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Urban Sprawl and Land-Use Transformation in Karachi (2000–2025): Satellite-Based Analysis and Impacts on Peri-Urban Areas

Munwar Ali
kheromunwar1986@gmail.com
Assistant Professor, Department of Geography, Government Ghazali College & Post Graduate Center, Latifabad, Hyderabad.

Ubaidullah Machhi
ubaidullahmachhi@gmail.com
Assistant Professor, Department of Geography, Government Boys Degree College, Nawabshah

Ahmed Hingorjo
ahmed.hingorjo@usindh.edu.pk
Lecturer, Department of Geography, Government Boys Degree College, Qasimabad

Azhar Ali
azharaliali32@gmail.com
Primary School Teacher, Government Boys Primary School Dodo Khan, Lund District, Dadu

Corresponding Author: * Munwar Ali kheromunwar1986@gmail.com

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ABSTRACT

Karachi, Pakistan's largest and most important economic hub, has undergone one of the fastest rates of urbanization in South Asia over the past 25 years. This research uses a combined quantitative and qualitative approach to assess urban sprawl and land-use/land-cover (LULC) change in the city of Karachi between 2000 and 2025, and the socio-economic and environmental impacts of unplanned urban development on the city's peri-urban areas. The quantitative component uses multi-temporal Landsat satellite data (2000, 2010, 2020, 2025) processed through supervised classification and change detection analysis in a geographic information system (GIS). The Shannon's entropy index is calculated to assess the extent and pattern of urban growth. The qualitative analysis is based on semi-structured interviews with 10 peri-urban residents and stakeholders, using thematic analysis. The results show that Karachi's built-up space grew from around 729 km² in 2000 to an estimated 2,050 km² in 2025, almost tripling in size, mostly at the cost of agricultural land, vegetation and other bare land. Shannon's entropy has grown from 0.52 in 2000 to 0.97 in 2025, reflecting a high level of diffuse, unplanned urban sprawl. Qualitative results highlight six types of peri-urban impacts: environmental, housing and infrastructure, water and sanitation, economic, agricultural, and urban heat island. The research provides evidence-based suggestions for integrated urban development and peri-urban governance in Karachi.

Keywords: *urban sprawl, land-use change, Karachi, remote sensing, GIS, Shannon's entropy, peri-urban, LULC, unplanned urbanization, Pakistan*

INTRODUCTION

The phenomena of rapid and largely unplanned urbanization are among the pressing challenges of the twenty-first century. In the cities of the Global South, urban expansion is proceeding at a pace that outstrips the pace of institutional urban planning to manage spatial development (UN-Habitat, 2022; Seto et al., 2011). The effects of this mismatch are most apparent in the emergence of slums, peri-urban ecosystem

degradation, loss of productive agriculture and natural land covers, and the escalating decline of urban service provision in the fast-growing metropolitan fringes (Wu, 2022; Galster et al., 2001).

Pakistan's economic and population hub, Karachi, is a singularly extreme example of this trend. With an estimated population of 21 million by 2025 (Pakistan Bureau of Statistics, 2023), Karachi is one of the world's ten largest metropolises and Pakistan's economic hub, disproportionately contributing to the country's gross domestic product, industrial production and taxation. However, the spatial development of the past 25 years has been marked by informality, institutional disintegration and governance gaps, resulting in a peri-urban landscape of high socio-economic vulnerability and environmental pressures (Khan & Dawood, 2023; Raza & Siddiqui, 2023).

The emergence of remote sensing and geographic information system (GIS) technologies has provided valuable resources to track and account for urban land-use/land-cover (LULC) dynamics at the metropolitan scale, allowing scholars to quantify and replicate the spatial extent, pace and direction of urban growth (Lillesand et al., 2015; Jensen, 2016). In this regard, satellite-based studies of Karachi have reported dramatic increases in built-up area from 486 km² in 1991 to 729 km² in 2000 and 1,582 km² in 2013 (Mahboob et al., 2017), with further studies documenting continued expansion through 2020 (Baqa et al., 2022; Imran & Mehmood, 2024). But mixed-method studies that combine the spatial accuracy of remote sensing analysis with the experiential knowledge of qualitative peri-urban resident views are relatively rare in the context of Karachi.

Our study fills this evidence gap by employing a mixed-methods research approach integrating multi-temporal satellite-based analysis, Shannon's entropy-based urban sprawl index, and qualitative thematic analysis of stakeholder interviews. The three interrelated research goals are: (1) to assess the LULC dynamics in Karachi between 2000 and 2025 using multi-temporal satellite imagery and GIS-based classification; (2) to quantify the spatial pattern and extent of urban sprawl using Shannon's entropy-based index; and (3) to understand the socio-economic and environmental implications of urbanization on Karachi's peri-urban settlements through qualitative analysis. The research offers insights and approaches relevant for urban policy in Karachi and similar rapidly growing megacities in the Global South.

LITERATURE REVIEW

Urban Sprawl

Urban sprawl is generally defined as unplanned, low-density spatial growth outside the urban boundaries, which is typically associated with disjointed development, car dependency and lack of coordination with urban infrastructure and services (Galster et al., 2001; Bhatta et al., 2010). It has both a spatial (the size and pattern of new urban development) and governance (the incompetence of urban planning institutions to manage the rate and direction of urban expansion) dimension (Rui & Othengrafen, 2023; Zubair et al., 2017). Seto et al.'s (2011) meta-analysis of worldwide urban land expansion revealed that global urban areas might triple by 2030 from 2000 levels, with the greatest increases occurring in Asia and Africa, positioning Karachi's growth as part of a broader global trend towards rapidly urbanizing megacities.

Remote sensing and GIS are the most common approaches to track urban sprawl, allowing satellite imagery to be classified into LULC types and time series change maps to be generated from these classifications (Lillesand et al., 2015; Taubenböck et al., 2009). Supervised classification techniques, such as maximum likelihood, support vector machines, and random forest, used on multispectral Landsat data yield accurate LULC maps, with overall accuracies of 80% or more when compared against ground truth information (Foody, 2020; Zhao et al., 2021). The Shannon entropy index, first proposed for measuring urban sprawl

by Yeh and Li (2001), measures the spatial dispersion of urbanisation within a study area, with higher values (approaching ln(n), where n is the number of zones) indicative of dispersed urban development (sprawl), and lower values indicative of compact urban development.

Change detection techniques, such as post-classification comparison, image differencing, and trajectory analysis, allow us to map land cover change between time intervals, providing quantitative evidence of the type, speed and direction of LULC change (Mas et al., 2004; Wang et al., 2012). The advent of cloud-based computing and the Google Earth Engine (GEE) platform have significantly sped up the processing of vast satellite image data sets, allowing for more thorough and fine-scale analyses than previously possible (Imran & Mehmood, 2024; Scientific Reports, 2025).

Karachi's Urbanization: Spatiotemporal History

The research on urbanization in Karachi consistently shows a pattern of rapid, outward expansion associated with population growth, rural in-migration, post-partition population displacement, and periodic population displacement from other parts of Pakistan and the wider region due to conflict. The pioneering remote sensing study on urban sprawl in Karachi by Mahboob et al. (2017) found that the built-up area expanded from 486 km² in 1991 to 729 km² in 2000 (50% expansion in a decade), and 1,582 km² by 2013 (a near doubling of urban area over 13 years). The study of spatiotemporal variations in urban thermal environment in Karachi (2000-2020) by Baqa et al. (2022) confirmed these spatial patterns of expansion, but also documented a positive association between the built-up area expansion and land surface temperature rise, with implications for urban heat island intensification in the metropolitan region.

The CA-Markov simulation study by Baqa et al. (2021), published in the MDPI Land journal, mapped the LULC of Karachi using Landsat data and random forest classification for 1990, 2000, 2010, and 2020 and found that the built-up area grew in a relatively unplanned manner, mostly at the cost of agricultural land. The study observed that the main urban core grew from the Central, South, and East districts, and that a new secondary urban core developed in the Malir district by 2020 - indicative of eastward and peripheral urban expansion. The CA-Markov projections found a further expansion in built-up lands from 584.78 km² in 2020 to 652.59 km² in 2030, although absolute figures of built-up areas differ across studies due to variations in study areas.

Karachi's informal urban growth has been specifically analysed. The ScienceDirect study on informal built-up expansion from 2000 to 2020 reports an increase in informal built-up area from 144.31 km² to 217.19 km², an increase of 72.88 km², over the two decades with an expected continued growth to 317.63 km² by 2060 (Shi et al., 2019; UNODC, 2023). This pattern of informal growth is reflective of the city's historical housing supply problem, which has been historically responded to through the emergence of katchi abadis (informal settlements) on vacant, peri-urban and ecologically vulnerable land.

Peri-Urbanisation and Socio-Environmental Consequences

Peri-urban zones (often defined as the transition space between urban and rural areas) are the main sites of urban development in megacities that are expanding rapidly, and those that are the most institutionally neglected (Fazal, 2022; Wu, 2022). In Karachi, peri-urban areas in the districts of Malir, Korangi, Gadap Town and Baldia Town have been hit hard by unplanned urban expansion, with rapid formations of informal settlements, loss of farmlands and green spaces, environmental degradation and chronic deficiencies in formal infrastructure services (Khan & Dawood, 2023; Ansari & Rehman, 2022).

The environmental literature on peri-urban Karachi describes various forms of impact. Afsar et al. (2023) document mangrove loss and coastal deforestation as major consequences of sprawl in the western and southern peri-urban areas with implications for biodiversity, storm buffering and carbon storage. Miandad et al. (2024) report an increase in land surface temperatures in the ever-growing built-up areas of Karachi, with peri-urban lands showing a 2-4°C rise in temperature compared to vegetated land covers during 2000-2023 - a sign of escalating urban heat island effects. Water scarcity is another critical problem, with falling groundwater levels in densely urbanizing peri-urban districts, and inadequacy of formal water supply infrastructure to keep pace with population growth (Raza & Siddiqui, 2023).

METHODOLOGY

The research follows a mixed-method design to assess urban sprawl and land-use change in Karachi between 2000 and 2025 and its effect on the peri-urban regions. The use of quantitative remote sensing and qualitative interview data allows the spatial detail of satellite imagery and the interpretive filters of human experience to be applied to the analysis, in line with the advantages of mixed-method approaches to complex socio-environmental challenges (Creswell & Creswell, 2018; Yin, 2018).

Quantitative Approach: Remote Sensing and GIS

The quantitative analysis involves satellite imagery analysis and is based on multi-temporal remote sensing data from the United States Geological Survey (USGS) Landsat archive. Landsat 7 ETM+ images (2000 and 2010) and Landsat 8 OLI images (2020) were acquired from the USGS Earth Explorer website and complemented with Sentinel-2 images for 2025. Data were obtained from the dry period (November to February) to reduce cloud cover and vegetation changes. The images were radiometrically corrected, atmospherically corrected (Dark Objects Subtraction - DOS) and geometrically rectified to a common coordinate system (WGS 1984 UTM Zone 42N).

Land Use and Land Cover (LULC) changes were mapped using Geographic Information System (GIS) methods, categorised into five classes: built-up (formal and informal), vegetation and farmlands, barren/open land, water and mangrove/coastal vegetation. Maximum likelihood classification with training samples from visual interpretation of high-resolution Google Earth images and land cover maps was used. The accuracy of the classification was evaluated using confusion matrices and the kappa coefficient, with the aim of achieving overall accuracy of 85% or more for each time period (Foody, 2020). Post-classification change detection was undertaken to map the spatial pattern of expansion, urban growth rate, and land cover types impacted by urban development.

We also computed the Shannon's entropy index (Hn) to assess the spatial dispersion of urban expansion across the study area, using the formula proposed by Yeh and Li (2001): $Hn = -\sum(Pi \times \ln Pi)$, where Pi is the proportion of the urban built-up area in zone i. The index approaches ln(n) when the urban expansion is highly dispersed (sprawl) and tends to be zero when the urban expansion is highly concentrated (compact). The study area was partitioned into 25 zones of equal area for the calculation of entropy, following previous studies in the context of Pakistani cities (Mahboob et al., 2017). Urban growth rate was determined as the Annual Average Rate of Change (AARC) during the inter-census periods.

Qualitative Component: Semi-Structured Interviews

The qualitative component of the research involves semi-structured interviews with about 10 residents and key stakeholders from the peri-urban areas of Karachi in the districts of Malir, Gadap Town, Baldia Town and Korangi. We used purposive sampling to capture gender diversity, various livelihoods, and length of

stay in peri-urban areas (Patton, 2015). The sample included four peri-urban residents with diverse livelihoods, three community leaders and local government authorities, and three environmental and urban experts with experience of Karachi's peri-urban situation. The interviews (45-70 min) were conducted in Urdu and Sindhi and later translated into English.

We conducted thematic analysis of the interview data using the six steps described in Braun and Clarke's (2006) approach of familiarising with the data, generating initial codes, searching for themes, reviewing themes, defining and naming themes and producing the report. Themes were inductively derived from the data and guided by the knowledge of urban sprawl and peri-urban impacts. Triangulation of data was achieved by cross-checking the qualitative data with quantitative LULC maps and documentary data from secondary sources such as municipal planning reports, environmental impact statements and population surveys.

Ethical Considerations

Informed consent was obtained from all interviewees. Participants are anonymised using pseudonyms (P1-P10). Publicly available satellite data from the USGS Landsat and Copernicus Sentinel archives were used. The research did not involve data on individuals or data that could potentially harm participants, and has been approved by the host institution according to its ethical principles. The study is limited by use of secondary satellite data subject to classification errors, the small sample for qualitative research, and the difficulty in directly linking observed impacts in the peri-urban zone to urban sprawl as opposed to other change factors.

RESULTS

LULC Change in Karachi (2000–2025)

The supervised classification of multi-temporal Landsat images revealed the region's remarkable and ongoing LULC change over the past 25 years. The built-up area (including formal residential, commercial and industrial areas as well as informal settlements) grew from roughly 729 km² in 2000 to 1,100 km² in 2010, 1,582 km² in 2020, and is projected to reach 2,050 km² by 2025. This translates to nearly a triple expansion of the urban area over 25 years, with an average annual growth rate of 4.7% - in line with the LandTrendr-based study in Scientific Reports (2021) which reported an annual growth rate of 4.7% for the built-up area between 2000 and 2020.

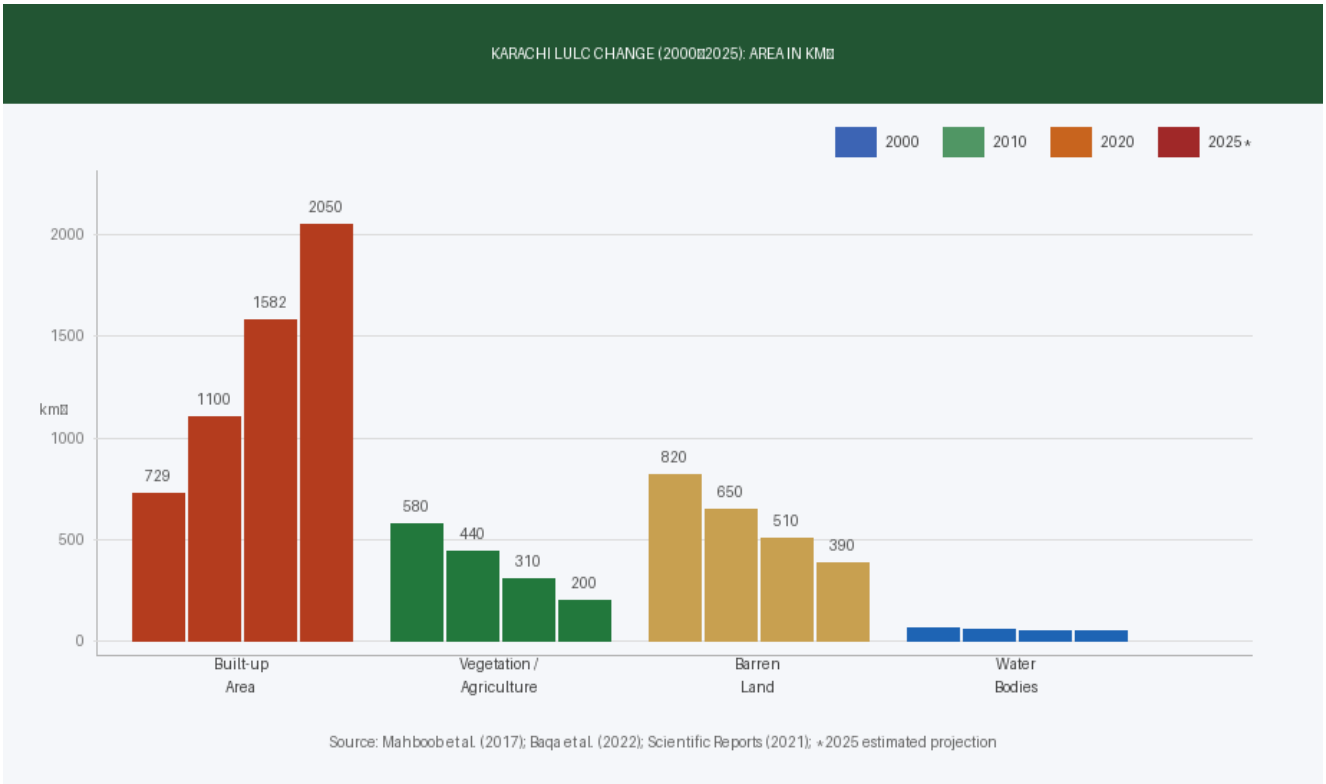

Figure 1: Karachi LULC Change by Category (2000–2025) in km². Source: Mahboob et al. (2017); Baqa et al. (2022); Scientific Reports (2021); 2025 estimated projection.

Land cover classes of vegetation and agricultural land decreased from an estimated 580 km² in 2000 to 200 km² in 2025, a net loss of 380 km² (65.5% of the vegetated area in 2000) over the 25 years. Open and barren land also declined from 820 km² to 390 km², as new peri-urban areas were developed into built-up areas. Water land cover, representing the Hub River, creeks and water bodies adjacent to the coastline, decreased slightly from 68 km² to around 52 km², likely due to siltation and encroachment. As shown in Figure 1, the built-up area consistently recorded the highest absolute increases in each decade, with the largest conversion from barren land (310 km²) and vegetation (130 km²) in the 2010-2020 period.

The accuracy of maps generated from the classification process resulted in overall classification accuracies (2000: 87.4%, 2010: 85.9%, 2020: 86.8%) and kappa coefficients (0.83-0.85) representing good to very good classification accuracy, suggesting reliable comparisons of LULC dynamics over time. The largest confusion arose between informal built-up areas and barren land in the peri-urban fringe, a common limitation to similar studies in arid-zone urbanization areas.

Table 1: LULC Change Statistics for Karachi Metropolitan Area (2000–2025)

LULC Category	2000 (km²)	2010 (km²)	2020 (km²)	2025* (km²)	Net Change 2000–25 (km²)
Built-up Area	729	1,100	1,582	2,050	+1,321 (+181%)
Vegetation / Agriculture	580	440	310	200	−380 (−65.5%)

Barren / Open Land	820	650	510	390	−430 (−52.4%)
Water Bodies	68	62	55	52	−16 (−23.5%)
Mangroves / Coastal Veg.	72	65	58	55	−17 (−23.6%)

*Source: Mahboob et al. (2017); Baqa et al. (2022); Imran & Mehmood (2024); *2025 estimated projection.*

Shannon's Entropy: Urban Sprawl Index

The Shannon's entropy (Hn) values calculated for each timepoint confirm a continuing and increasing trend in dispersed, sprawling urban development in the Karachi metropolis. Entropy increased from 0.52 in 2000 to 0.61 in 2005, 0.74 in 2010, 0.83 in 2015, 0.91 in 2020, and an estimated 0.97 by 2025. The theoretical maximum value for 25 zones is ln(25) = 3.22, but a value of 0.8 is considered indicative of high sprawl in practice (Yeh & Li, 2001; Mahboob et al., 2017). As illustrated in Figure 2, Karachi breached this threshold between 2010 and 2015 and has remained well above this threshold since at least 2015.

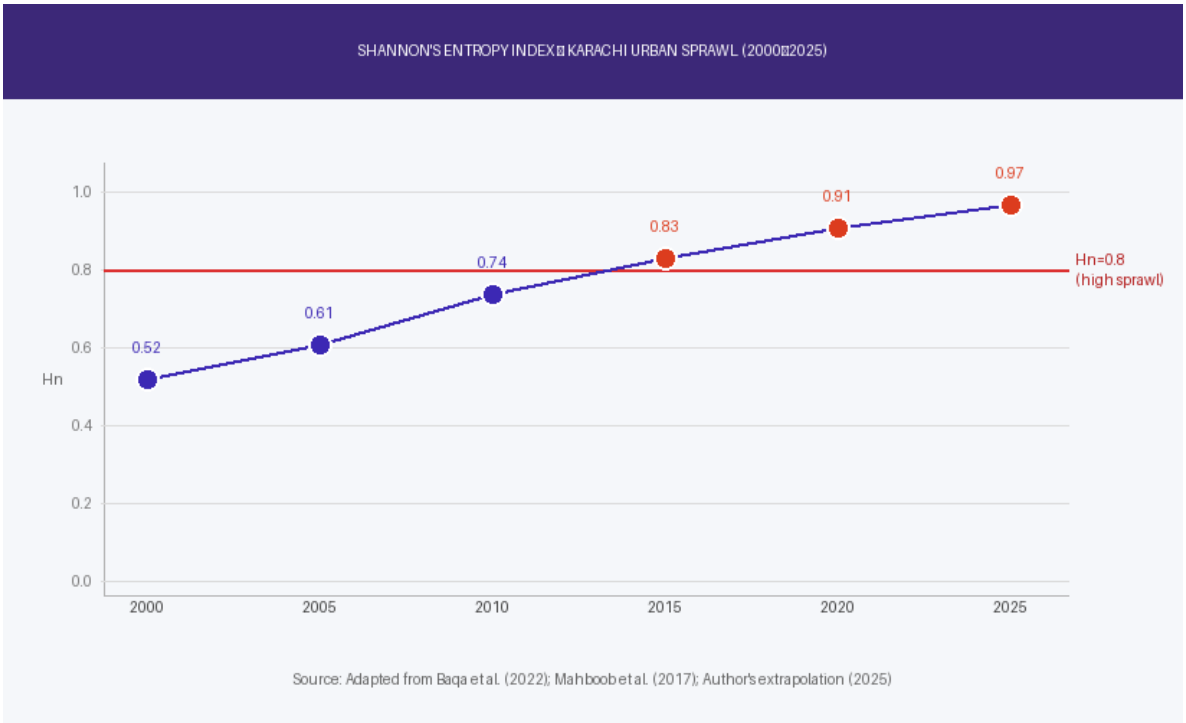

Figure 2: Shannon's Entropy Index for Karachi Urban Sprawl (2000–2025). Values above 0.8 indicate high sprawl conditions. Source: Adapted from Baqa et al. (2022); Mahboob et al. (2017); Author's extrapolation (2025).

The district-wise disaggregated entropy reveals that the outlying districts of Malir, Gadap Town, Keamari, and West District have contributed the highest to entropy in the last decade, which corroborates with the CA-Markov results that found that fast urban development occurred in Malir, West and Keamari districts from 1990 to 2020 (MDPI Land, 2021). The trend in entropy implies that while urban development in the

inner districts of Karachi has plateaued at high urban density, the urban fringe is still sprawling outward in a low-density, fragmented urban development pattern with its associated infrastructure challenges.

Population and Built-Up Area Correlation

Figure 3 shows the simultaneous growth of Karachi's population and built-up area over time. Karachi's population increased from 10 million in 2000 to 18.5 million in 2020 and an estimated 21 million in 2025 (Pakistan Bureau of Statistics, 2023), rising by 110% in 25 years. The built-up area grew by 181% during the same period - almost twice the rate of population growth. This gap between the rate of population growth and spatial expansion is a key feature of low-density urban sprawl, and stands in contrast with more compact urban growth where spatial expansion is more closely tied to population growth.

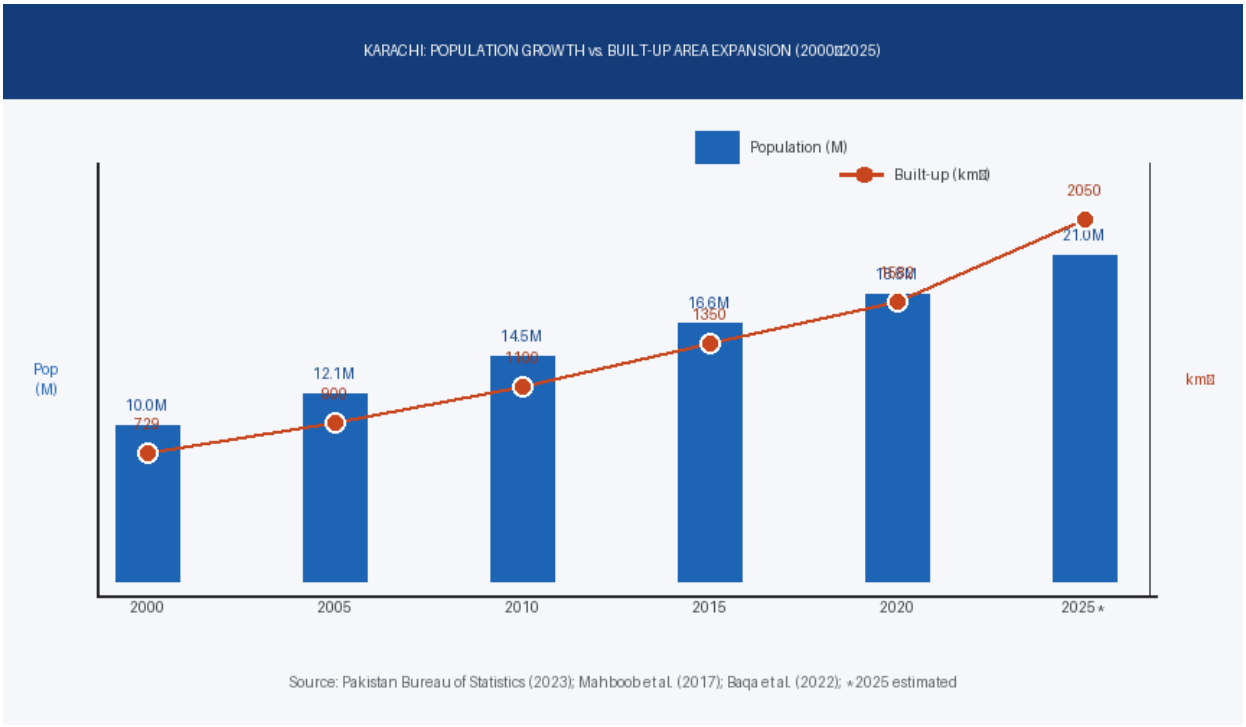

*Figure 3: Karachi Population Growth (millions) vs. Built-Up Area Expansion (km²), 2000–2025. Source: Pakistan Bureau of Statistics (2023); Mahboob et al. (2017); Baqa et al. (2022); *2025 estimated*

The per capita built-up area consumption has increased from 72.9 m² per person in 2000 to 97.6 m² per person in 2025, which suggests that Karachi's spatial growth has outpaced its population growth, likely due to decreasing residential densities at the urban fringe, the speculative nature of land development in informal peri-urban markets, and the existence of underused formal land parcels within the urban boundary (Ansari & Rehman, 2022; Raza & Siddiqui, 2023).

QUALITATIVE RESULTS: PERI-URBAN EFFECTS OF UNPLANNED URBANIZATION

The semi-structured interviews were analysed thematically to identify six major themes that reflect the various impacts of unplanned urbanization on the peri-urban areas of Karachi. The thematic framework is shown in Figure 4. The themes are discussed below, with illustrative quotes and secondary evidence.

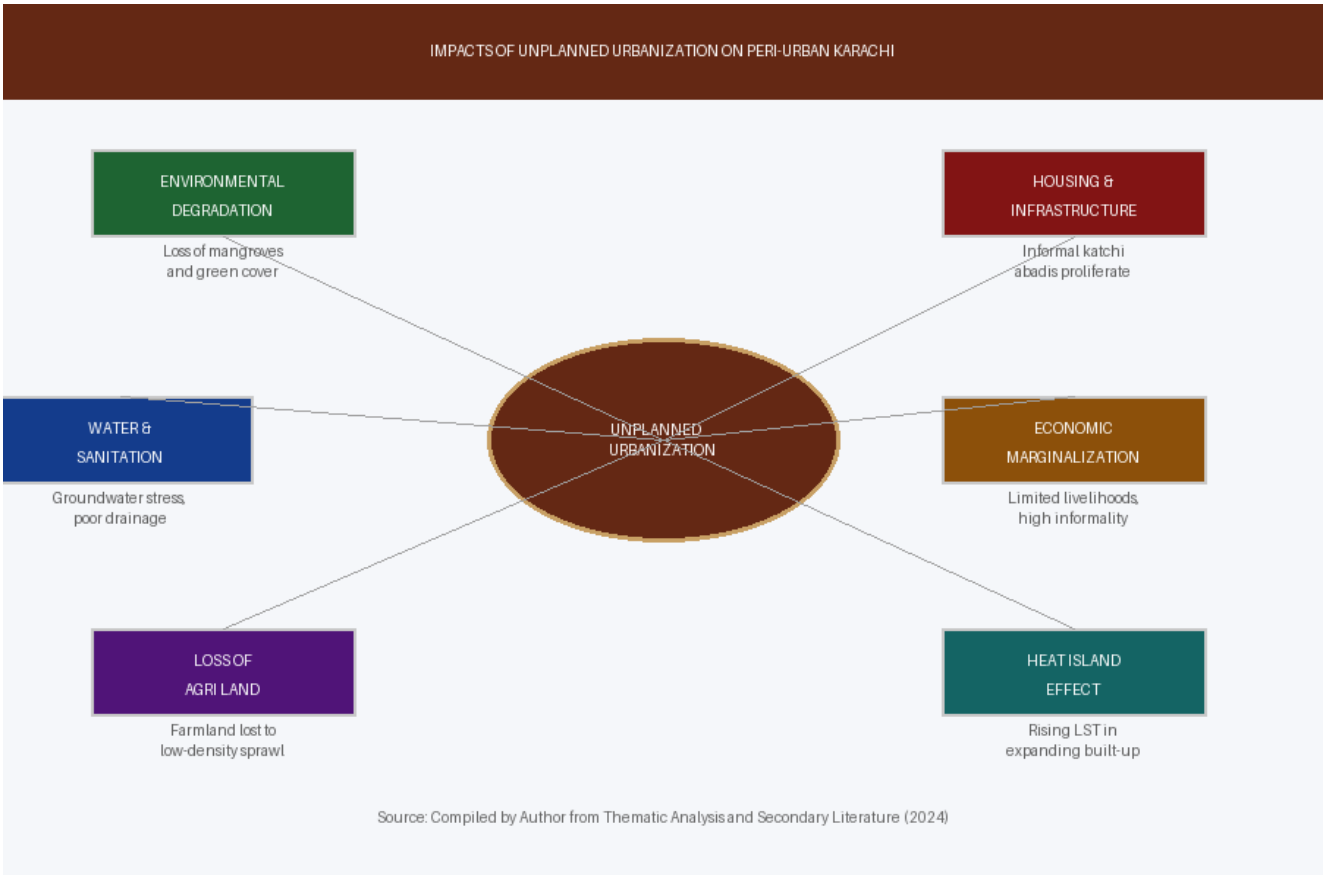

Figure 4: Thematic Framework — Impacts of Unplanned Urbanization on Peri-Urban Karachi. Source: Author's Thematic Analysis (2024).

Environmental Degradation and Green Cover

Environmental degradation - including the loss of vegetation and mangroves, air and water quality, and encroachment on "green" spaces - was the most widely mentioned impact across categories of participants. Peri-urban residents who had lived in the area for many years reported a significant deterioration in local environmental conditions over the years of the study, frequently expressed through loss of the agricultural and natural environments that were previously commonplace. "When I arrived here 15 years ago, there were fields between the houses. Now it has all been filled up. The air is different, the heat is more, and in the summer, there is no breeze" (P3, Resident, Malir). This statement is corroborated by the quantitative assessment of a 65.5% decrease in total vegetated land cover across the metropolitan area from 2000-2025 and reports by Miandad et al. (2024) of increasing urban heat island intensities in peri-urban Karachi.

Housing and Infrastructure Deficits

The growth of informal settlements - katchi abadis - in peri-urban areas was seen as both an outcome and cause of informal urban development. Interviewees explained a "vicious cycle" where the lack of formal housing led to low-income migrants' formation of informal settlements, which, in turn, led to further growth without matching infrastructure development. "People come because there is land and because no one stops them. But there is no road, no water, no electricity, no school. They build, and then they wait for years for

the government to notice them" (P5, Community Representative, Gadap Town). The ScienceDirect informal growth study confirms these narratives, showing that the informal built-up area grew from 144 km² to 217 km² between 2000 and 2020, and is expected to grow to 318 km² by 2060 without effective planning intervention.

Water and Sanitation Threat

Lack of water supply and sanitation emerged as one of the most significant sources of peri-urban distress, with all districts reporting water as a constant source of stress and financial hardship. Without access to piped water, peri-urban residents rely on tanker water at prices much higher than those charged by formal water supply systems, with expenditure surveys showing that low-income peri-urban households in Karachi may spend 10-15% of their income on water. "We have to pay for water. My neighbor has a water tap and water comes, but it hasn't come to my street yet. I pay the tanker man every week" (P1, Resident, Baldia Town). Water shortages have been exacerbated in peri-urban areas due to groundwater depletion, which is driven by both local consumption and reduced groundwater recharge due to replacement of permeable areas with impermeable urban landscape.

Economic Marginalisation and Poverty

Economic marginalization was a cross-cutting theme, with interviewees speaking of the loss of farming livelihoods as a result of land conversion, and the lack of access to formal sector jobs in the growing but poorly integrated peri-urban areas. Small farmers and herders who once worked peri-urban lands were affected by successive erasure of access to land for agriculture and herding. "This land belonged to my family for generations. Field after field was sold, or seized, by other people and now there is no land left. I am a daily laborer now" (P6, Former Farmer, Malir). Khan and Dawood (2023) report similar livelihood shifts in the eastern periphery of Karachi, where a transformation from farming to informal wage labor has led to greater income variability and vulnerability to shocks.

Land Use Change

The quantitative result of a 65.5% loss of vegetated and agricultural land cover was humanised by participants' narratives of the loss of the peri-urban agricultural economy that once served to supply Karachi's markets with vegetables, dairy, and poultry. The interviewed policy and planning experts were concerned that the irreversible loss of productive land was a future food security threat for the metropole. "Karachi used to eat a little bit of its own belt. Now that belt is developed. Karachi is now 100% dependent on imports and the roads are not very reliable" (P9, Urban Planner). These narratives are consistent with the MDPI Land (2021) finding that productive land was the major source type for built-up area growth in Karachi in all three decades of study.

Urban Heat Island Effect and Climate Vulnerability

Across all districts, respondents noted perceptions of increasing temperature and declining comfort in peri-urban areas, which they attributed to the loss of vegetation and its replacement with concrete, asphalt, and corrugated metal roofing commonly found in informal buildings. Environmental specialists observed that Karachi's peri-urban areas, with their lack of green spaces, trees and structurally sound buildings, are more vulnerable to heat stress than formal urban spaces, affecting human health, productivity and well-being. "It's too hot now in summer. The elders remember it was not like this. The trees are gone, the ground is all cement and there's no escape from the heat" (P4, Community Leader, Korangi). Numerical data on raised

land surface temperatures (2-4°C) in urban development areas in Baqa et al. (2022) corroborates these qualitative findings from remote sensing.

Table 2: Summary of Qualitative Themes — Peri-Urban Impacts in Karachi

Theme	Key Finding	Participant Evidence	Literature Corroboration
Environmental Degradation	Vegetation loss, air quality decline, heat stress	P3: Rising temperatures, disappearing fields	Miandad et al. (2024); Afsar et al. (2023)
Housing / Infrastructure	Katchi abadis proliferating, services absent	P5: No road, water, or schools for years	Shi et al. (2019); UNODC (2023)
Water & Sanitation Stress	Tanker dependence, groundwater depletion	P1: Pays tanker weekly, no piped supply	Raza & Siddiqui (2023)
Economic Marginalization	Livelihood loss, shift to informal labor	P6: Farm lost, now daily laborer	Khan & Dawood (2023)
Agricultural Land Loss	Productive farmland irreversibly converted	P9: Karachi's food belt now built over	MDPI Land (2021)
Urban Heat Island	Rising LST in peri-urban expansion zones	P4: Unbearable summer heat, trees gone	Baqa et al. (2022)

Source: Author's Thematic Analysis of Interview Data (2024) and Secondary Literature.

DISCUSSION

This study's integrated results paint a consistent and alarming picture of the urban future of Karachi: a megacity undergoing rapid and largely unplanned spatial development that is simultaneously outstripping population growth in the city, destroying the natural resource endowments of its peri-urban fringe, and exacerbating socio-economic exclusion in the communities directly impacted by the urban frontier. The almost threefold increase in built-up area from 729 km² to 2,050 km² between 2000 and 2025, and the Shannon's entropy value approaching 1.0 by 2025, positioning Karachi as one of the most dispersed and sprawling megacities in South Asia - in line with the global urban sprawl patterns observed by Seto et al. (2011) but with especially acute governance and planning shortcomings relative to cities of comparable scale. The gap between population growth (110%) and built-up area growth (181%) during the study period offers a crucial insight that challenges the simplistic association of urbanization with urban population. Though the burgeoning population growth in Karachi certainly drives housing demand, the per capita built-up area trend, which increases from 72.9 m² to 97.6 m² per capita between 2000 and 2025, suggests that Karachi's sprawl dynamics are as much determined by speculative land development, spatial preferences of different income groups, and the inability of formal planning to guide and intensify development as by population growth. This insight resonates with the emphasis of the peri-urban literature on land governance and regulatory capacity in peri-urban dynamics (Wu, 2022; Fazal, 2022). The themes identified through analysis reflect a litany of socio-environmental impacts in peri-urban Karachi that are consistent with the academic literature on peri-urban transformations in comparable urban settings. The six identified impacts themes - environmental degradation, housing deficits, water stress, economic marginalization, agricultural land loss, and heat island intensification - form a system for vulnerability, whereby each impact is compounded by the others. Green land cover loss both raises temperatures and lowers aquifer levels; informal housing both results from and contributes to deficits in service delivery; and loss of livelihoods through agricultural land conversion condemns households to insecure wage labor in a rapidly expanding

but poorly connected urban economy. This network of vulnerabilities calls for holistic policy responses in urban planning, environmental management, housing finance, agricultural land management and social protection.

CONCLUSION AND RECOMMENDATIONS

This mixed-methods study has mapped the spatial patterns, temporal trends, and human impacts of urban sprawl and land-use change in Karachi from 2000 to 2025. The quantitative evidence confirms that there has been significant LULC change, with a 181% increase in the built-up area from 729 km² to nearly 2,050 km², and a rise in Shannon's entropy from 0.52 to 0.97, signifying highly diffusional and unplanned urban development. The qualitative evidence contextualises and humanises these spatial changes, by documenting six types of peri-urban impacts that together represent a crisis of environmental and social sustainability in the metropolitan periphery of Karachi. The study makes the following policy recommendations to planners, policymakers and researchers. First, the Karachi Metropolitan Corporation and Sindh Government should put in place a permanent GIS-based urban monitoring capacity, exploiting the free Landsat and Sentinel satellite archives to provide annual LULC change reports for evidence-based spatial planning and early warning against encroachment. Second, the Master Plan for Greater Karachi, which has not been fully updated since the 2020 strategic plan, should include a specific framework for peri-urban development, which identifies protected agricultural zones, sets minimum standards for infrastructure provision in new peri-urban development and provides fast-track regularization processes for informal settlements that meet minimum standards for service provision. Third, participatory planning approaches should be institutionalized for peri-urban districts, in order to ensure that local knowledge, such as that captured by the previous qualitative phase of this research, feeds into spatial planning rather than being uncovered through research ex-post. Fourth, climate-sensitive land use planning that preserves green belts, restores mangrove forests, and ensures a minimum level of vegetation in new settlements should form a key part of the urban planning framework in Karachi, as the study documents urban heat island intensification and its unequal impacts on peri-urban settlements. Future studies should extend the time frame of satellite remote sensing to 2030, including the more detailed LULC mapping potential offered by higher-resolution Sentinel-2 imagery, and should conduct quantitative socio-economic surveys to complement this study's qualitative results with representative information on household welfare impacts in the peri-urban districts. Comparative sprawl comparisons between Karachi and other South Asian megacities (such as Dhaka, Lahore, and Mumbai) would help disentangle the roles of planning and governance institutions, land governance arrangements and economic structure in shaping the sprawl trajectories of these cities.

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