—about the size of Iraq—by 2030. Although urban land covers only 2% to 3% of the Earth's surface, the effects of urban growth are significant, resulting in both socioeconomic and environmental challenges. The rise of impervious surfaces due to urbanization exacerbates peak discharges during storms and snowmelt, increasing the risk of downstream flooding as stormwater exceeds the capacity of stream channels. Additionally, changes in surface materials affect the reflection and absorption of solar radiation, leading to micro-climate changes that contribute to the urban heat island effect. This phenomenon impacts human health and comfort, while increasing energy demands for cooling. Moreover, pollutants concentrated on urban surfaces degrade the biological, chemical, and physical qualities of lakes, streams, and estuaries receiving urban runoff, altering aquatic and terrestrial habitats [13].

Authored by Martin Brockerhoff in 2000, this article has two primary objectives. First, it aims to critically assess the reported deceleration in urban growth across the developing world, as noted by the United Nations in recent years. This assessment is conducted at various levels of population aggregation—regions, countries, and cities—to determine whether this trend is widespread across the Global South or if it is specific to certain areas and influenced by population size. Second, the article seeks to reevaluate the effectiveness of predictive models for city and urban growth, which were developed around 1980 by demographers and economists. By incorporating urban population data from the 1980 and 1990 censuses, as well as subsequent data reflecting changes in factors such as economic conditions, this reevaluation aims to identify any forces contributing to a recent slowdown in urban growth, if such a slowdown has indeed occurred [14].

Methodology:

The objective of this study was to determine the urban footprint from 2002 to 2022 using remote sensing data and GIS, with a focus on assessing the expansion of built-up land over this 20-year period. The research analyzed the spatiotemporal trends of informal urban growth in the rapidly developing city of Karachi, Pakistan. A comprehensive research framework was developed to achieve these objectives, encompassing the collection and analysis of spatial data. The various methods used for spatial data collection and analysis are discussed in detail below.

Data Collection:

This study applies remote sensing and GIS to analyze urban sprawl. Historical remote sensing data is readily accessible from various online sources, and GIS facilitates efficient and cost-effective analysis of this data. For this study, cloud-free Landsat 7 ETM+ images of Karachi from 2002 and Landsat 8 OLI images from 2022 were obtained from the USGS Landsat archives. Additionally, population data were extracted from Macrotrends to illustrate the time series trend of Karachi's growth.

Data Processing:

Preprocessing was performed to develop the Area of Interest (AOI). The downloaded images of the study area were geometrically corrected and projected to the Universal Transverse Mercator (UTM) projection system, zone 32. The spheroid and datum were set to WGS 1984.

Data Analysis:

The change detection technique was employed to evaluate alterations in land use and land cover (LULC) within the study area. Landsat 7 imagery from 2002 and Landsat 8 imagery from 2022 were analyzed, with a primary focus on changes in built-up areas. To accurately extract urban built-up areas, supervised maximum likelihood classification was utilized. This

method, a supervised classification approach for pattern recognition, calculates the probability of a pixel belonging to each of a predefined set of classes, then assigns the pixel to the class with the highest probability [15].

Upon reviewing the imagery patterns, the classification was determined to be necessary for four classes: Urban land (including dense, green, and sparse urban areas), Vegetation (comprising dense and sparse vegetation, with the study area featuring a significant mangrove forest to the south), Water bodies, and Open barren land. The maximum likelihood classification was performed on a natural color composite image (Band Combination 3, 2, 1), using 10 samples for each of the four classes, distributed randomly across the image. Classes were identified through visual interpretation, resulting in the creation of a thematic map of the four classes. The same classification procedure was applied to the second image (Figure 5).

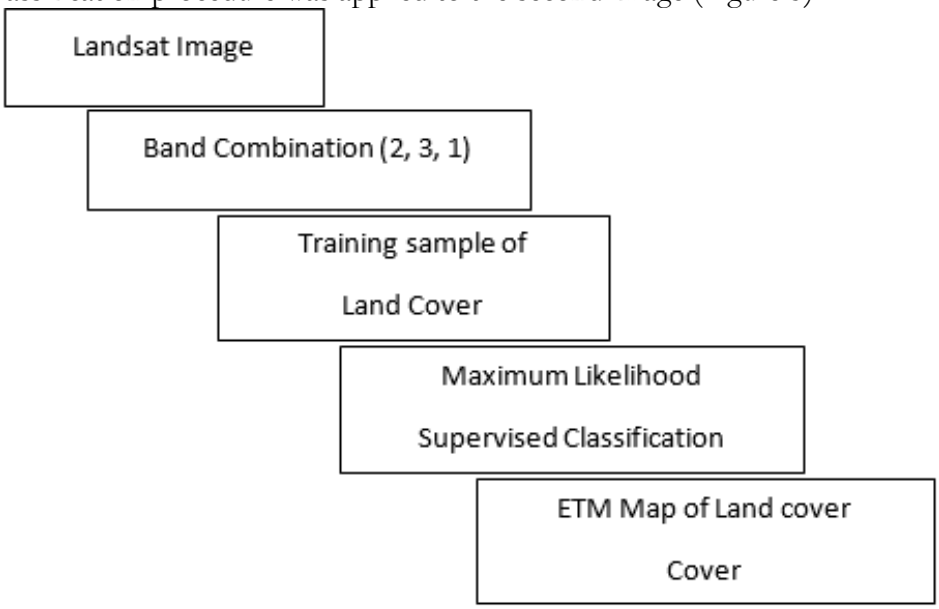

Figure 5: Methodological Framework to extract LULC

Result and Discussions:

Due to its strategic geographical location, Karachi has long served as a crucial trade route for merchants from the subcontinent, but its significance grew notably during British rule. The British development of perennial irrigation schemes in Punjab and Sindh played a major role in Karachi's growth. Additionally, the expansion of railways facilitated the swift transportation of agricultural products, leading to increased agricultural production. This boost in production allowed Karachi to become the largest exporter of wheat and cotton to India [2]. In 1935, when Sindh separated from Bombay, Karachi was established as the capital of Sindh, and government offices and trade organizations were relocated from Bombay to Karachi. Following Pakistan's independence in 1947, Karachi was designated as the first capital of the new country. Data extracted from Macrotrends shows that Karachi's population was 9.3 million in 1998. By 2023, the population had surged to approximately 17.2 million (Karachi, Pakistan Metro Area).

Table 1: Annual Population Statistics (Data Source: Macrotrends)

Year	Population	No. Year	Percent Change	Growth
1951	1,147,000	10	0	0
1961	1,954,000	10	70	5.77
1972	3,461,000	11	77	6.01
1981	5,267,000	10	52	3.79
1998	9,346,000	17	77	3.32
2017	15,021,000	19	60.1	3.55
2023	17,236,000	6	14.7	4.55

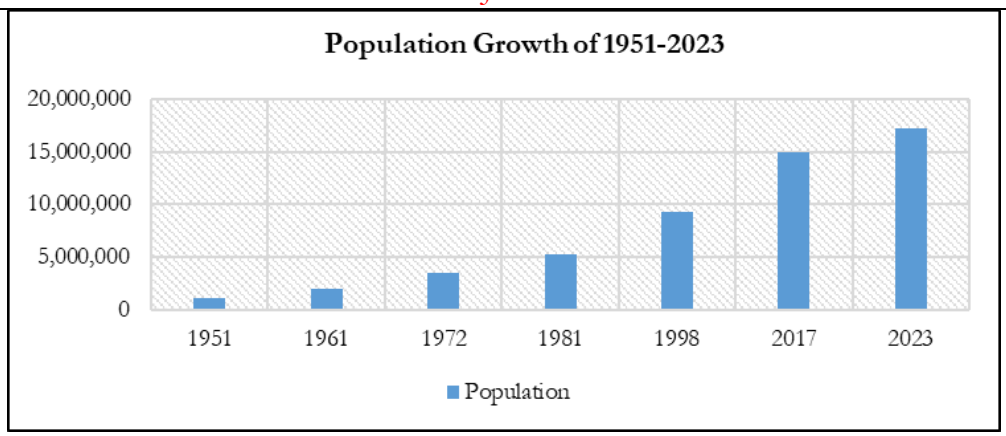

Figure 6: Population Growth of Karachi (1950-2023)

Notes: Author own estimation by excel sheet and data were extracted from macrotrends.

From 1947 to 1951, Karachi experienced a significant population increase of 161% due to the migration of approximately 600,000 refugees from India. This influx posed considerable challenges for the newly established local government, as refugees settled both on the periphery and within the city itself. This demographic and ethnic shift dramatically transformed Karachi's population structure [15]. Due to the lack of planning and strategy from higher authorities, many refugees ended up living in squatter settlements and katchi abadis. Although five master plans were developed after 1985 to guide the city's development, their implementation has been hindered by ongoing political instability.

Administratively, Karachi covers an area of approximately 3,600 square kilometers, with more than half of this area (approximately 2,455.5 acres) consisting of vacant land. Land cover features such as water and vegetation fluctuate throughout the year due to varying climatic conditions. The urban built-up area has expanded over time, primarily driven by migration from interior Sindh, Punjab, and Khyber Pakhtunkhwa in search of better opportunities in the city. This has led to a decrease of 100 square kilometers in open land, with 50 square kilometers being converted into built-up areas.

According to the City District Government of Karachi (CDGK) Karachi Strategic Development Plan 2020, the actual built-up land is 396 square kilometers. However, document figures indicate that the built-up area, including developed open spaces, was reported as 1,300 square kilometers. These developed open spaces, initiated in the 1970s, 1980s, and 1990s, remain largely vacant, with occupancy rates as low as 5%, as illustrated in the table below.

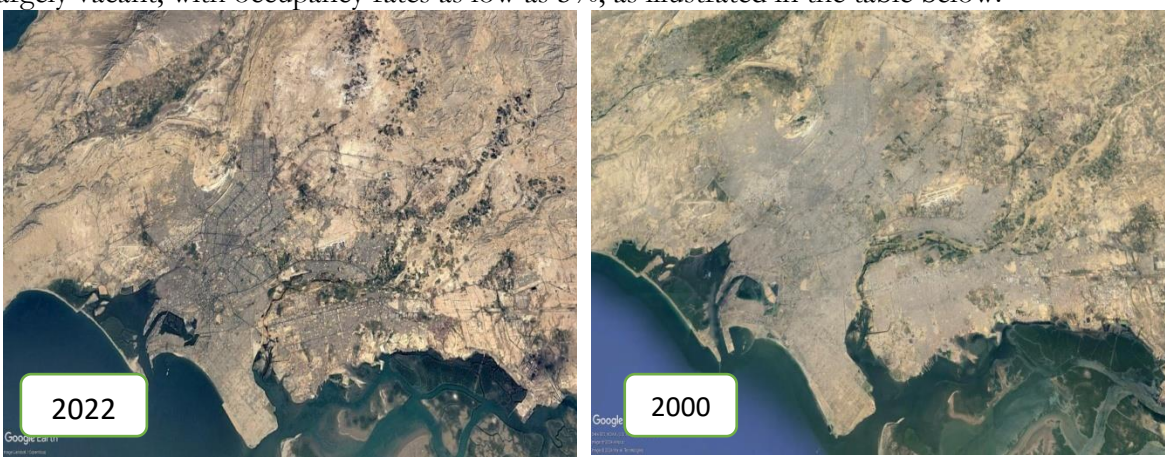

Figure 7: Satellite Data 2002-2022 (Data Source: Google Earth)

The data presented in the table below shows a notable 18.82% increase in built-up land, indicating substantial urban development. At the same time, there has been a 26.2% decrease in

open land, reflecting a significant reduction in undeveloped areas. These changes highlight the ongoing transformation of land use and the expansion of urban areas.

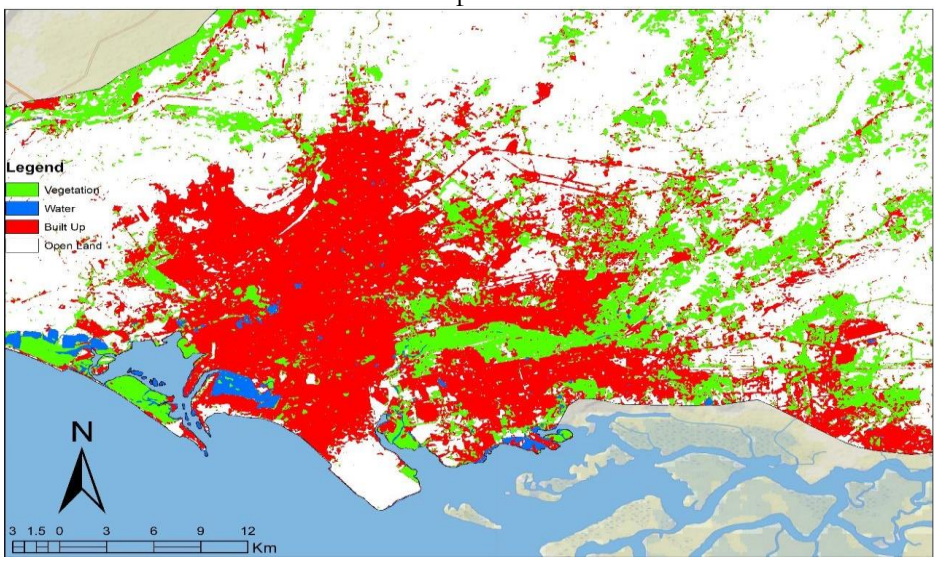

Figure 8: LULC Classification 2002 (Data Source: Landsat 7 ETM+, 2002)

Table 2: Occupancy Status of New Housing Scheme (CDGK Plan 2020, 2007) (Data CDGK)

S. No.	Name of Scheme	Year of Notification	Current Occupancy Status (%)
1	Scheme No. 25-A	1980	5%
2	Scheme No. 33	1971	20%
3	Scheme No. 42	1983	5%
4	Scheme No. 43	1986	0%
5	Scheme No. 45	1986	5%

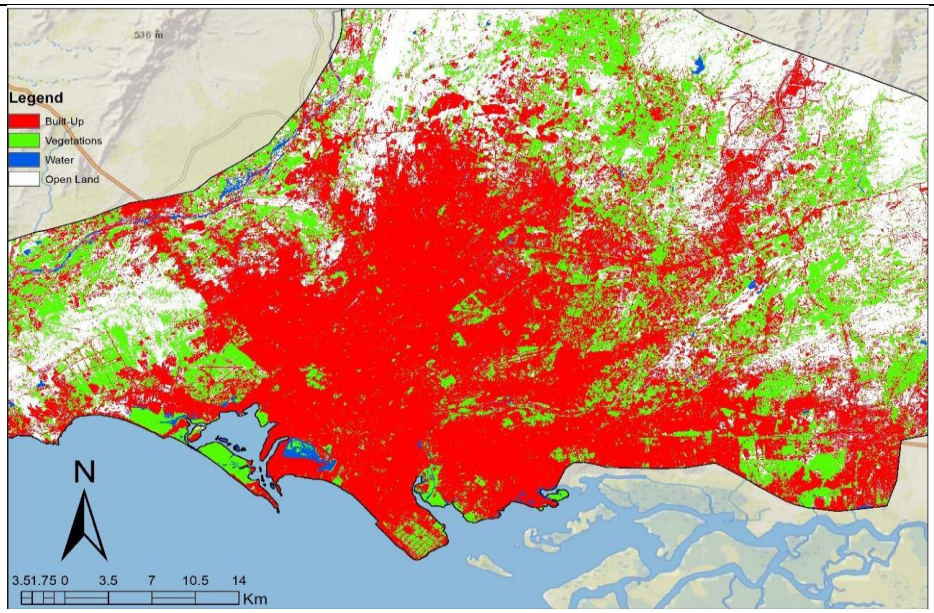

Figure 9: LULC Classification 2022(Data Source: Landsat 8 OLI, 2022)

Table 3: Area Covered by each Class for the Year 2002 to 2022 in Sq.km

Class	Area (2002) Sq.Km	Area (2022) Sq.Km	Change Sq.Km	Change %
Water	26.04	56.79	30.00	0.85%
Vegetation	375.26	612.97	237.71	6.53%
Built-Up	517.87	1198.48	680.61	18.82%
Open Land	2645.61	1725.07	-920.54	-26.21%

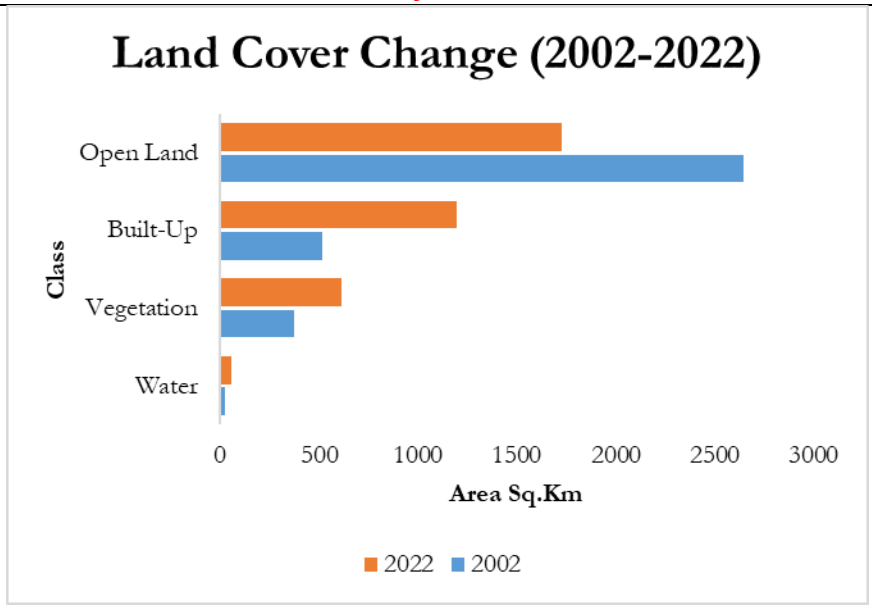

Figure 10: LULC Change (2002-2022)

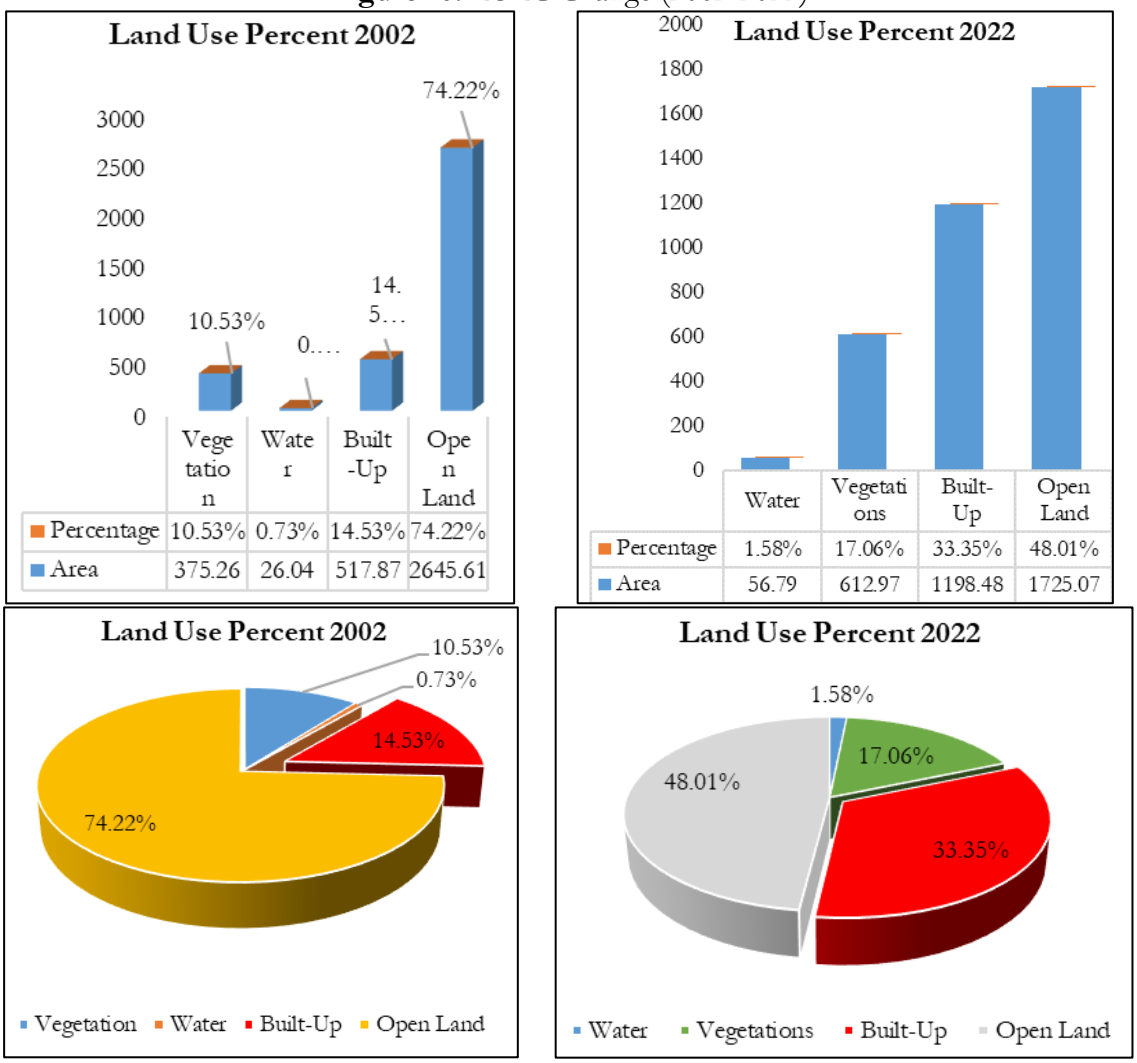

Figure 11: LULC Comparison 2002-2022 (Percentages).

The figures presented above offer a dynamic analysis of urban growth in Karachi from 2002 to 2022. We have examined four crucial factors influencing urban growth: vegetation,

water, built-up areas, and open land. The pie charts illustrate significant changes in these variables over the two decades. In 2002, open land had the largest share at 74.22%, followed by built-up areas at 14.53%, vegetation at 10.53%, and water at 0.73%. However, by 2022, these proportions had shifted dramatically. The percentage of open land decreased significantly, from 74.22% to 48.01%. Conversely, built-up areas increased from 14.53% to 33.35%, vegetation grew from 10.53% to 17.06%, and water coverage rose from 0.73% to 1.58%. These changes highlight a substantial urban expansion and support findings discussed in the literature review. Numerous empirical studies indicate that unplanned urban growth significantly impacts various socioeconomic and political aspects, affecting both current and future generations.

The marked decrease in open land and the concurrent increase in built-up areas underscore the phenomenon of urban sprawl. Specifically, the area of built-up land expanded sharply from 517.87 square kilometers in 2002 to 1,198.49 square kilometers in 2022. In contrast, open land decreased from 2,645.61 square kilometers to 1,725.08 square kilometers. This inverse relationship between urban sprawl and open land is well-documented in both empirical and theoretical literature. Increased population demands infrastructure, leading to the conversion of open land into urban areas, often referred to as a "cement jungle." This phenomenon is also associated with global warming and exacerbates issues such as socioeconomic inequality, biodiversity loss, deforestation, and public health concerns. To mitigate these effects and protect both current and future generations, it is crucial to implement effective and consistent pre- and post-development policies.

Conclusion and Recommendation:

The analysis of spatiotemporal changes in Karachi's urban growth reveals a significant increase in population, which has surpassed 21 million. Given Karachi's total area of 3,600 square kilometers, this equates to a population density of approximately 5,000 persons per square kilometer. Over the past 20 years, the population has increased by about 18.82%. Meanwhile, the urban built-up area has expanded substantially, growing from 517.87 square kilometers in 2002 to 1,198.48 square kilometers in 2022, marking an increase of 680.61 square kilometers over two decades. This rapid expansion of built-up areas highlights the swift rate of concrete development. Such extensive urbanization has led to the depletion of resources, environmental degradation, and a shortage of recreational spaces within city centers. These issues adversely affect the social, environmental, and economic conditions of the city, complicating efforts to achieve sustainable development. This study aimed to evaluate the extent of concrete expansion in Karachi as a key indicator of urban growth. However, other indicators could also be identified and assessed using Remote Sensing (RS) and Geographic Information Systems (GIS) techniques.

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