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

Sumaiya Bano[1], Shahnawaz[1]
[1]Federal Urdu University of Arts, Science and Technology, Gulshan Campus, Karachi
***Correspondance:** sumiahmed564@gmail.com

Karachi, once the capital of Pakistan and now it is the capital city of Sindh province, stands as the country's largest city and the 12th most populous city globally. It plays an important role in the country's economy by contributing 60-70% of its total revenue. However, the city struggles with the challenges of rapid urban sprawl, a preventable trend, particularly in developing countries. The uncontrolled expansion of Karachi's urban landscape, often referred to as the "concrete jungle" poses significant risks due to inadequate management and a lack of long-term planning. It is a great risk to manage the urbanization of this city of light because of mismanagement and development without long-term planning. The expansion of the urban population has brought several issues such as increased population density, resource deficit, management challenges ecological pressure, etc. The expansion of the city is the uncontrolled spreading of urban growth. Remote sensing and GIS are now being used for change detection and applications. Urban expansion is one of them, which can be analyzed efficiently by using satellite data available online in the form of present as well as historical images in different spatial resolutions. In this study, change detection techniques have been used to assess urban growth through the historical maps with Landsat 7 ETM+ sensor of 2002 and Landsat 8 OLI images of 2022. Utilizing the satellite images, conducted measurements and analysis to assess the urban growth of Karachi. Although the many unstable conditions in this city, its population growth is tremendous i.e. approximately 4% per year. This growth is due to high natural increase as well as substantial migration from other parts of the country. It is measured that the living population in 1998 was 9.34 million and in the census 2017 that population became 15 million, which was far greater than in 1998. Over the past two to two-and-a-half decades, Karachi has expanded at a rate of approximately 15 percent annually, incorporating an additional 2 sq. km/year to accommodate its growing population, resulting in a significantly high population density.

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

Introduction:

Karachi is the capital of the province of Sindh. Situated on the Arabian Sea (Figure 1), Karachi serves as a transport hub, and is home to Pakistan's two largest seaports, the Port of Karachi and Port Bin Qasim, as well as the busiest airport in Pakistan. Even though people lived in the Karachi region for thousands of years, the city itself was established in 1729 as the fortified village of Kolachi [1].
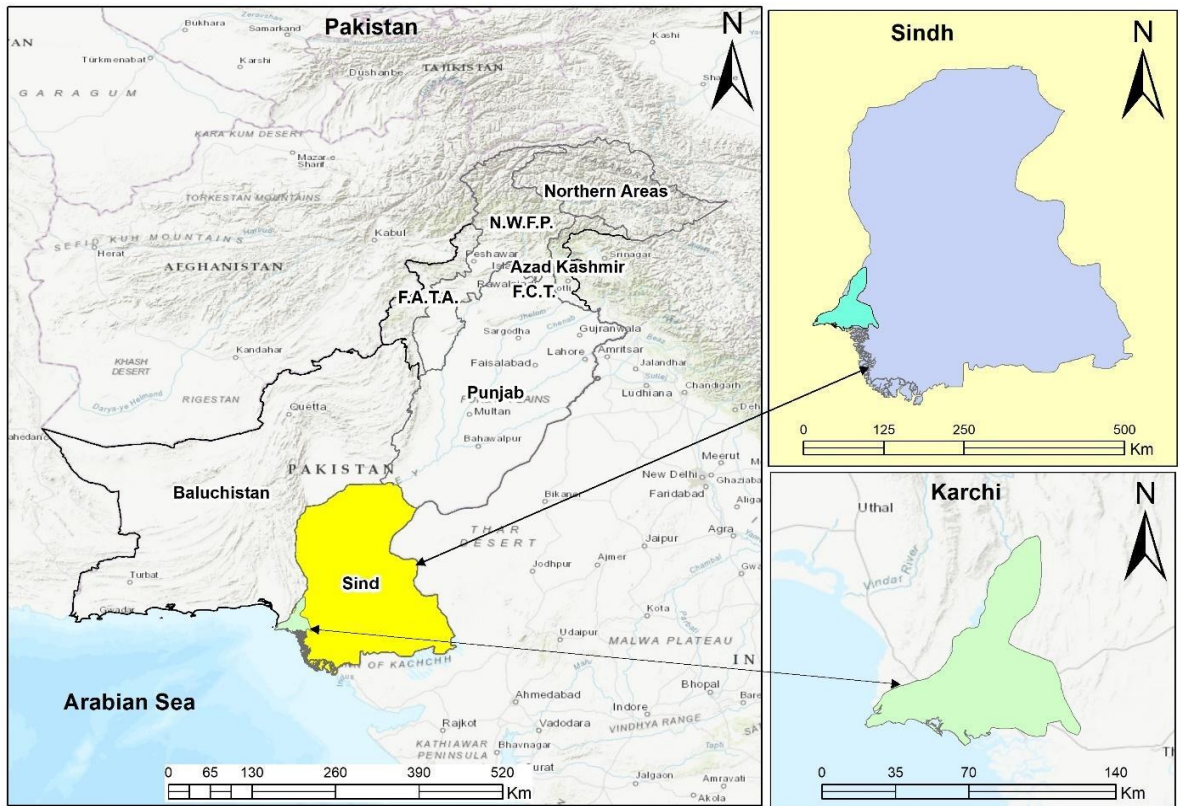
Figure 1: Study Area; Karachi

Karachi sprawls across coastal plains punctuated by scattered rocky formations, hills, and coastal marshes. Mangrove forests thrive in the brackish waters surrounding Karachi Harbour and extend southeastward towards the vast Indus River Delta. To the west of the city lies Cape Monze, also known as Ras Muari locally, distinguished by its sea cliffs, rocky sandstone formations, and untouched beaches [2].

Karachi is one of the world's fastest-growing cities and has communities representing almost every ethnic group in Pakistan. In this comparison, we focus our interest on the city of Karachi. It is the heart of the Pakistani economy, crossed by the Indus River, and has experienced enormous expansion over the last few decades. Karachi has quickly become the second most populous city in the world after Shanghai.

Urbanization:

As urbanization advanced, an increasing portion of the world's population relocated to cities. In 1800, only 3% of the global population lived in urban areas. A significant milestone was reached in 2008 when urban residents officially outnumbered those in rural areas. Particularly noteworthy is the rapid urbanization observed in less developed regions, with more people moving from rural to urban areas as cities and their infrastructures develop [3].

Several factors drive this migration. Firstly, people have diminished their reliance on land as a primary means of production, transitioning away from agriculture. Consequently, cities, offering diverse job opportunities, become more attractive. Secondly, the division of labor in cities results in a plethora of products and services, enhancing the quality of life for residents.

Lastly, the advancement of education within cities contributes to a more educated populace, placing greater emphasis on human capital, encompassing knowledge and creativity, rather than traditional labor-based capital [4].

Urban Growth Models:

In the United States, urban sociologists have developed three models of urban growth. The concentric zone model depicts a city growing outward from the center, with distinct zones like the Central Business District (CBD), transitional areas, residential zones, and suburbs. This model was historically reflected in cities like Chicago but became less evident as transportation systems evolved. The sector model, an updated version, incorporates different sectors within concentric zones, influenced by transportation developments such as railways and highways. This model is more applicable to contemporary cities, with examples like Chicago and Calgary [5]. The multiple nuclei model suggests that a city can have multiple centers or nuclei, each with specialized activities. Even if a city originally had one central business district (CBD), it can develop smaller business districts, as seen in cities like Mumbai and Shanghai. Each nucleus has distinct activities, such as clusters of fast-food restaurants or retail districts, drawing consumers based on similar land use in adjacent areas [6].

History of Karachi:

Karachi was a small fishing village when a group of traders moved there in the early 18th century. The settlement expanded rapidly and was already of significance when it was captured in 1839 by the British, who annexed it in 1842, together with the province of Sindh [7].
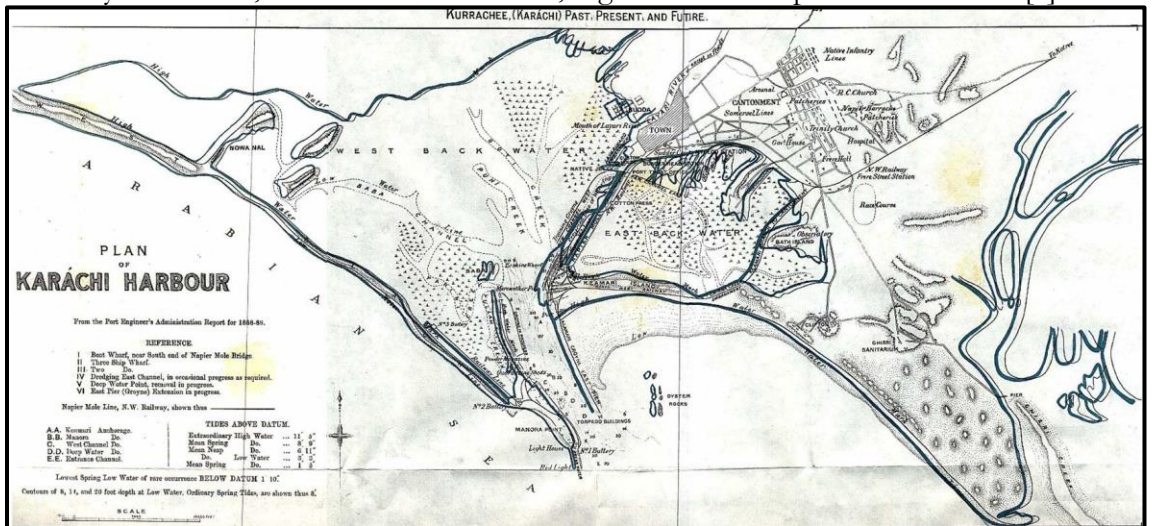

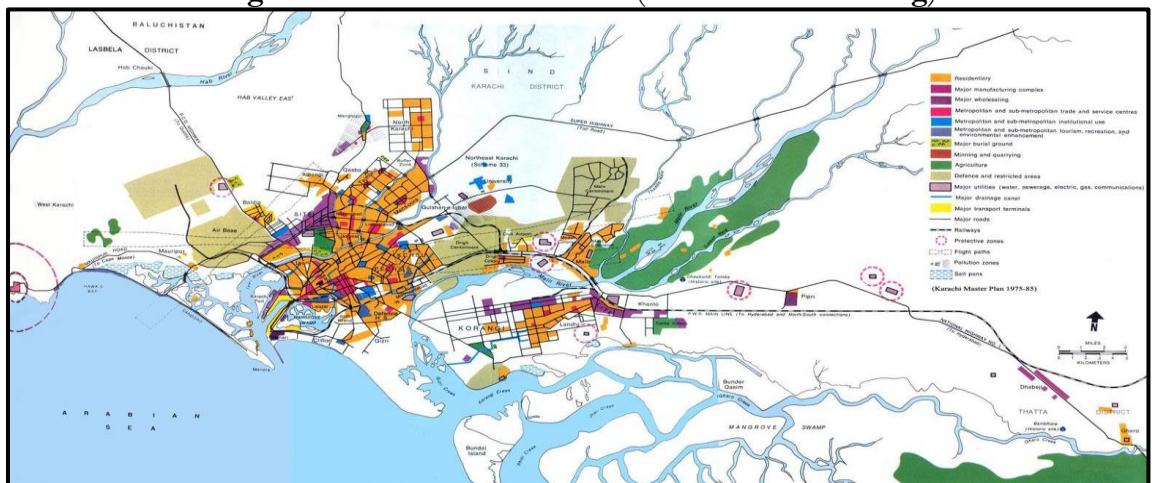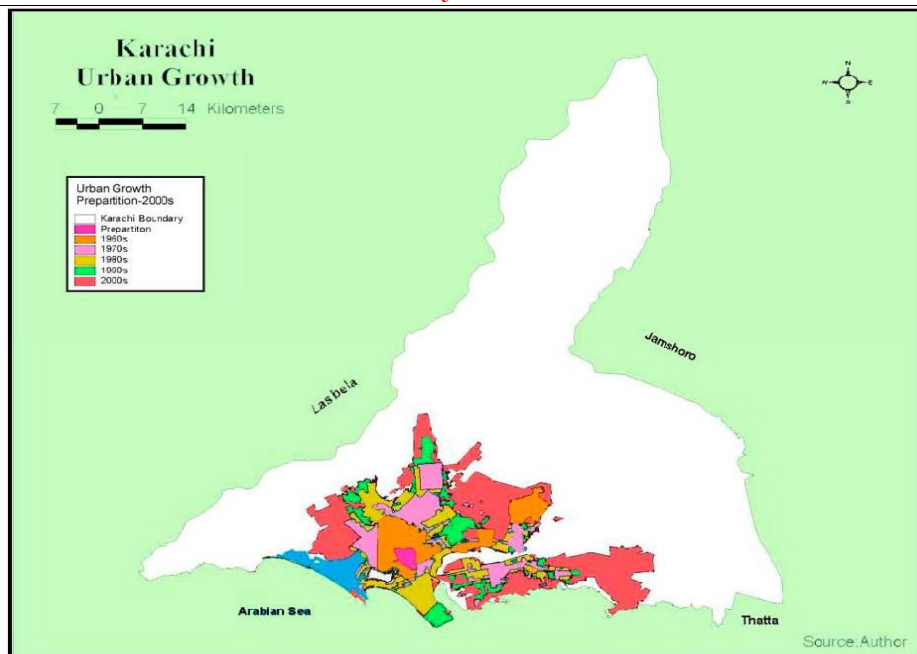**Figure 2:** Karachi Harbour 1890 (Source: A**rifhasan.org**)

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

Figure 4: Karachi Urban Growth [8]

It then became an army headquarters for the British and also began to develop from a fishing village into the principal port for the Indus River region. The importance of Karachi grew, and it became a full-fledged seaport. By 1873 it possessed an efficient and well-managed harbour. With the creation of Pakistan in 1947, Karachi became not only the capital and premier port of the new country but also a center for industry, business, and administration. Before the capital permanently moved to Islamabad in 1969, Karachi maintained its preeminence as Pakistan's business and industrial hub (Figure 2 &3). This premier economic status subsequently contributed to an enormous increase in Karachi's population, as a huge influx of job-seeking immigrants from rural areas nearly doubled the city's size in the final two decades of the 20th century. With the city's infrastructure already overburdened to the breaking point, fully one-third of these new arrivals were forced to take up residence in urban shantytowns, which ordinarily lacked power, running water, or sanitation. The delivery of basic city services remained an ongoing problem for Karachi into the 21st century (Figure 4) [9].

The economy of Sindh is the 2nd largest of all the provinces in Pakistan. Much of Sindh's economy is influenced by the economy of Karachi, the capital of the province and also the largest city and economic capital of the country [10]. Karachi continues to be an important financial and industrial center for the country and handles most of the overseas trade of Pakistan and the central Asian countries. It accounts for a large portion of the GDP of Pakistan and a large chunk of the country's white-collar workers. Karachi's population has continued to grow. The current economic boom in Pakistan has also resulted in a new period of resurgence in the economy of Karachi [11].

Literature Review:

The swift urbanization worldwide, particularly in developing nations like India, raises significant concerns. Urbanization involves the irreversible loss of productive agricultural lands, forests, surface water bodies, and groundwater resources, primarily driven by unregulated population growth. This phenomenon gives rise to critical issues such as food scarcity, informal settlements, environmental pollution, disruption of ecological structures, and unemployment. The uncontrolled establishment of low-density human settlements of this nature ultimately results in urban sprawl. Characterized by a disorganized patchwork of development, urban sprawl signifies inadequate city planning, often stemming from the conversion of land use/land

cover. In this scenario, the expansion of urbanized areas significantly outpaces population growth within a defined timeframe, leading to the predominance of low-density impervious surfaces [12].

The phenomenon of urbanization has witnessed a substantial increase over the past two centuries. In 1800, only 2% of the global population resided in cities, a figure that surged to 12% by 1900. Recent research indicates a remarkable shift, with more than 50% of the world's population living in urban areas by 2008. Projections suggest that this percentage will further rise to 75% by the year 2030. It is anticipated that the global expansion of urban land use will encompass an additional 430,000 square kilometers, approximately the size of Iraq, by 2030. Despite urban land cover occupying a mere 2% to 3% of the Earth's surface, the consequences of urban growth are profound, manifesting in both socioeconomic and environmental challenges. Notably, the emergence of impervious surfaces resulting from urbanization significantly amplifies peak discharges during storm and snowmelt events, heightening the risk of downstream flooding as storm waters surpass stream channel capacities. The modification of surface materials also influences the reflection or absorption of solar radiation, inducing micro-climate changes through alterations in temperature and humidity. These changes contribute to the urban heat island phenomenon, impacting human health and comfort while elevating energy demands for cooling. Moreover, concentrated pollutants on urban surfaces degrade the biological, chemical, and physical attributes of lakes, streams, and estuaries that receive urban runoff, leading to modifications in aquatic and terrestrial habitats [13].

This article was authored by Martin Brockerhoff in 2000. This article aims to achieve two primary objectives: firstly, to critically examine the observed deceleration in urban growth across the developing world, as reported by the United Nations in recent years, at various levels of population aggregation—such as regions, countries, and cities. The goal is to determine whether this trend is universally prevalent in the South or if it is specific to certain areas and influenced by population size. Secondly, the article seeks to reassess the robustness of predictive models pertaining to city and urban growth that were formulated around 1980 by demographers and economists. Taking into account the urban population data available from the 1980- and 1990-round censuses, along with subsequent data that may capture changes in influential factors like economic conditions, this reexamination of models aims to identify the potential forces contributing to a recent slowdown in urban growth, if indeed such a phenomenon has occurred [14].

Methodology:

The objective of this study was to determine the urban footprint for the year 2002 to 2022 using remote sensing data and GIS, to figure out the extension of built-up land within 20 years (2002-2022). This research analyzed the spatiotemporal trend of informal urban built-up growth in the rapidly developing Karachi, Pakistan. A detailed research framework is designed to achieve the research objectives of collecting and analyzing the spatial data. The different methods of spatial data collection and analysis are widely discussed as follows.

Data Collection:

This study is an application of remote sensing and GIS in Urban Sprawl analysis. As recent as historical remote sensing data is freely available on the various websites. Further, using GIS on its remote sensing data for different analyses can be done efficiently and cost-effectively. For this study, the Landsat 7 ETM+ sensor cloud-free image of Karachi captured in 2002 and the Landsat 8 OLI sensor image captured in 2022 were acquired from the Landsat archives available at the USGS websites. In addition, the population data are extracted from the macrotrends, to highlight the time series trend of Karachi.

Data Processing:

The preprocessing was carried out for the development of AOI. Downloaded images of the study area were geometrically corrected and corrected and projected to the Universal

Transverse Mercator (UTM) projection system, zone 32. The spheroid and datum were referenced to WGS1984.

Data Analysis:

The **change detection** technique was adopted to assess the change in land use and land cover (LULC) of the study area. Collected and Processed Landsat 7 images from 2002 and Landsat 8 images from 2022 were used while the main focus was on build-up area changes. To extract the Urban built-up the more accurately supervised maximum likelihood classification was done. The **Maximum Likelihood Classification** is one of the supervised classification approaches for pattern recognition in which the probability of a pixel belonging to each of a predefined set of classes is calculated, and then the pixel is assigned to the class for which the probability is the highest [15].

By carefully observing the pattern in the image, it was concluded that the classification should be done for 4 classes i.e. Urban land, (including dense, green as well as sparse Urban Areas), Vegetation (including dense and sparse vegetation as the study area had a vast mangrove forest towards its south), Water bodies and open barren land. Maximum likelihood Classification was done on a natural color composite image (Band Combination 3, 2, 1) by training 10 samples of four classes distributed randomly in the image. Classes were identified by visual interpretation. From this, a thematic map of four classes was generated. The same procedure was applied to the other image (Figure 5).
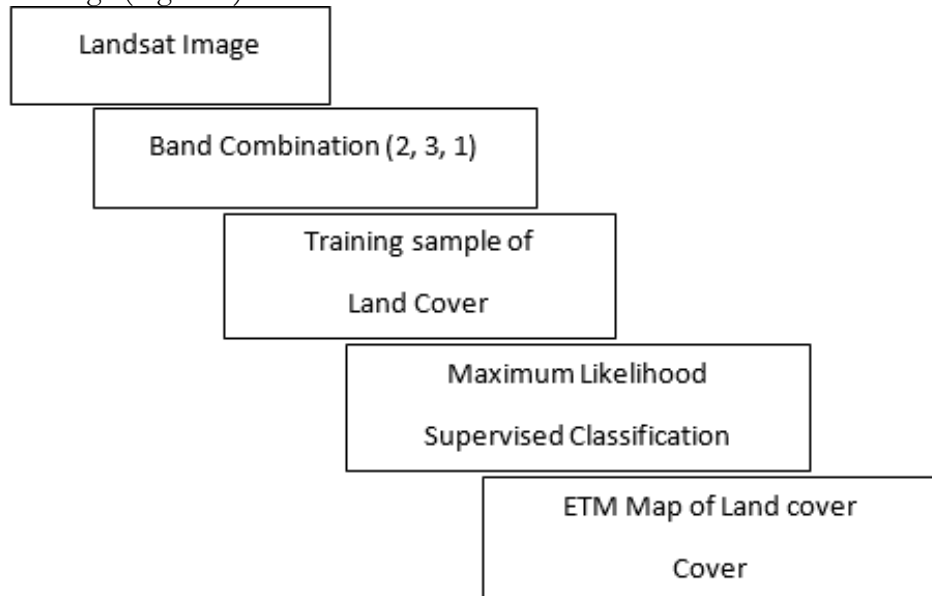
Figure 5: Methodological Framework to Extract LULC

Result and Discussions:

Due to its favorable geographical location, Karachi has always been a trade route for the merchants of the subcontinent, but it gained its importance under British rule. The development of perennial irrigation schemes by the British in Punjab and Sindh mainly accounted for the growth of Karachi along with the development of railways, making the quick transportation of agricultural material that in turn increased agricultural production which was exported through Karachi which made it the largest exporter of wheat and cotton to India [2].

In 1935, when Sindh separated from Bombay, Karachi became the capital of Sindh, Government offices and trade organizations were shifted from Bombay to Karachi. In 1947, Pakistan gained independence and Karachi became the first capital of Pakistan.

The data was extracted from macrotrends. From the below graph, we can see that the population of Karachi was 9.3 million in 1998, there is a tremendous increase of around 17.2 million in 2023 (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
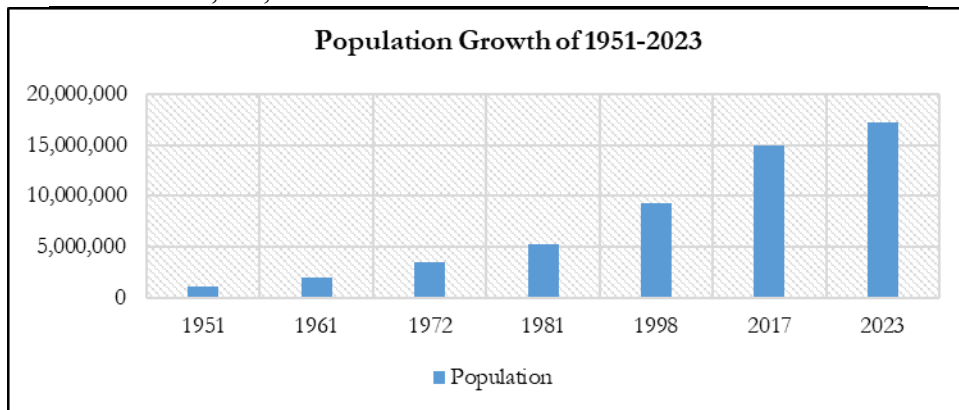
Figure 6: Population Growth of Karachi (1950-2023)

Notes: The author's own estimation by Excel sheet and data were extracted from macrotrends.

There was a significant increase of 161% from 1947-1951, because of the migration of 600,000 refugees from India. The settlement of those refugees was a challenge for the newly built local government. The refugees started to live on the periphery and within the city itself, as a result the government of Karachi totally changed not only demographically but also ethnically [15]. The responsibilities of higher authorities and lack of planning and strategy, the refugees unwillingly started to live in squatter settlements and katchi abadis. After 1985, five master plans were developed for the development of the city, but the implementation of those plans has always been an issue because of political instability within the country.

The Karachi city administratively is spread over an area of approximately 3,600 sq. Km. More than half of this area (approximately 2455.5 acres) consists of vacant land. The land cover feature, such as water and vegetation, changes throughout the year because it depends on climatic conditions at a particular time. The urban built-up area has extended from time to time. The reason behind this rapid increase in population within the city is the migration from interior Sindh, Punjab, and Khyber Pakhtunkhwa to find better opportunities in the mega city. There is a 100 square km decrease in open land from 50 sq. Km land is converted into built-up land.

The actual built-up land is 396 sq. Km but as per document figures by the City District Government of Karachi (CDGK) Karachi Strategic Development Plan 2020, the built-up land was 1300 sq. km. It was a combined built-up and developed open space. Developed open spaces are those housing societies that were initiated in the 1970s, 1980s, and 1990s, however, even after their infrastructure developed, they are vacant and hardly 5% occupied as shown in the below table.

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

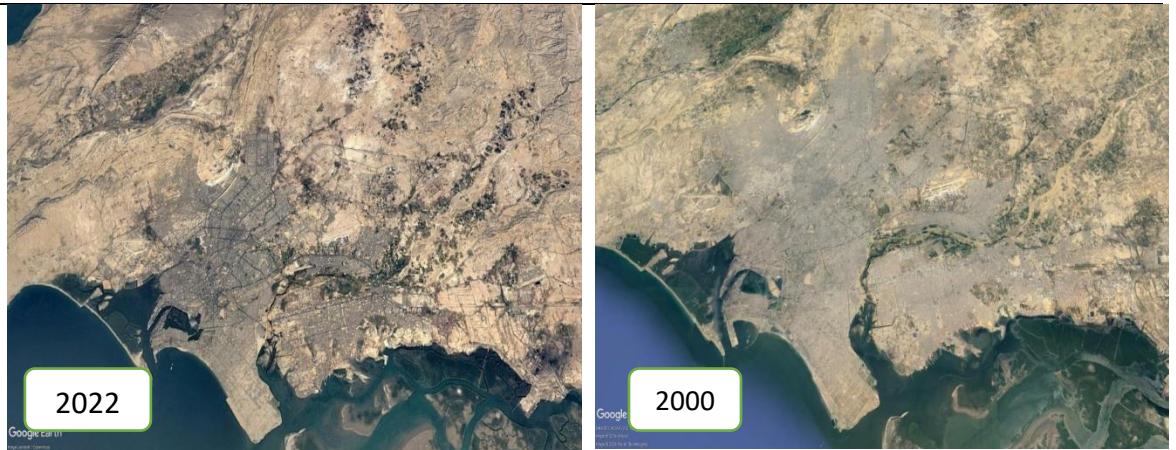| S. No.	Name of Scheme	Year of Notification	Current Occupancy Status (%)
1	Scheme No. 25-A	1980	5%
2	Scheme No. 33	1971	20%
3	Scheme No. 42	1983	5%
4	Scheme No. 43	1986	0%
5	Scheme No. 45	1986	5%

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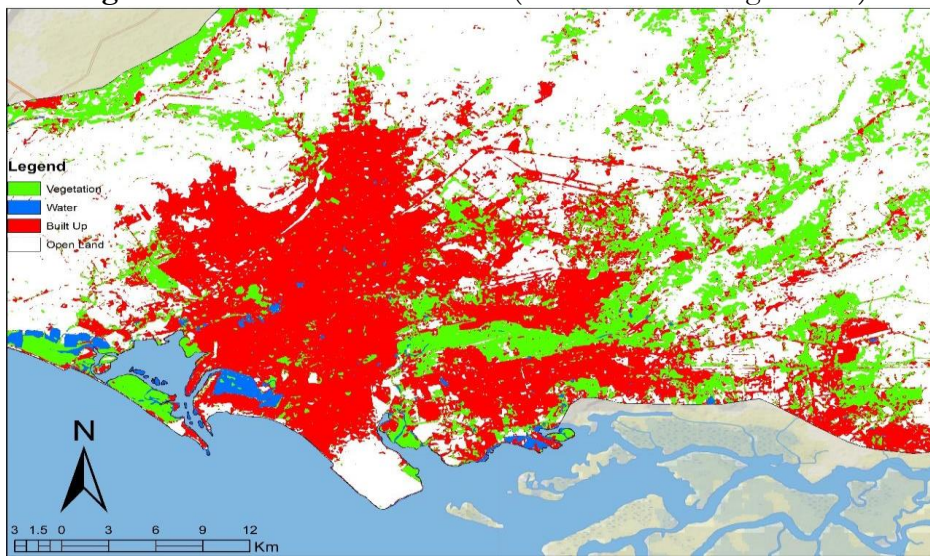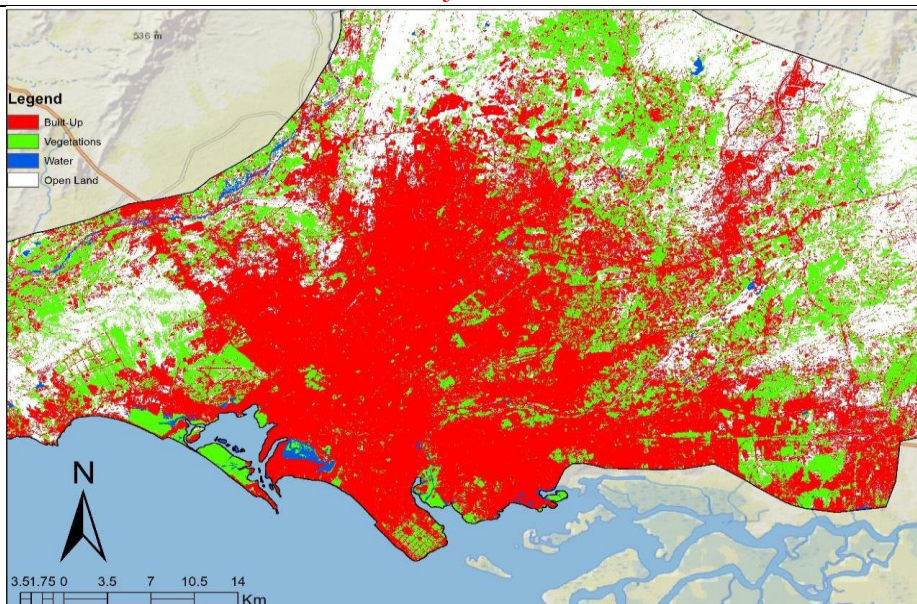

**Figure 8:** LULC Classification 2002 (Data Source: Landsat 7 ETM+, 2002)

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

From the below table, we can see that there is an 18.82% increase in built-up land and a 26.2% decrease in open land.

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

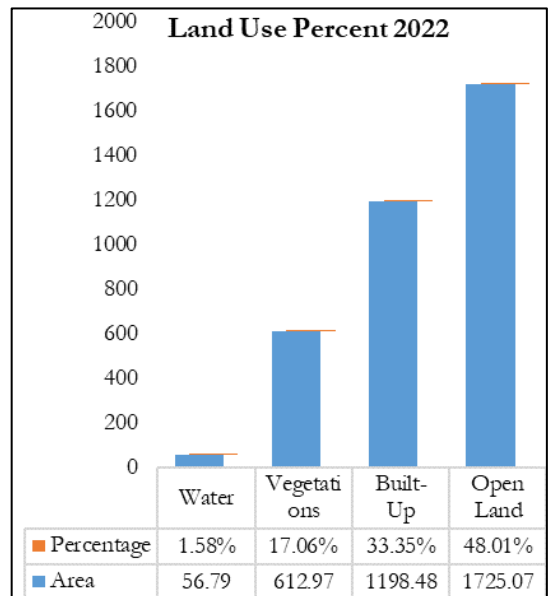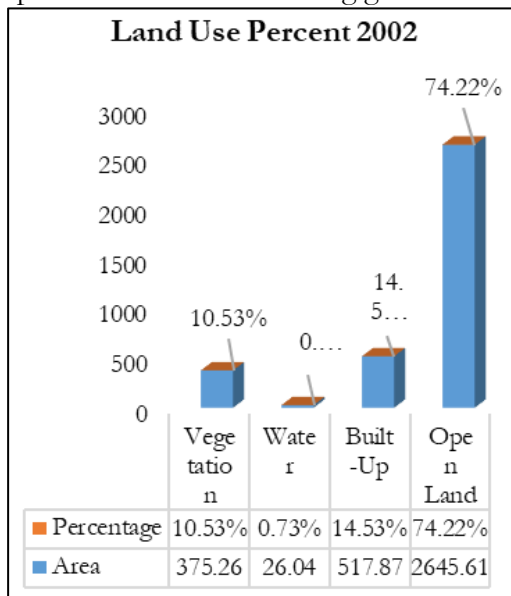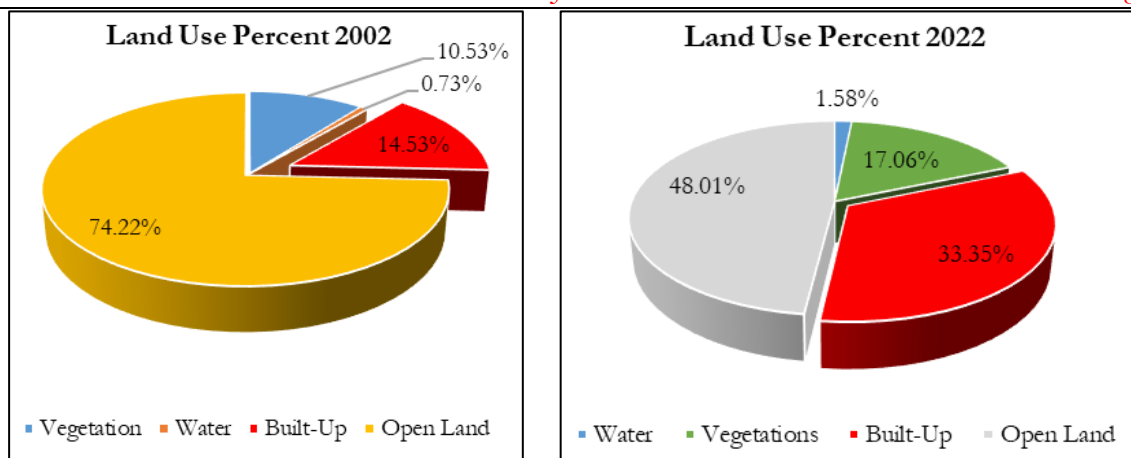| Class	Area (2002) Sq. Km	Area (2022) Sq. Km	Change Sq. Km	Change %
Water	26.04	56.79	30.00	0.85%
Vegetation	375.26	612.97	237.71	6.53%
Built-Up	517.87	1198.48	680.61	18.82%
Open Land	2645.61	1725.07	-920.54	-26.21%
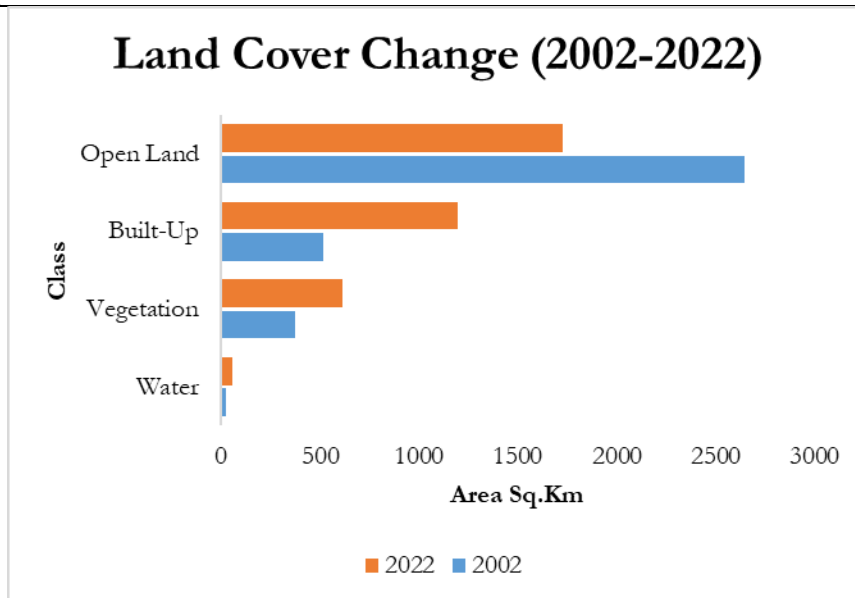
Figure 10: LULC Change (2002-2022)

The above figures reflect the dynamic analysis of the urban growth of Karachi city 2002 to 2022. In addition, we have selected the four most crucial factors of urban growth, these are respectively; vegetation, water, built-up, and open land. Furthermore, the pie charts indicate a significant variation in the selected variables from 2002 to 2022. Additionally, in 2002 open land had the highest share which is 74.22%, the second largest is built-up 14.53%, the third one is

vegetation, which shares 10.53% and the last one is water and its share is .73%. However, these percentages have changed in 2022 in contrast to 2002. The percentage of open land decreased significantly which is respectively 74.22% to 48.01% and the rest of the variables have increased. The built-up increased by 14.53% to 33.35%, vegetation increased 10.53% to 17.06% and water increased 0.73% to 1.58%. in addition, these statistical figures indicate a significant increase in urban growth and we have mentioned in the literature review section, where a number of empirical studies highlight that unplanned urban growth has a significant impact on the dynamics of various spectrums of the socioeconomic and political aspect of current as well as next generations.

The significant percentage decrease in the open land and other hand considerably increased the built-up, which has confirmed the urban sprawl. In addition, the total area built was in 2002, 517.87SQ-KM while the area has sharply increased 517.8787SQ-KM to 1198.4887SQ-KM and on the other hand, the open land has impulsively declined 2645.61SQ-KM to 1725.0787SQ-KM. These statistical figures affirm that there is an inverse relationship between urban sprawl and open land. There are a number of empirical and theoretical literature which have revealed that the increasing population leads to the demand for infrastructure thus the open land converts into cement jungle. The modern body of literature also accounts that the cement jungle is one of the deterministic factors of global warming; it has further expanded the number of issues such as socioeconomic, biodiversity, deforestation health, living standard, and political unsuitability of the current generation and also impacts on the coming generation. In addition, we should perceive effective consistent pre and post-policy measures to overcome and to protect current and coming generations.

Land Use Percent 2002

	Vegetation	Water	Built-Up	Open Land
Percentage	10.53%	0.73%	14.53%	74.22%
Area	375.26	26.04	517.87	2645.61

Land Use Percent 2022

	Water	Vegetations	Built-Up	Open Land
Percentage	1.58%	17.06%	33.35%	48.01%
Area	56.79	612.97	1198.48	1725.07

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

Conclusion and Recommendation:

The study of spatiotemporal changes in the urban growth of Karachi reveals that the urban growth of Karachi reaches more than 21 million and if we consider the total area of Karachi that is 3600 Sq.km, the population density is 5000 persons per square kilometer about 18.82% of its population has increased in last 20 years. However, the urban built-up area has extended from 517.87 Sq.km in 2002 to 1198.48 Sq.km in 2022 which is a change of 680.61 Sq.km in 20 years. It shows that the concrete expansion is increasing very rapidly. That results in the depletion of resources, degradation in environmental conditions, and lack of recreational areas within the city centers. All these factors produce bad impacts on the social, environmental, and economic conditions of the city and make it difficult to achieve sustainable development. This study was conducted to assess the condition of concrete expansion in Karachi which is an effective indicator; however, many other indicators can also be identified and assessed, by using the techniques of RS and GIS.

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