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Accelerating Urban Sprawl and Its Encroachment on Agricultural Land: A Two-Decade Geospatial Assessment of Dera Ismail Khan City, Pakistan

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ABSTRACT

Urban sprawl poses a major challenge worldwide, affecting land use patterns, food security, and long-term sustainable development. This research examines the spatiotemporal dynamics of urban expansion and its implications for farmland in Dera Ismail Khan (D-I Khan), a rapidly growing medium-sized city in northwestern Pakistan. Using Remote Sensing and Geographic Information Systems, land cover transformations were mapped across three periods, 2004, 2014, and 2024, through supervised classification of Landsat satellite images of 30m and 15m resolution. The study identifies population growth, large-scale influx of internally displaced people following military operations such as Zarb-e-Azb, and the development of the Chashma Right Bank Canal irrigation scheme as primary forces behind urban expansion. Over the 20 years, built-up areas rose dramatically from 24.44% (1,590.15 ha) in 2004 to 45.64% (2,969.1 ha) in 2024, with the annual expansion rate accelerating to 6.18% after 2014. Concurrently, irrigated agricultural land nearly doubled, increasing from 16.51% (1,051.04 ha) to 31.73% (2,064.07 ha), whereas barren land declined sharply by 58.71%. Skyrocketing property values in the city centre, rising 15 to 30-fold, further reflect intense pressure on land resources. These findings highlight the complex interplay between conflict-induced migration, infrastructure projects, and unchecked urbanisation. This study emphasises the critical need for coordinated spatial planning to curb sprawl, protect productive farmland, and promote environmentally sound urban growth in similar developing regions.

Keywords: Urban sprawl, agricultural land, GIS, remote sensing, land use change, Temporarily Displaced Persons

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Introduction

Urban sprawl, characterized by unplanned peripheral expansion, threatens agricultural sustainability globally (Youssef et al., 2020), driven in part by the rapid growth of urban land use, which has emerged as the fastest-expanding land cover type, due to nearly 50 % of the global population now residing in urban centres (UN-Habitat, 1996). Urban expansion results in increased exploitation of natural resources (Scherr, 1997). It is projected that by 2050, 69% of the global population will reside in urban areas, exacerbating land use conflicts (UNDESA, 2012). Urban Sprawl is the expansion of built-up areas without planning, categorised as modest-density physical development without basic infrastructure (Xu et al., 2019). The sprawl is attributed to other factors, including a lack of planning and the desire of dwellers to flee poor governance and poor control policies (Nechyba & Walsh, 2002). Glaeser and Kahn (2001) attributed sprawl to a natural manifestation of growing cities, and it can provide opportunities for inhabitants to enjoy low land value and low housing prices (Glaeser & Kahn, 2004). The increasing rate of urbanization and urban expansion is a worldwide process, and it is placing pressure not only on existing urban land use but also negatively impacting the urban farmland in developing countries (Prasad & Sreenivasulu, 2014; Rimal, 2005; Small, 2004). Due to the increasing urban population, a large share of agricultural land is converted into housing schemes, industries, educational institutions and other infrastructure (Quasem, 2011).

Therefore, assessing urban sprawl and land use/land cover (LULC) changes is essential for monitoring the city's expansion for planning and management. The most efficient assessment approach is to utilise high-resolution remote sensing data to monitor growth (Jensen et al., 2004). Change detection techniques are used in many applications such as environmental degradation, deforestation, urban sprawl, coastal change and other cumulative changes (Ramachandra & Kumar, 2004). Mapping of urban sprawl through geographic information system (GIS) analysis is a cost-effective method that uses digital change detection techniques of multi-temporal satellite imagery (Olokeogun et al., 2014; Rawat & Kumar, 2015). For sustainable development, accurate, diachronic, and recurrent data on LULC (land use/land cover) changes of the Earth's surface are highly valuable, playing a fundamental role in effective land use planning (Basha et al., 2018; Corner et al., 2014; Purwanto & Andrasmoro, 2021)

D-I Khan City, a semi-arid region in Khyber Pakhtunkhwa, faces dual pressures from population growth and TDP migration due to military operations. The 2003 Chashma Right Bank Canal (CRBC) project transformed barren land into irrigated farms, but post-2014 urban expansion reversed gains. The key drivers that changed the dynamics of LULC in D-I Khan were the completion of the Chashma Right Bank Canal in 2003 and the influx of TDPs in 2009. The CRBC is a 272 km long irrigation canal with a command area of 250,000 ha, more than 50 % of which lies in the D-I Khan district. The canal transformed the agriculture sector of the area (Rahman & Khan, 2012).

Similarly, the city of D-I Khan received a large number of temporarily displaced people from the South Waziristan District as a result of Operation Rahe-e-Nijat, launched by the Pakistan Army against non-state armed elements. According to the FATA Disaster Management Authority, 350,000 people migrated out of the conflict zone to D-I Khan, Bannu, and Lakki Marwat. The majority of these temporarily

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dispersed persons (TDPs) have bought properties and permanently settled on Tank and Karachi roads in D-I Khan City. (Din, 2010; Mohsin, 2013). Due to the aforementioned factors, demand for shelter increases, leading to the built environment consuming farmland and threatening future food security. The objective of this study is to analyse the spatio-temporal dynamics of urban sprawl and its impact on agricultural land in Dera Ismail Khan City over twenty years (2004, 2014 and 2024). The study uses multi-temporal Landsat imagery, supervised classification and land-use dynamic degree models (SLUDD and CLUDD) to quantify changes in built-up, agricultural, barren and water classes. It also aims to identify the key drivers of land transformation, including irrigation expansion through the Chashma Right Bank Canal and the influx of displaced populations, and to assess how these changes have influenced land values and future land availability for sustainable urban development.

Literature Review

Concept and Drivers of Urban Sprawl

Urban sprawl is a long-standing and well-documented process in which cities expand horizontally, often in low-density, unplanned ways (Nechyba & Walsh, 2002). The economic and transport sectors' expansions emphasise how cheaper land, infrastructure investments, and preferences for lower-density living interact to produce outward growth. Classic economic behaviours show that sprawl is not simply a planning failure but a mix of market forces, infrastructure supply, and household choices, which together shape the pattern and pace of growth (Barnes et al., 2001).

Impacts of Urban Sprawl on Land and Environment

A major consequence of urban sprawl in many low and middle-income countries is the conversion of agricultural and peri-urban land to built-up areas, which creates trade-offs between short-term development gains and long-term food security and ecosystem services (van Berkum, 2023). Systematic reviews and syntheses show that sprawl reduces the area and continuity of productive farmland, fragments agricultural land parcels, alters local water regimes, and can reduce both crop diversity and productivity near expanding urban edges (Duan, 2024). These effects are mediated by local governance, land markets, and infrastructure projects that change the value and usability of land.

Application of Remote Sensing and GIS in LULC Analysis

Remote sensing and GIS are now core tools for quantifying spatio-temporal LULC change. Multitemporal Landsat imagery, combined with supervised classification and change-detection metrics, provides robust, replicable estimates of how land classes expand or contract over decades(Abidi, 2024). Recent reviews highlight that improvements in the Landsat archive, preprocessing, and classification algorithms have increased accuracy and temporal resolution, enabling studies to identify not only net change but also conversion trajectories, for example, agricultural to built-up versus barren to agriculture (Panuju et al., 2020). These methodological advances strengthen the evidence base on where and how quickly cities grow.

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Quantitative Measurement of Land Use Dynamics

Quantitative metrics that measure the rate and intensity of change, such as single land use dynamic degree (SLUDD) and comprehensive land use dynamic degree (CLUDD), are widely used in urban land-change studies (Huang et al., 2018). These indices convert area changes into annualised rates, making it easier to compare periods and locations and to relate change rates to drivers like infrastructure projects or migration. Case studies using these methods show consistent patterns of infrastructure and irrigation projects often stimulate agricultural expansion in the short term, while later urbanization pressures can reverse those gains (Deal & Schunk, 2004; Li et al., 2014; X. Wang et al., 2025).

Socio-Political Factors and Displacement-Driven Urban Growth

Local socio-political shocks, including large inflows of displaced people, can accelerate urban expansion and reshape land markets. Research on Pakistan and comparable contexts documents how waves of internally displaced persons (IDPs) concentrate in nearby towns, creating sudden housing demand, informal settlement growth, and rapid peripheral development(Shah et al., 2025). The literature stresses that displacement-driven urban growth interacts with land scarcity and weak land-use controls to drive fast conversion of agricultural and barren land into residential colonies (Okwei et al., 2025). These dynamics make displacement an important but under-studied driver of LULC change in conflict-affected regions.

Synthesis and Relevance to D-I Khan Context

While considered collectively, the literature points to several interconnected mechanisms that are pertinent to D-I Khan: (1) infrastructure projects and irrigation can promote agricultural expansion ahead of urban growth; (2) market and demographic shocks (including IDP inflows) can rapidly raise demand for housing and increase land values; and (3) the net outcome depends on the timing and interaction of these drivers, plus governance capacity to manage land conversion. Methodologically, combining Landsat-based classification with SLUDD/CLUDD metrics and field validation produces robust, policy-relevant evidence on these processes.

Materials and Methods

Study Area

Dera Ismail Khan is the southernmost district of Khyber Pakhtunkhwa. It shares its eastern boundary with Dera Ghazi Khan and Bhakkar districts in Punjab. The Indus River also forms part of its eastern boundary and supports a fertile alluvial plain. To the southwest, the district borders FR D-I Khan and South Waziristan, while Tank District lies to the northwest. The study area is shown in Figure 1. Administratively, D-I Khan comprises five tehsils, Daraban, D-I Khan, Kulachi, Paharpur and Paroa, and includes a total of 47 union councils. The alluvial plain of D-I Khan is separated from the Marwat plain by the Shaikh Badin Hills. The area is part of the Shaikh Badin National Park. Near Indus lies the Kafir Kot hill, where the ancient complex of Kafir Kot is located (GoP, 1998).

The D-I Khan city is located on the west bank of the mighty Indus River, some 230

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km south of Peshawar. According to the 2017 census, the total population of the city is 217,457 compared to 41603 in 1951, 46140 in 1961, 58778 in 1972, 68145 in 1981 and 217457 in 1998, making it the 5th largest city of Khyber Pakhtunkhwa (GoP, 1951, 1961, 1981, 2004, 2017).

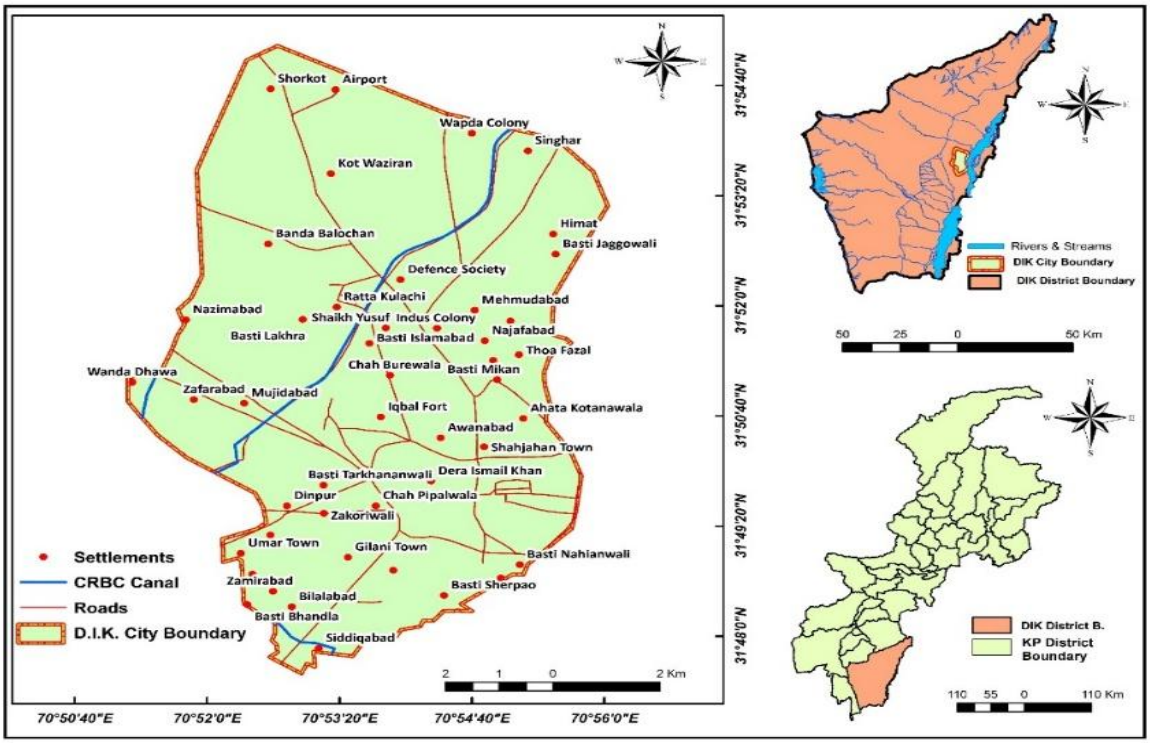


Figure 1: Location map of D.I. Khan City, Pakistan

Data Sources

Primary data

The primary data regarding land value and the GPS location of various settlements were collected from the field. Regarding land values and new residential development, interviews with real estate agents were also conducted. A total of 60 sample points were collected using GPS for the different (LULC) classes, i.e., agriculture, built-up area, and barren land. The land use value estimate comes from the different estate agents, the district revenue office and the community residing in the study area.

Secondary data

The secondary data regarding the temporal land cover change analysis were downloaded from the USGS website (https://earthexplorer.usgs.gov/), a freely available source for satellite data for the years 2004, 2014, and 2024. Further analysis has been carried out in ArcMap 10.5. The detailed metadata of the images is given below.

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Table 1 Description of the Satellite Imagery in the Study

Attribute	2004	2014	2024
Acquisition Date	05-07-2004	05-10-2014	5-30-2024
Spacecraft Identifier	LANDSAT_5	LANDSAT_8	LANDSAT_9
Land Cloud Cover	6	5	0.11
Data Type Level-1	Thematic Mapper, TM_L1TP	Enhanced Thematic Mapper Plus, ETM_L1TP	OLI_TIRS
Map Projection	UTM	UTM	UTM
UTM Zone	42	42	42
Datum	WGS84	WGS84	WGS84
Centre Latitude	31°41'43.80" N	31°41'43.80"N	31°41'43.80"N
Centre Longitude	70°46'03.36"E	70°46'03.36"E	70°46'03.36"E

Source: USGS Earth Explorer Website: https://earthexplorer.usgs.gov/

Data Analysis

We adopted the Supervised Image Classification technique for this study. For the classification, we used the ArcMap 10.5 software. The process is shown in Figure 2. The following steps were involved in the process:

Data Preprocessing

The Pan-sharpening technique of ArcMap was adopted for Landsat 5 TM (2004), and Landsat 8 OLI (2014) 30m resolution images were fused with panchromatic bands to enhance resolution to 15m. After that, the AOI of the city boundary, digitised from Tehsil Municipal Office data, was georeferenced in ArcMap 10.5 to extract the study area from satellite images.

Supervised Classification

Four LULC classes built up, agriculture, barren land, and water, were identified. Over 100 training samples per class (except for water, which had 20 samples) were collected using high-resolution colour composites. Spectral signatures for each class were stored in ASCII files, capturing the mean, variance-covariance matrices, and cell counts. A Maximum Likelihood algorithm in ArcMap 10.5 was then used to classify the images into thematic maps.

Accuracy Assessment

Reference data were obtained from 60 GPS waypoints and Google Earth Pro historical imagery to validate the classified maps. An error matrix was used to calculate omission and commission errors, overall accuracy, and the Kappa coefficient.

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Land Use Dynamic Analysis

LULC Dynamic Degree (LUDD) is important to determine the rate of LULC change; it can be used not only to compare the spatio-temporal differentiation but also to forecast the tendency of variation in land use and land cover patterns. The land use land cover change over time can be computed and measured by a Dynamic model of Land Use Type within a particular period for a specific study area. (Quan et al., 2015). The following model from (Quan et al., 2015) was applied for analysis:

$$SLUDD = \frac{U_b - U_a}{Ua} \times \frac{1}{T} \times 100\%$$

Where;

U_b represents the land use area at the end of the observation period, while U_a indicates the land use area at the start. The difference between these values, $U_b - U_a$, shows the net change in land use, with positive values indicating an increase and negative values showing a decrease. The relative change in land use, calculated by $\frac{U_b - U_a}{Ua}$, reveals the magnitude of change as a proportion of the initial value. *T* is the duration of the observation period in years, and dividing by *T* converts the total change to an annual rate through $\frac{1}{T}$. Finally, multiplying by 100% expresses the result as a percentage, offering a clear and comparable measure of the annual dynamics in land use change.

Single land use dynamic degree (SLUDD)

Comprehensive Land Use Dynamic Degree (CLUDD).

Single land use dynamic degree

SLUDD shows the variation in a particular LULC class throughout a provided period in a particular area. This can be calculated by following the formula:

$$SLUDD = \frac{U_b - U_a}{Ua} \times \frac{1}{T} \times 100\%$$

Where;

U_a is the area of land use type at the initial time (2004 & 2014), U_b is the area of land use type at the later time (2014 & 2024), and *T* is the gap between the initial time and the later time

According to Quan et al. (2015), LUDD is the measure of the variation of total land that's converted into other types of LULC. The dynamics Degree comprehensively shows the changes in LULC of the given area. The LUDD is a suitable measure of the percentage change per annum.

Comprehensive Land Use Dynamic Degree (CLUDD)

The Comprehensive Land Use Dynamic Degree (CLUDD) measures the overall intensity and rate of land use and land cover (LULC) change within a study area over a specific period. Unlike the Single Land Use Dynamic Degree (SLUDD), which focuses on the change of one land use category, the CLUDD reflects the *aggregate level of transformation* across all land use types. It is calculated using the following formula:

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$$\text{CLUDD} = \left(\sum_{i=1}^{n} \Delta S_{i-j}\right) \frac{1}{2\sum_{i=1}^{n} S_i} \times \frac{1}{T} \times 100\%$$

where;
ΔSi−j represents the total land area converted from land use type *i* to other types *j* during the study period. *Si* denotes the initial area of land use type *i*, *T* refers to the study period in years, and *n* indicates the total number of land use classes.
The CLUDD provides a quantitative measure of the overall change intensity across all land use categories. A higher CLUDD value indicates more dynamic land use conversion, implying significant landscape transformation or rapid urbanization, while a lower value reflects relative stability in land use structure.

Land Value Impact Analysis
Fieldwork in Dera Ismail Khan was conducted to examine the relationship between land-use/land-cover (LULC) dynamics and spatial patterns of land prices. During systematic ground surveys, a handheld GPS unit was used to log observation points as waypoints. Each waypoint recorded two key pieces of information: precise geographic coordinates and the land price reported by local informants or owners at that spot. These locations covered the main land-use types found in the area, namely agricultural, residential, and commercial zones.
The collected GPS points played two important roles in the research. They provided the primary dataset for investigating how land values varied across space, and they also served as independent validation points for evaluating the accuracy of the supervised LULC classifications.
Following the fieldwork, all waypoints were brought into ArcGIS as a point feature layer. The attribute table was carefully checked, corrected, and standardised. To generate continuous land-value surfaces for 2004 and 2024, the Inverse Distance Weighting (IDW) interpolation method was applied separately for each year. IDW gives greater weight to closer sample points and progressively less weight to points farther away, which makes it particularly effective for representing local price gradients driven by urban development.
The resulting raster surfaces were reclassified into high, medium, and low land-value classes using the natural breaks (Jenks) algorithm. To quantify change over the two-decade period, the 2004 raster was subtracted from the 2024 raster, yielding a difference map that highlights both the extent and the geographic distribution of price appreciation or depreciation.
The areas showing the strongest value increases aligned closely with zones of intensive urban sprawl, newly developed housing schemes, and emerging commercial axes revealed by the LULC change analysis. In summary, this interpolation-based workflow made it possible to measure and map the economic consequences of land-use transformation, demonstrating how population growth, infrastructure investments, and urban expansion have reshaped the land market in Dera Ismail Khan between 2004 and 2024.

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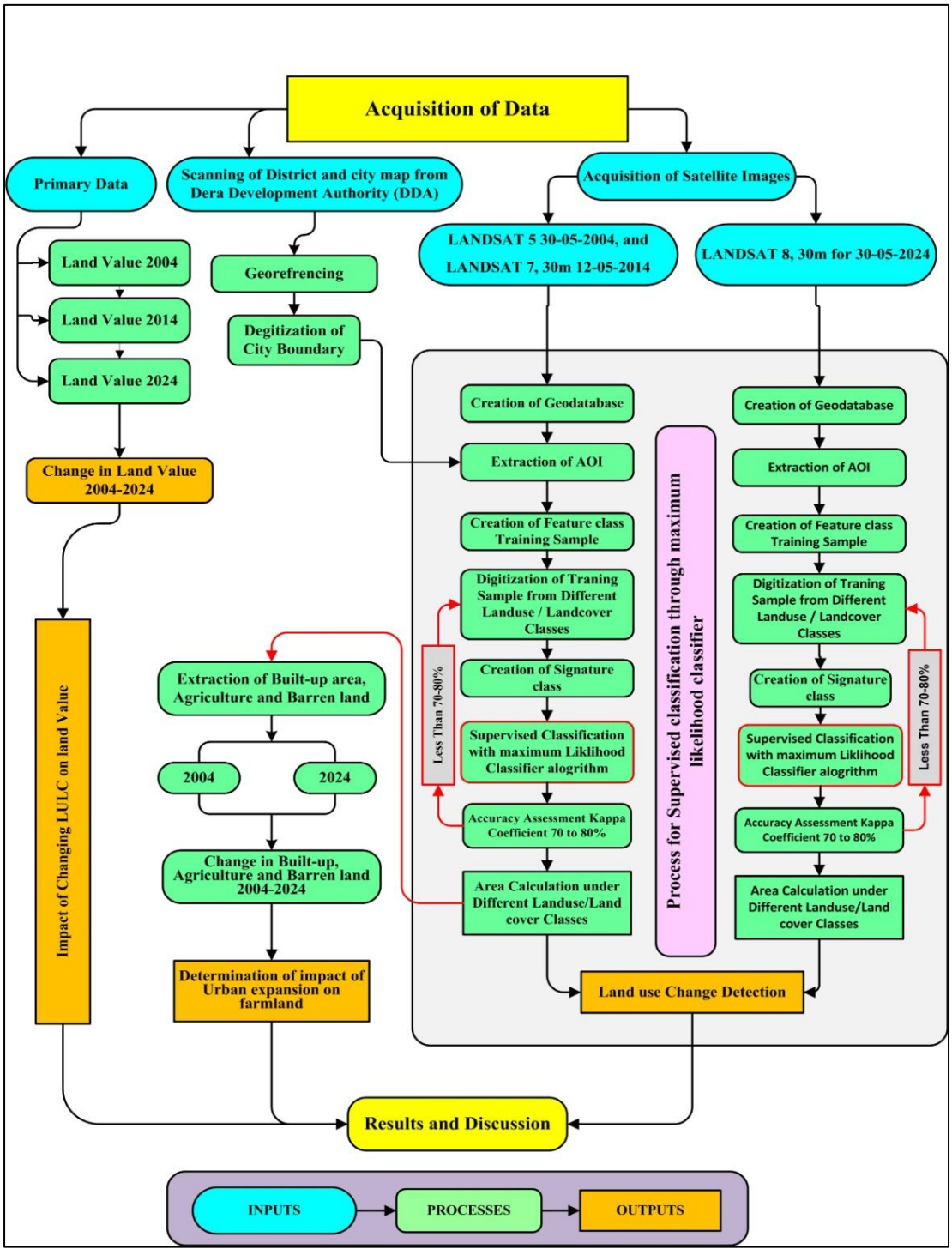


Figure 2: Flow Chart of the Methodology adopted for this Study

Results

Land Use/Land Cover (LULC) Dynamics (2004, 2014 and 2024)

The analysis of LULC changes in D-I. Khan City, over three decades, from 2004 to 2014 and 2024, reveals significant transformations driven by anthropogenic activities

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and infrastructural developments, particularly the construction of the Chashma Right Bank Canal (CRBC). The spatiotemporal analysis of land cover shows that the urban expansion exhibited a consistent upward trajectory. In 2004, built-up areas covered 1,590.15 hectares (24.44%) of the city, increasing to 1,834.34 hectares (28.20%) by 2014, and surging sharply to 2,969.1 hectares (45.64%) by 2024. This represents a net increase of 1,378.95 hectares over 20 years, underscoring rapid urbanization and population growth.

Similarly, following the construction of the Chashma Right Bank Canal, the area of agricultural land increased significantly, rising from 1,051.04 hectares (16.51% of the total area) in 2004 to 2,183.19 hectares (33.56% of the total area) in 2014. This represents an increase of 1,132.15 hectares, attributed to the availability of irrigation water for previously rain-fed agriculture.

The introduction of the CRBC catalyzed agricultural intensification. Between 2004 and 2014, cropland expanded from 1,051.04 hectares (16.51%) to 2,183.19 hectares (33.56%), a 113.2% increase attributed to improved irrigation access. However, by 2024, agricultural land slightly declined to 2,064.07 hectares (31.73%), reflecting encroachment by urban sprawl. Barren land, initially the dominant class at 3,819.11 hectares (58.71%) in 2004, decreased to 2,430.8 hectares (37.37%) by 2014 and further to 1,421.29 hectares (21.85%) by 2024. This 62.8% reduction highlights the conversion of uncultivated land into productive agricultural and urban zones.

Minor fluctuations were observed in water bodies, increasing from 44.06 hectares (0.67%) in 2004 to 56.03 hectares (0.86%) in 2014, then stabilising at 49.9 hectares (0.76%) by 2024. These changes are linked to seasonal variations and canal management. Table 2 summarises the analysis results, and Figure 3 depicts the spatial distribution of land-use/land-cover classes in the study area for 2004, 2014, and 2024.

Table 2: Historical LULC Analysis of D-I Khan City (2004, 2014 and 2024)

	5/7/2004		5/10/2014		5/30/2024	
Land Use Land Cover Classes	**Area in Hectare**	**%of Total Area**	**Area in Hectare**	**%of Total Area**	**Area in Hectare**	**%of Total Area**
Built-up	1590	24.4	1834.3	28.2	2969.1	45.6
Agricultural land	1051	16.5	2183.1	33.5	2064.07	31.7
Barren land	3819	58.7	2430.8	37.3	1421.2	21.8
Water bodies	44	0.6	56.03	0.8	49.9	0.76
Total	**6504**	**100**	**6504.36**	**100**	**6504.36**	**100**

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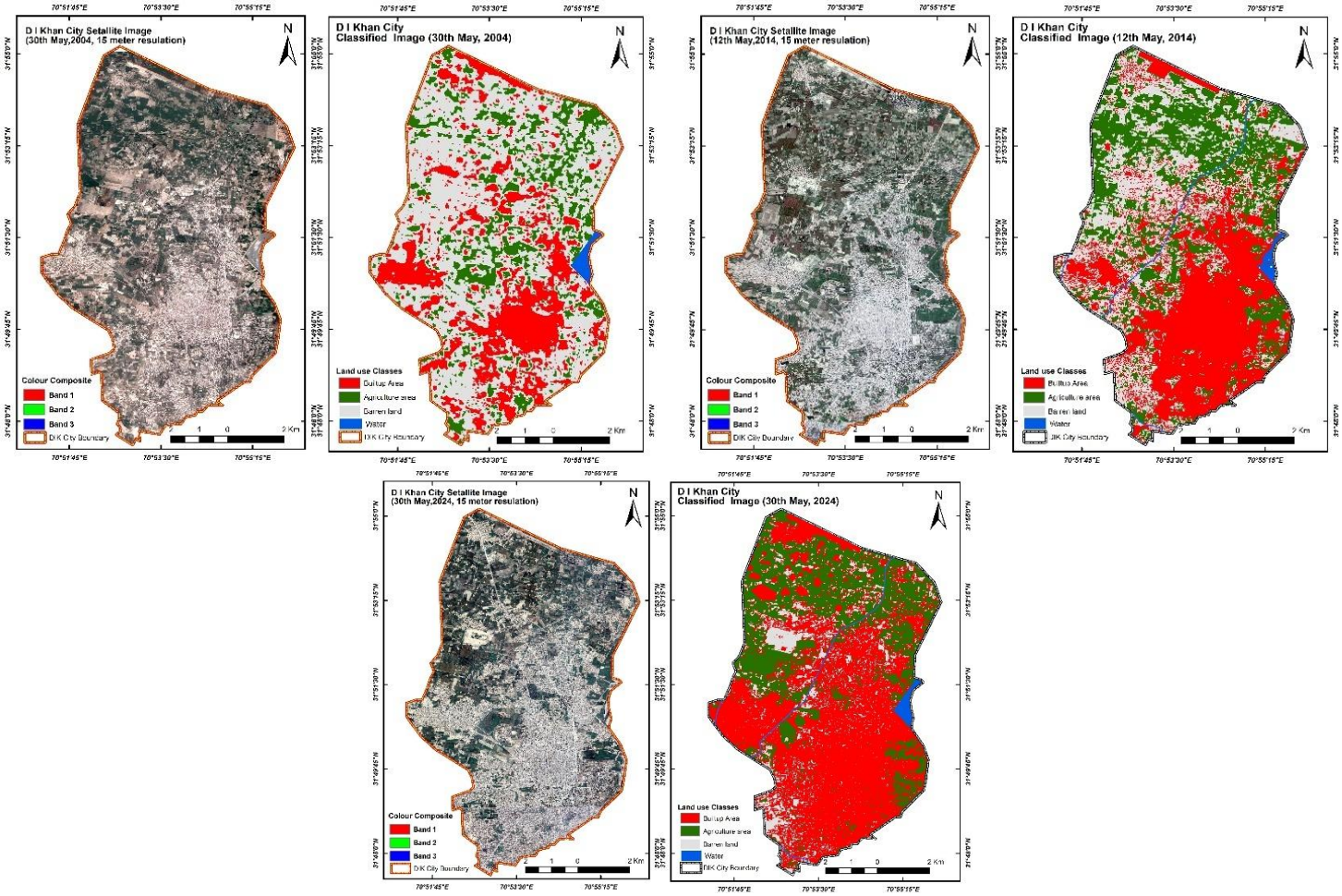


Figure 3: Land Use/Land Cover Classification of 2004, 2014 and 2024 of D-I Khan City

Accuracy Assessment of LULC Classification

The accuracy assessment was carried out for 2004 and 2014 and was evaluated using 130 reference points and Cohen's Kappa Coefficient. The results are summarised in Table 3 below.

Table 3: Summary of Classification Accuracy for 2004 and 2024

Accuracy Metrics	2004 Classification (Landsat 5, 30m)	2024 Classification (Landsat 9, 15m)
Overall Accuracy (%)	60.4	82.0
Kappa Coefficient	0.64 (Moderate)	0.75 (Moderate to High)
Producer's Accuracy (%)	Built-up: 65 Vegetation: 65 Barren Land: 55 Water: 100	Built-up: 85 Vegetation: 75 Barren Land: 87.5 Water: 80

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User's Accuracy (%)	Built-up: 65 Vegetation: 72.2 Barren Land: 50 Water: 100	Built-up: 75.5 Vegetation: 85.7 Barren Land: 85.3 Water: 88.8

The overall accuracy improved from 60.4% in 2004 to 82% in 2024, mainly due to higher resolution imagery and better spectral differentiation. The Kappa coefficient increased from 0.64 (moderate) in 2004 to 0.75 (moderate to high) in 2014, indicating improved classification reliability. Water bodies showed the highest accuracy in both years due to distinct spectral signatures. Barren land and built-up areas had the highest confusion due to spectral similarities, although accuracy improved significantly in 2024.

Land Use/Land Cover Dynamic Degree

The SLUDD results show a steady increase in built-up land between 2004 and 2014; the city experienced consistent outward growth in built-up cover. The developed area grew from 1,590.15 hectares to 1,834.34 hectares, yielding an average annual SLUDD rate of 1.53%. This steady expansion mainly took the form of new housing colonies and small commercial clusters pushing into the urban fringe. The gradual pace largely mirrored rising population numbers and the slow conversion of both farmland and vacant plots into residential and commercial uses. The positive SLUDD figure for this period signals that urbanisation was already underway, steadily reshaping the city's footprint.

The following decade (2014–2024) saw a marked acceleration. Built-up land jumped from 1,834.34 hectares to 2,969.1 hectares, pushing the annual SLUDD value to 6.18%. This surge reflects a wave of large-scale housing projects, intensified construction activity, and heightened land demand fuelled by continued demographic growth and economic opportunities. When the two periods are placed side by side, the shift from modest, incremental expansion to rapid, large-scale sprawl becomes evident, with mounting encroachment on nearby agricultural fields and open spaces. Table 4 and Figure 4 illustrate the detailed spatial dynamics of built-up areas.

Built-up area 2004-2014-2024

The Single Land Use Dynamic Degree (SLUDD) was calculated using

$$SLUDD = \frac{U_b - U_a}{Ua} \times \frac{1}{T} \times 100\%$$

where;

Ua is the initial area (hectares), Ub is the final area (hectares), and T is the time period (years)

Table 4: SLUDD Analysis of Built-up Area (2004–2024)

Period	Initial Area (Ua)	Final Area (Ub)	SLUDD Formula	SLUDD (%)
2004–2014	1590.15 ha	1834.34 ha	(1834.34 - 1590.15) / 1590.15 × 1/10 × 100	1.53
2014–2024	1834.34 ha	2969.1 ha	(2969.1 - 1834.34) / 1834.34 × 1/10 × 100	6.18

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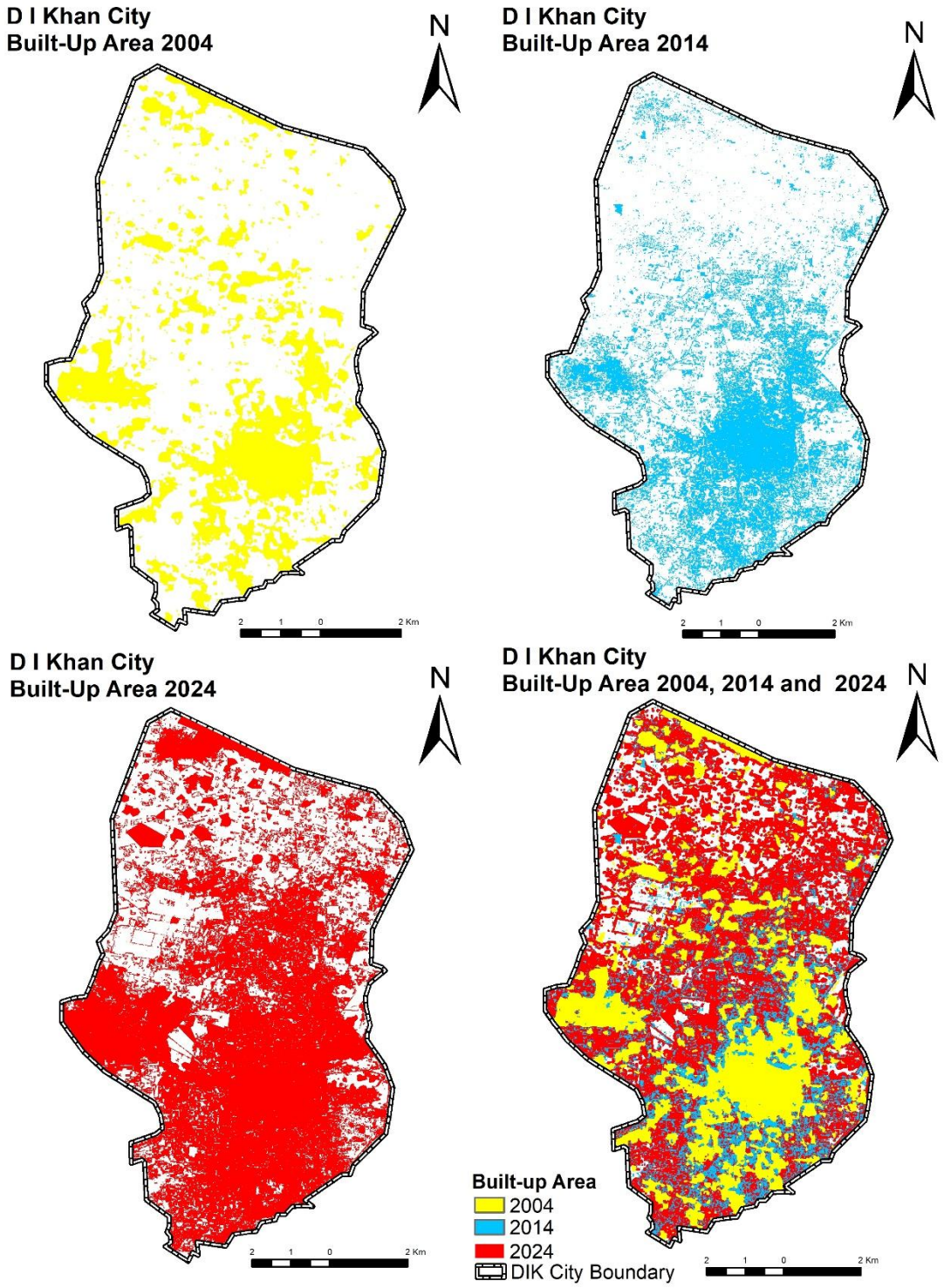


Figure 4: Built-up Land Use Dynamics of D-I Khan City, A, 2004, B, 2014 and C, 2024

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Vegetation 2004-2024

The SLUDD results for vegetation reveal two distinct phases across the 20-year study period. Between 2004 and 2014, vegetation cover expanded dramatically, rising from 1,051.04 hectares to 2,183.19 hectares and registering an impressive annual SLUDD rate of 10.7%. This strong growth stemmed directly from the rollout of reliable irrigation through the Chashma Right Bank Canal. Large tracts of formerly barren or rain-dependent land were brought under cultivation, leading to a visible surge in cropped area and greener landscapes around the city.

From 2014 to 2024, however, the trend reversed. Vegetation declined modestly from 2,183.19 hectares to 2,064.07 hectares, producing a negative SLUDD value of -0.54% per year. The slowdown and subsequent loss reflect mounting competition for land as the city's built-up footprint expanded aggressively during these years. Prime irrigated plots on the urban fringe were increasingly converted into housing societies, roadside shops, and infrastructure, gradually eating into farmland. Taken together, the data trace a clear transition: the first decade was dominated by agricultural intensification made possible by new water resources, while the second decade saw urban pressures begin to erode those earlier gains in cultivated area. Table 5 and Figure 5 illustrate the detailed spatial dynamics of vegetation areas.

Table 5: SLUDD Analysis of Vegetation Area (2004–2024)

Period	Initial Area (Ua)	Final Area (Ub)	SLUDD Formula	SLUDD (%)
2004–2014	1051.04 ha	2183.19 ha	(2183.19 - 1051.04) / 1051.04 × 1/10 × 100	10.7
2014–2024	2183.19 ha	2064.07 ha	(2064.07 - 2183.19) / 2183.19 × 1/10 × 100	-0.54

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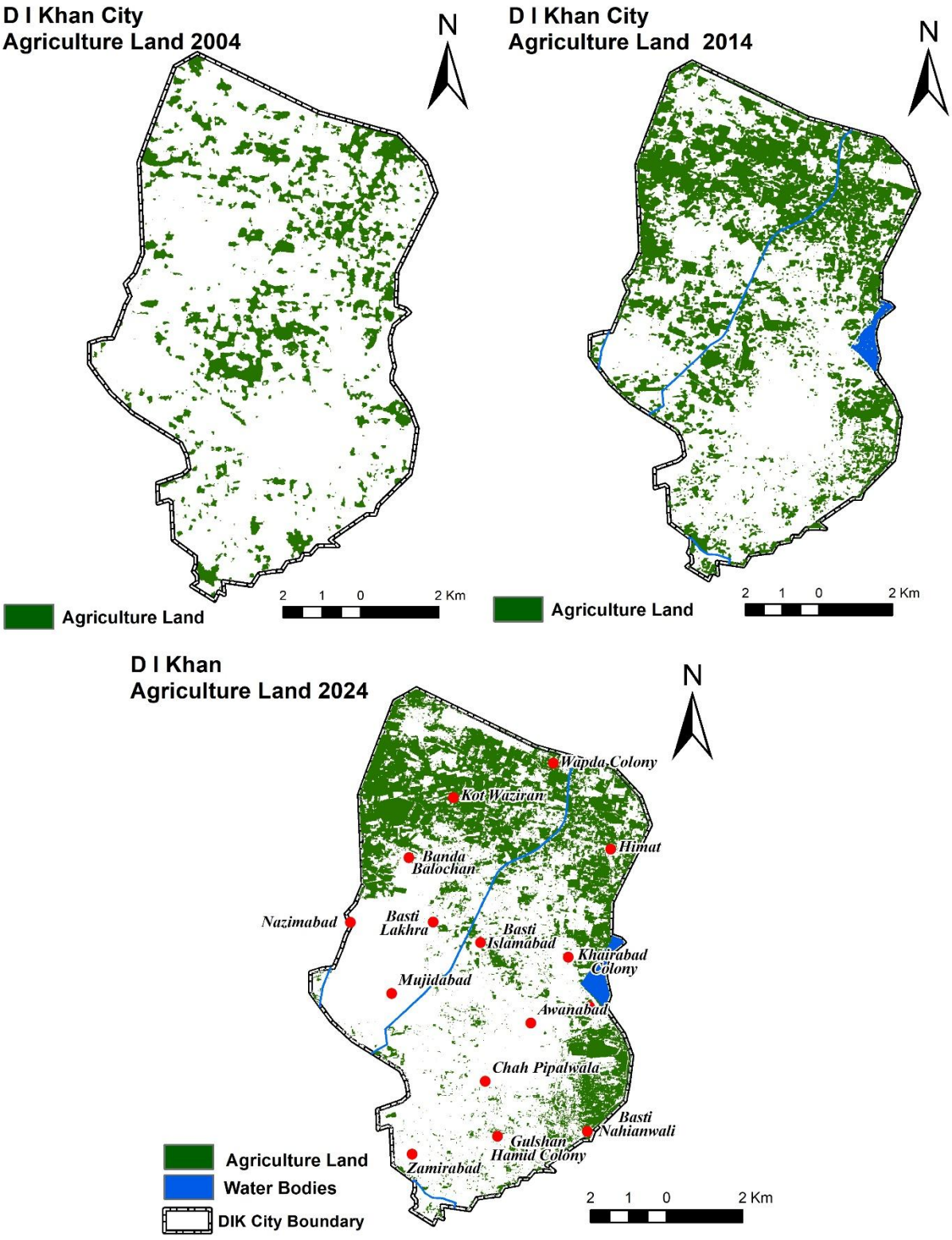


Figure 5: Agriculture Land Use Dynamics of D-I Khan City, A, 2004, B, 2014 and C, 2024

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Barren Land 2004-2024

The SLUDD results for barren land show a consistent decline across both decades, reflecting the steady conversion of open and unused land into agricultural and built-up areas. Between 2004 and 2014, barren land decreased from 3819.11 hectares to 2430.8 hectares, producing a SLUDD value of –3.63% per year. This reduction is closely linked with the expansion of agriculture during this period, supported by improved irrigation infrastructure, as well as the gradual outward spread of settlement areas. The decline continued from 2014 to 2024, when barren land further decreased from 2430.8 hectares to 1421.29 hectares, yielding a slightly higher negative SLUDD value of –4.14% per year. This sharper rate of decline reflects the accelerated pace of urban expansion in the second decade, during which peripheral barren lands were increasingly converted into new housing schemes, commercial corridors and roadside developments. In short, the continuous reduction in barren land highlights increasing development pressure and the diminishing availability of open land around the city. Table 6 and Figure 6 illustrate the detailed spatial dynamics of built-up areas.

Table 6: SLUDD Analysis of Barren Land (2004–2024)

Period	Initial Area (Ua)	Final Area (Ub)	SLUDD Formula	SLUDD (%)
2004–2014	3819.11 ha	2430.8 ha	(2430.8 - 3819.11) / 3819.11 × 1/10 × 100	-3.63
2014–2024	2430.8 ha	1421.29 ha	(1421.29 - 2430.8) / 2430.8 × 1/10 × 100	-4.14

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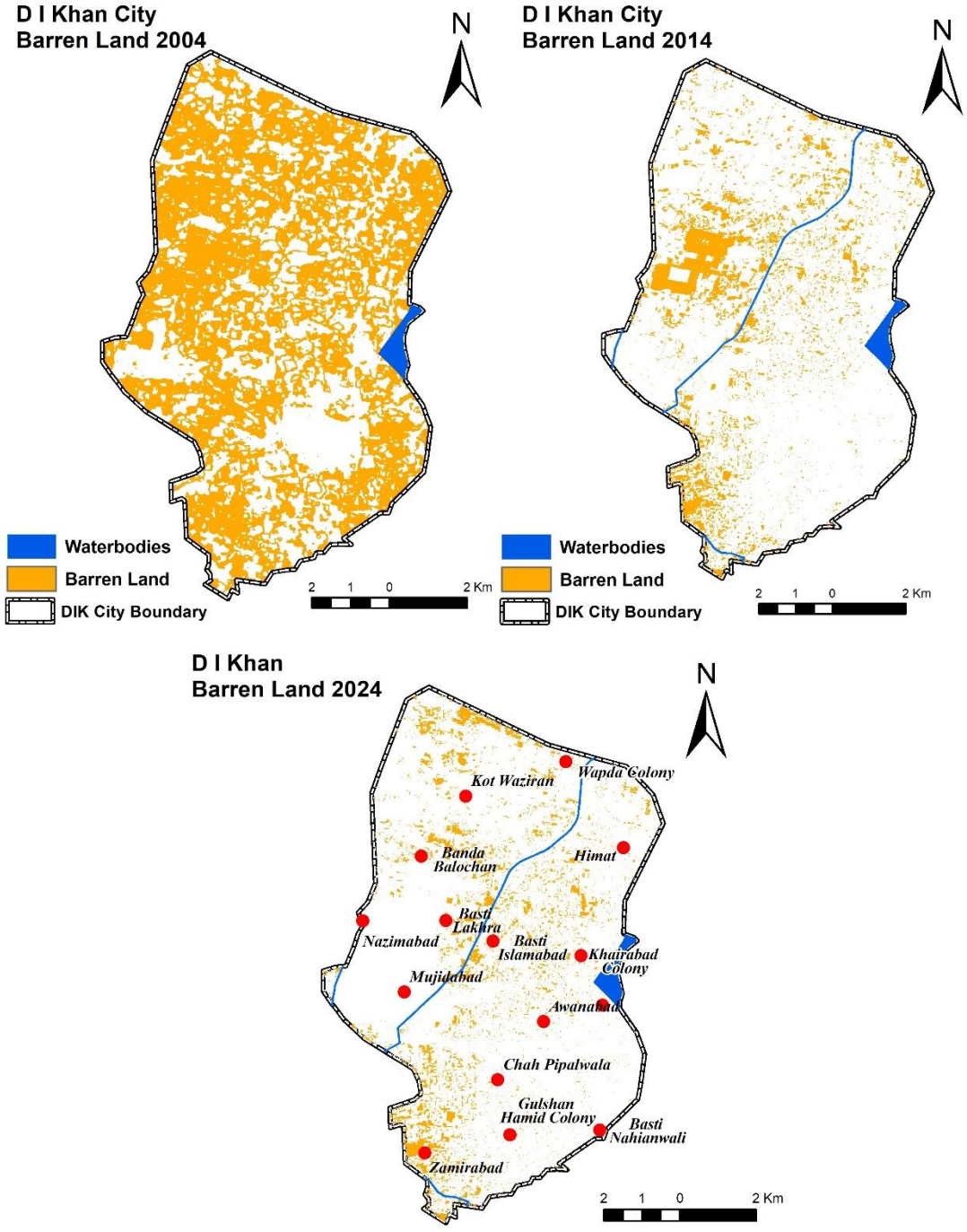


Figure 6: Barren Land Use Dynamics of D-I Khan City, A, 2004, B, 2014 and C, 2024.

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The results of SLUDD analysis show that during the period 2014-2024 in the study area, the variability in the built-up area is positive, demonstrating that the built-up area is increasing, and the greatest annual change rate is 1.53%. The variation direction of vegetation is also positive, i.e. 10.7% while barren land is negative, with a manifestation of the total area under barren land decreasing, and the maximum annual variation rate of vegetation is -3.63%.

Table 7 shows the SLUDD result for the annual change rate of various LULC classes, while Figure 7 shows it pictorially. The agricultural land increased by 10.7% during 2004-2014, but it recorded a decrease (-0.14%) between 2014 -2024. Built-up areas record an increasing trend in both decades, 1.53% and 6.18% during 2004-2014 and 2014-2024, respectively. The annual change in barren land /open spaces indicated a decreasing trend in both decades. During 2004-2014, the rate of decrease calculated was -3.63, while in the 2014-2024 period, the barren land decreased at the rate of -4.14%. The analysis reveals that during the 2004-2014 ten-year period, both agricultural land and built-up areas recorded an increasing trend. However, agricultural land increased at an annual rate of 10.7%. While the built-up area records a moderate annual rate of 1.53%. The barren land decreases at a moderate rate of -3.36% annually.

As far as the ten years from 2014 to 2024 are concerned, the agricultural land decreased at a rate of -0.14 /annum, while the built-up area increased at an accelerated rate of 6.16% /annum. For the same period, the barren land shows an accelerated decrease, i.e., -3.36% / annum. Quantitative results of the Single Land Use Dynamic Degree are presented in Table 7, while the patterns are visualised in Figure 7.

Land Use Land Cover Classes	**SLUDD**	
	2004-2014	**2015-2024**
Built-up	1.53	6.18
Agricultural land	10.7	-0.54
Barren land	-3.63	-4.14

Table 7: Single Land Use Dynamic Degree (SLUDD)

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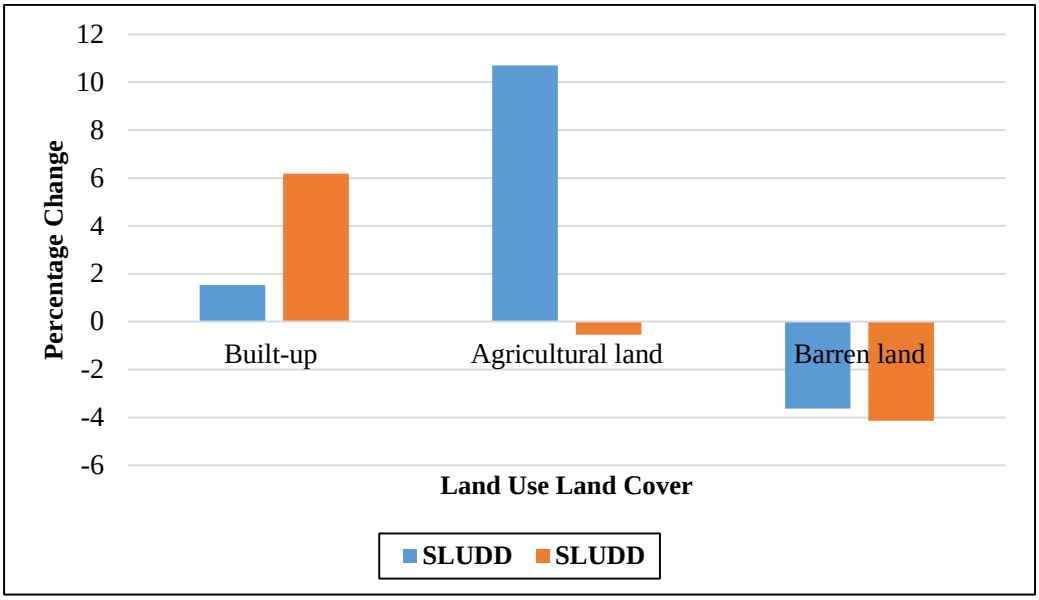


Figure 7: Dera Ismail Khan city, Single Land Use Dynamic Degree (LUDD)of 2004, 2014 and 2024.

Comprehensive Land Use Dynamic Degree

The CLUDD is the measurement across all the LULC classes, compared to SLUDD, which is the measure of annual change for each LULC class. CLUDD indicate the annual rate of land use change in the study area (X. L. Wang & Bao, 1999). The equation of the comprehensive land use dynamic degree (CLD) is as follows;

$$\mathrm{CLD} = \sum_{ij}^{n} \left(\frac{\Delta S_{i-j}}{S_i}\right) \times \frac{1}{T} \times 100\%$$

where;

CLDD is the comprehensive Land Use Dynamic Degree within the study period, S_i is the total area of land use type ***i*** at the beginning of that study period, ΔS_{i-j} is the total area of land use type ***i*** converted to the other types during the study period, and T is the Time Spane.

The CLUDD values reveal a pattern of intense land-use transformation, though with varying intensity across the two decades. Between 2004 and 2014, the annual CLUDD reached 4.26%, signalling rapid landscape restructuring. This period was dominated by a near-doubling of agricultural land, which expanded from 1,051.04 hectares to 2,183.19 hectares, driven by newly available irrigation. At the same time, barren land contracted substantially, falling from 3,819.11 hectares to 2,430.8 hectares as large areas previously unsuitable for farming were converted into productive fields.

In the subsequent decade (2014–2024), the pace of overall land-use change slowed to a CLUDD of 3.48% per year. Although the rate of transformation eased slightly, the nature of change shifted markedly toward urbanisation. Built-up area surged from

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1,834.34 hectares to 2,969.1 hectares, reflecting aggressive horizontal expansion of the city. This later phase, therefore, marks a transition from irrigation-led agricultural growth in the first decade to urban-driven land consumption in the second, even as the overall speed of landscape alteration moderated somewhat.

Land Value Surge in D-I Khan City from 2004-2024

Land use change and land use regulations may affect the market value of property. Some of the effects of Land use change and land use regulations are straightforward; in most cases, they are complex. Generally, it is considered that land use policies reduce property values, but in fact, they often have positive effects. The positive effect of land use policies and land use change on property occurred in two ways, i.e. amenity effect and the scarcity effect.

The amenity effect is created when land use policies and regulations assist, increase or produce services that benefit property owners. For example, infrastructure facilities make a particular area an attractive place to live, which in turn raises property value.

The Scarcity effect is mainly the result of land use and land cover change. The change in land use from one category to another can cause a scarcity of land available for a particular use in a particular location. For example, limited land available for physical development in one location is likely to increase the price of already developed land. This effect is some time can sometimes cause a very large price rise, and this has a spillover effect on land prices in other locations.

Just like other cities of Khyber Pakhtunkhwa, D-I Khan city's commercial land is mostly located along roads and transportation arteries and residential land use is mostly concentrated in the city centre or Central Business district.

The high-class residential area is mostly concentrated in the city centre due to the availability of infrastructure facilities and services. The land value in these high-class residential and commercial areas is very high. The low land value is mostly located in the suburbs and peripheral areas. In between these lie some places of middle-class residential areas. Commercial land is located in the city centre, which mainly consists of many bazars where commercial activities are concentrated. Due to the rapid growth of the population and influx of TDP, the expansion of the city is taking place towards the peripheral areas. The scarcity of land in the city centre is also keeping the land value high. Urban densification is taking place in the open spaces within the city centre. The open spaces and barren areas decreased from 3819.11 hectares in 2004 to only 1421.29 hectares in 2024.

High-value commercial land is located near DHQ hospital, Topanwala Bazar Bannu Adda (Bus Stand) and on the circular road, including Muslim bazar, Bakri bazar, Kamashnari bazar, Pawanda bazar and Khawar bazar. The land value reports a sharp rise from 2004 to 2024. The land value in these localities ranged from RS 0.6 to 2 million in 2004, which increased to RS 20 to 30 million. Figure 8 shows the land value of various localities in D-I Khan City for the years 2004 and 2024, respectively.

The analysis reveals that the high land value area in 2004 was concentrated in the southeast of the city, comprising the areas of Ali MC, Bannu Adda, DHQ, and Topanwala area, where the land value was from RS. 0.8 to 2 million. In 2024, the land value of these areas increased to RS 16 to 30 million. These areas are mostly located on the circular roads (North, East and South Circular Roads)

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The low land value is mostly reported from the peripheral areas of the city. The Northern part of the city is a predominantly agricultural area with low land value. After the influx of TDPs in 2009-10 mushrooming of housing colonies started on these low-value agricultural lands. A comparison of land values in 2004 and 2024 across different localities of D-I Khan City is presented in Figure 8.

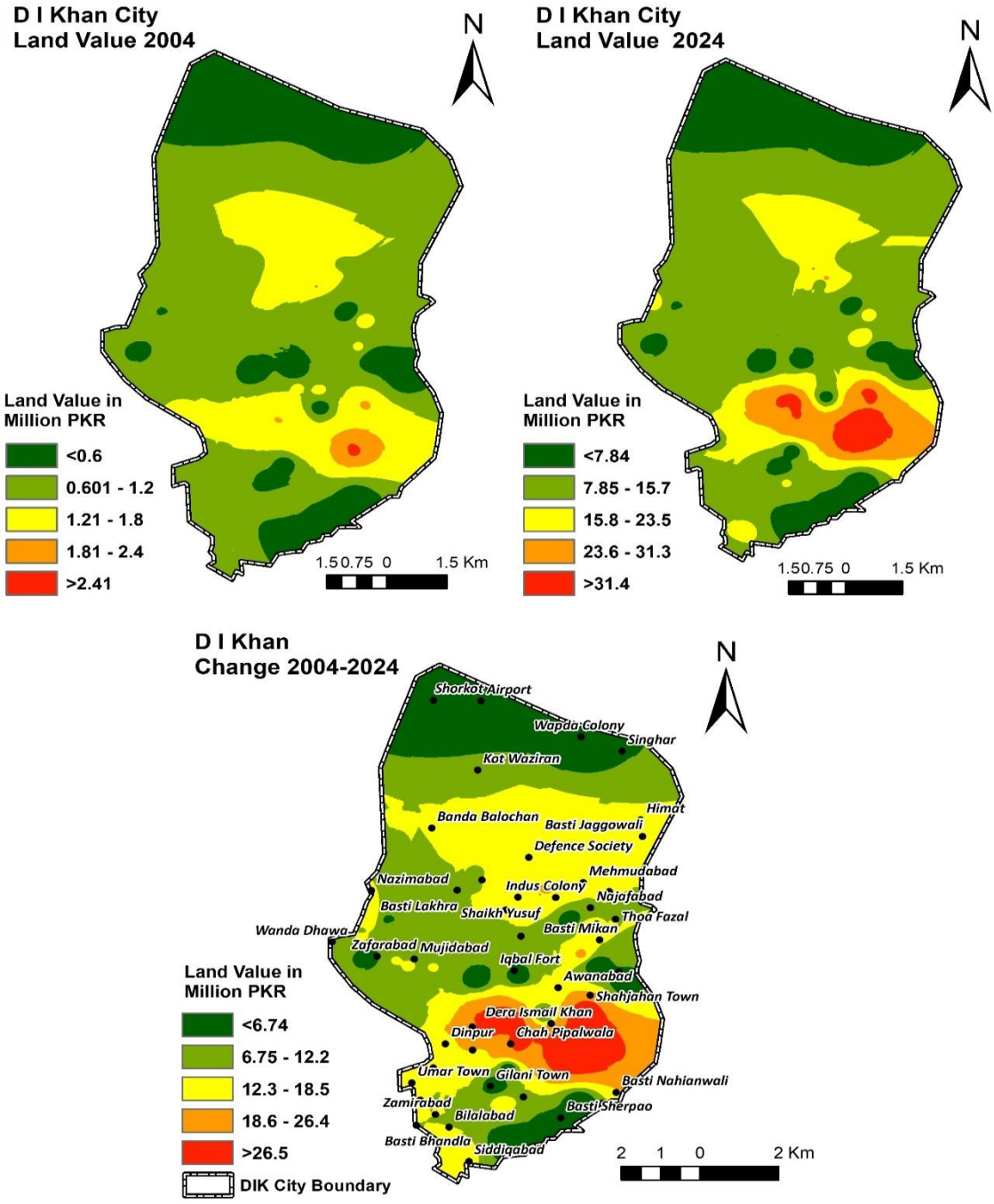


Figure 8: shows the land value of various localities in D-I Khan City for the years 2004 and 2024, respectively.

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Discussion

The findings of the land use and land cover changes in D-I Khan City from 2004 to 2024 present a dynamic narrative of urban transformation. Over these two decades, the built-up area expanded significantly, while the agricultural and barren lands experienced notable shifts. In 2004, the built-up area constituted 1590.15 hectares, representing 24.44% of the total area. By 2024, this figure had surged to 2969.1 hectares, accounting for 45.64% of the total area. This transformation indicates the rapid urbanization and land development processes that have taken place in the city.

A substantial factor contributing to this increase in built-up area was the influx of Temporarily Displaced Persons (TDPs) during the military operation Zarb-i-Azb. According to reports, 12,825 families were registered in D-I Khan, many of whom continue to reside in the city. Additionally, the city's natural population growth, which more than doubled from 125,807 persons in 1998 to 362,231 persons in 2017, further fueled the demand for residential and commercial spaces.

The availability of irrigation water through the construction of the Chashma Right Bank Canal (CRBC) in 2003 played a pivotal role in transforming previously barren and rain-fed agricultural lands. As a result, the agricultural area expanded from 1051.04 hectares in 2004 to 2183.19 hectares in 2014. However, despite this initial increase, the agricultural area slightly declined to 2064.07 hectares in 2024, as urbanization encroached upon these lands. The shift in agricultural land use underscores the pressure exerted by the growing built-up area.

Barren land, which constituted a significant portion of the city in 2004 (3819.11 hectares, or 58.71% of the total area), witnessed a dramatic reduction to 1421.29 hectares (21.85%) by 2024. This decrease can be attributed primarily to the conversion of these open spaces into built-up and agricultural areas. The SLUDD (Spatial Land Use Dynamic Degree) analysis highlights that the variation direction for built-up land was positive, with an annual increase rate of 6.18%, while barren land and agricultural areas show annual decrease rates of -4.14% and -0.54%, respectively.

The socio-economic landscape of D-I Khan has also evolved in tandem with its physical transformation. Commercial land use has become increasingly concentrated along key transportation arteries and major roads, such as Topanwala Bazar, Bannu Adda, and various bazaars along the circular road. High-value residential areas remain primarily located in the city center, where infrastructure facilities and services are readily available. Conversely, lower-value residential areas are more prevalent in the suburbs and peripheral zones of the city.

The land values have undergone a remarkable transformation between 2004 and 2024. In high-value commercial areas near DHQ Hospital and prominent bazaars, land prices surged from Rs 0.6 to 2 million in 2004 to an astonishing Rs 20 to 30 million by 2024. This sharp rise reflects the increasing demand for commercial spaces and the rapid urban development occurring in these areas. The overall accuracy of the land classification analysis for 2004 and 2024 was measured at 64.4% and 82%, respectively, with corresponding Kappa coefficients of 58% and 75%. These metrics underscore the reliability of the findings and provide valuable insights into the dynamic urban landscape of D-I Khan.

In conclusion, the analysis of land use and land cover changes in D-I Khan city

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highlights the multifaceted factors driving urban growth, including population dynamics, migration, infrastructure development, and socio-economic trends. The transformation from agricultural and barren lands to built-up areas illustrates the city's ongoing urbanization and the challenges associated with balancing development with sustainable land use practices.

Limitations and Future Research

While this study provides valuable insights into the spatial and temporal dynamics of urban sprawl in D-I Khan, certain limitations should be acknowledged to contextualize the findings and guide future research. The study relied on Landsat imagery with a spatial resolution of 30 meters, which, although suitable for regional-scale analysis, may not fully capture fine-grained urban transformations such as small residential clusters or informal settlements. Additionally, using three benchmark years (2004, 2014, and 2024) limits the temporal continuity of change detection and may overlook short-term fluctuations or transitional phases in land conversion.

Despite the use of supervised classification and accuracy assessment, the reliability of classification results depends on the quality and representativeness of training samples. Variations in atmospheric conditions, seasonal imagery differences, and spectral similarity between certain land cover types (e.g., barren and built-up) can introduce classification errors. Future studies could integrate Sentinel-2 data with higher spatial and temporal resolution to improve classification precision.

This research primarily focused on spatial and physical dimensions of land use change. However, urban sprawl is deeply influenced by socioeconomic and governance factors, including population dynamics, migration, land markets, and policy interventions. The absence of detailed socioeconomic datasets, household-level surveys, and institutional data limits the ability to comprehensively link observed spatial patterns with underlying human drivers.

The study did not deeply examine planning regulations, zoning enforcement, or institutional responses to urban growth in D-I Khan. Future research could explore the effectiveness of existing land-use policies, urban management frameworks, and the role of local authorities in guiding or mitigating unplanned expansion. Incorporating qualitative methods, such as stakeholder interviews or policy document analysis, could provide valuable insight into governance dimensions.

Future Research Opportunities

Future research should aim to integrate multi-source data (e.g., Sentinel-2, PlanetScope, or UAV imagery) to enhance temporal and spatial accuracy in urban change detection. Coupling remote sensing with socio-economic modelling or spatial regression analysis could help identify causal relationships between infrastructure, population movement, and land-use transitions. Furthermore, scenario-based simulations using cellular automata (CA) or agent-based models could predict future sprawl trajectories under different development policies. Longitudinal studies examining the social and environmental consequences of sprawl, such as loss of green space, changes in microclimate, and accessibility, would also contribute to more sustainable urban planning strategies in D-I Khan and similar regional cities.

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Conclusion

The study highlights the significant impact of urbanization and urban sprawl on agricultural land in D-I Khan City from 2004 to 2024, analyzed through geospatial and remote sensing techniques using ArcMap 10.5. The findings indicate a notable shift in land use patterns over two decades. During the first decade (2004–2014), agricultural land expanded significantly at an annual rate of 10.7%, primarily on barren land and open spaces, with prominent changes observed in the northern and northwestern parts of the city and areas along the Chashma Right Bank Canal (CRBC). Built-up areas increased at a modest rate of 1.53% annually, while barren land and open spaces decreased at a rate of -3.63%. The construction of the CRBC in 2003 was identified as a key driver, providing sufficient water for agriculture, which not only increased cultivated land by over 700 hectares but also introduced new crop varieties, such as sugarcane, whose cultivated area doubled from 2004 to 2014.

The second decade (2014–2024) witnessed a rapid increase in built-up areas, growing from 1,834.34 hectares in 2014 to 2,969.1 hectares in 2024, with an annual growth rate of 6.18%. Conversely, agricultural land decreased from 2,183 hectares to 2,064.07 hectares at an annual rate of -0.54%, while barren land declined from 2,430.8 hectares to 1,421.29 hectares at a rate of -4.14%. The driving forces behind these changes were the influx of internally displaced persons (IDPs) following military operations in South Waziristan in 2009 and natural population growth. D-I Khan's urban population tripled from 125,807 in 2014 to 362,231 in 2017, intensifying demand for housing and leading to the conversion of prime agricultural land and open spaces into residential colonies.

The study also underscores the impact of land use change on land value, which increased significantly between 2004 and 2024. The highest land values were recorded in the city centre, particularly between North and East Circular Roads, Shami Road, and the Topanwala area, driven by land scarcity and urban densification. Despite the relatively low annual decline in agricultural land (-0.54%) during the second decade, the shift from an annual increase of 10.7% in the first decade to a decline underscores the growing pressure on agricultural land due to urban expansion. The study concludes that population growth, migration, and land value escalation will likely exert further pressure on agricultural land in the coming decade, highlighting the need for sustainable urban planning and land management strategies. Urban sprawl and its impact on agricultural land are a global phenomenon. However, while international studies extensively explore the consequences of urban sprawl, limited research specifically addresses the role of conflict-induced displacement in driving land use change, particularly in Pakistan. This study bridges that gap by highlighting how the influx of IDPs from South Waziristan contributed to rapid urban expansion in D-I Khan.

Moreover, the study adds to global discourse by demonstrating how large-scale irrigation projects, such as the CRBC, can simultaneously promote agricultural growth and indirectly fuel urban sprawl. The findings stress the need for integrated land management strategies, aligning with global recommendations for sustainable urban growth (UN-Habitat, 2020). This study provides a foundation for future comparative research, urging urban planners and policymakers to balance urban expansion with agricultural preservation to ensure food security and sustainable

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development.

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Author's Contribution
All authors contributed to the conception and design of the study. Material preparation, data collection and analysis were carried out by Muhammad Ibrahim and Muhammad Jamal Nasir. Muhammad Ibrahim wrote the first draft of the manuscript, and all authors provided feedback and revisions to earlier versions of the manuscript. All authors read and approved the final version of the manuscript.

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Conflict of Interests
The authors declare no conflicts of interest.
Ethical Considerations
The study adheres to all applicable ethical standards and guidelines.

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