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Spatio-temporal Analysis of Land Use and Land Cover Change in Kirtipur Municipality

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Abstract

This study examines land use and land cover (LULC) dynamics in Kirtipur Municipality, Nepal, from 2005 to 2025 and analyzes the relationships among parameters influencing built-up expansion. This study used GEE and GIS techniques to process multi-temporal imagery from Google Earth Pro (2005, 2010 and 2015, 2020 and 2025). While GWR evaluated the spatial impact of topography, accessibility (road), and socioeconomic (population and building density) factors, and manual digitization were used to create LULC maps. Cultivated land decreased from about 69% to 49%, while built-up areas grew from about 11% to 32%. Waterbodies, shrubland/grass, and forests remained mostly unchanged. Urban growth seemed to be expanded towards flat to gently sloping terrain along the major roads, CBD, and markets. Over time, the direction of expansion shifted from the northern to the southern and southwestern regions. Institutional expansion, population growth, migration, and sociocultural changes were important drivers. The study emphasizes the importance of integrating agricultural land protection with urban planning to ensure sustainable development in Kirtipur Municipality.

Keywords: *LULC, urban expansion, GIS, CBD, GWR*

Introduction

Land use and land cover (LULC) are the physical components of the environment that are constantly modified by natural and human activities (Rimal *et al*., 2024; Edosa & Nagasa, 2023), and their transformation captures the complex relationships between socio-economic development and environmental systems (Kafle *et al*., 2023) which is important for sustainable urban planning and environmental management. Urbanization, or the increase in size and spatial extent of cities, is a universal global process that is highly prevalent in developing countries (Paudel *et al*., 2024; Hegazy *et al*., 2015), and rapid and uncontrolled urban sprawl has posed significant challenges to effective planning, ecosystem conservation, and food security (Bhatia *et al*., 2024; Yasin *et al*., 2025). With population increase, industrialization and infrastructure development there is conversion of natural and agricultural lands to built-up land use which causes major socio-economic and environmental changes (Zhou *et al*., 2021; Acharya *et al*., 2025; Aryal *et al*, 2023). The development of a road network, especially pubic bus route, is one of the most influential factors in urban expansion, reorganizing urban spatial structures and altering regional ecological systems (Mo *et al*., 2024). Thus, development of transport has always been considered among the main factors that determine the urban forms (Pratama *et al*., 2022).

Rapid urban growth caused by population expansion and infrastructure advancement has led to significant LULC changes, especially at the expense of agricultural land, forests, and other natural covers (Zaman and Real, 2025; Aggarwal and Garg, 2024; Zhai *et al*., 2021). At the city scale, human activities remain the main drivers of LULC change, and these changes significantly affect biodiversity, ecosystem productivity, and carbon storage (Wang *et al*., 2021; Xie *et al*., 2023; Seto *et al*., 2012). For instance, the growth of built-up areas in Nepal has primarily been at the expense of agricultural lands, which demonstrates the pressure of urban growth on the limited land resources in Nepal (Devkota *et al*., 2023), which requires more attention to sustainable land-use planning strategies (Bhomi *et al*., 2024; Khan *et al*., 2025).

The concentric zone model (Burgess,1939) advocates a city with a central business district at its core, surrounded by successive rings of land uses. On the other hand, the multiple nuclei theory (Harris & Ullman 1945) postulates that cities develop various centers of activities or nuclei as localized business districts for surrounding neighborhoods thereby disputing the assumption of having only one central business district in Burgess's model. On the other hand, sector theory (Hoyt, 1939) postulates that the patterns of urban land use develop in wedge-shaped sectors radiating out from the center of a city based on major routes and channels of transportation and communication. Thus, Urban land use is inherently dynamic, influenced by the spatial context of city-area activities and their temporal changes (Chen *et al*., 2023, Devkota *et al*., 2023). The first law of geography defines spatial variability of relationship depends on spatial distance that can be addressed by Geographically Weighted Regression Model (Fotheringham, *et al*., 1998; Tobler, 1971).

The study of LULC change is crucial to sustainable urban management. Although most studies consider regional or national scales, few consider long-term municipal dynamics and the expansion of built-up areas. They usually consider the combined influence of socioeconomic, environmental, and infrastructural factors. In this study, multi-temporal LULC changes (2005–2025) are analyzed, and the combined influence of these factors on urban growth is assessed, providing insights for sustainable urban planning and land management.

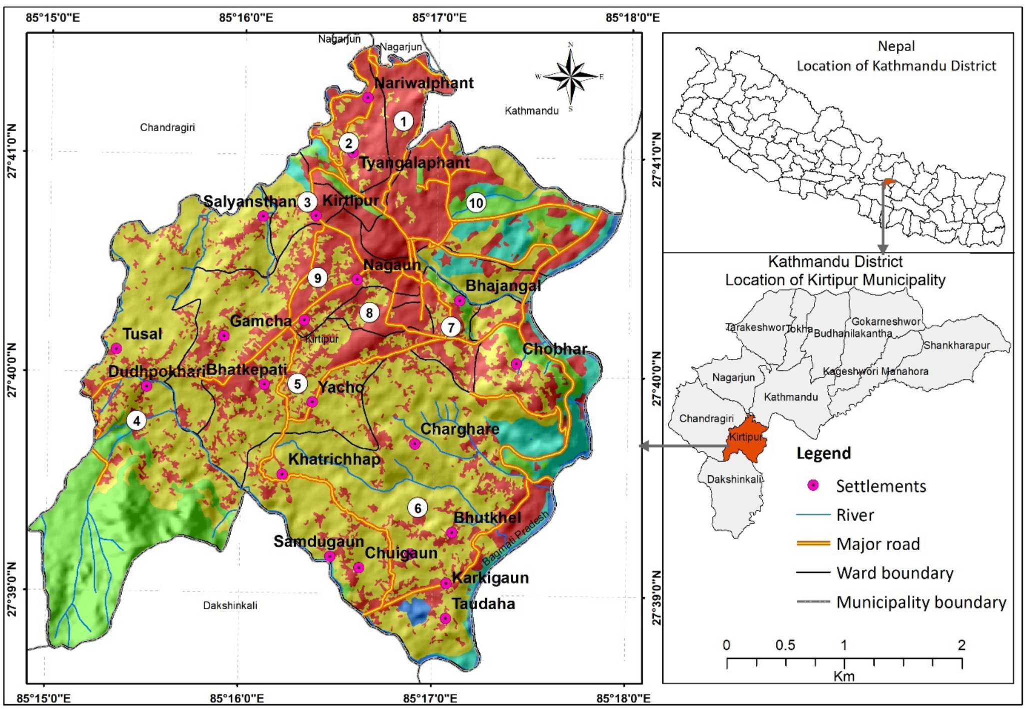
Materials and Methods

Study Area

The study area (Kirtipur Municipality) is located in the southwest part of Kathmandu Valley within Bagmati Province which lies 7 kilometers away from the city center of Kathmandu Metropolitan City. The area lies between 27°38′37″ and 27°41′36″ North latitude and 85°14′59″ to 85°18′00″ East longitude. Its elevation ranges from 1,284 to 1,524 meters above mean sea level (DoS, 1994). It is bounded by the Bagmati River to the east, Chandragiri municipality to the west, Kathmandu Metropolitan City to

Figure 1

Location of the Study Area



the north, and Dakshinkali municipality to the south. The area lies in a transitional zone between Kathmandu's dense urban core and the greenery hilly outskirts of the valley. The municipality has 24,150 households and a population of 81,578. The area has an average household size of 3.38, and the population density is 5,527 persons per square kilometer (NSO, 2022). In terms of population density, it is the fifth-highest among the 21 municipalities of Kathmandu valley. Population distribution varies across administrative ten wards, with higher concentrations near markets and major roads, and lower densities in the peripheral agricultural and hilly areas. The major settlements of Kirtipur municipality are Panga, Nagau, Itagol, Nalagol, Gamchaa, Dhalpa, Chitubihar, Samal, Bhatkepati, Bhajangal, Chobhar, Pandechhap, Naumule, Dudhapokhari, Taudaha, Tyangla Phat, Mitranagar, Chaadanichok etc. The city is recognized as one of the ancient historical settlement of Nepal (Figure 1).

Data and Methodology

Data Processing and Acquisition

The present study is based on the analysis of maps and associate attributes collected from the primary and secondary sources (Figure 2). The time series data were used to find out the land use change in by using spatial analysis of ArcGIS software. These time series data were extracted from Google Earth Pro images for the year of 2005, 2010, 2015, 2020 and 2025. To keep things consistent, all polygons are classified by the visual interpretation and similar categories in each time, and pre-processed them in vector format, so that the data would line up across the years. In the same way, necessary data of population attributes have been collected from the report of population statistics from the Nepal statistics Office (NSO). The profile report of municipality has been used for additional information. In addition, data from Open Street Map (OSM) and Google Maps are also used. For primary data, five key informants' surveys have been conducted in the field and field observations, which gave us a better idea of the social and economic factors shaping urban development and land use trends. The study area was classified into five major LULC categories: built-up, cultivated land, forest, shrubland/grass, and waterbody/sand with a focus on urban expansion. All these layers of the mentioned time periods were analyzed by using GIS tools (e.g. union and intersect in ArcGIS) to overlay pairwise and compute areas of transition and quantifying gains and losses between classes for each interval.

Preparation of Explanatory Variables

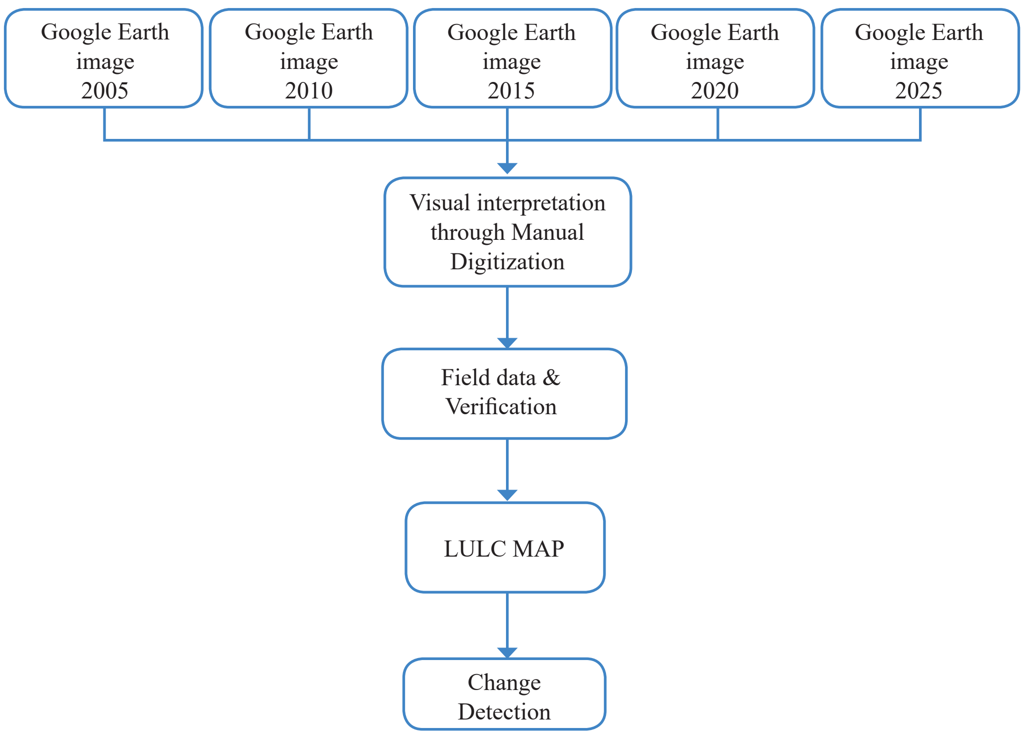
Explanatory variables such as the slope, solar exposure was derived from 12.5-meter resolution Digital Elevation Model (DEM) obtained from ALOS 2007 (Alaska Data

Facility, 2025) using ArcGIS tools; and distances to roads, rivers, and public facilities were used from OpenStreetMap (2025) datasets using kernel density estimation methods. Population for intermediate years was projected from census-based growth rates. To ensure uniformity in geographical analysis, all explanatory variables were normalized before further processing.

GIS-based overlay analysis, directional trend analysis, and geographically weighted regression (GWR) used to explore spatial and temporal patterns of built-up land expansion because it is able to address local variability of dependency that is not possible by global regression model (Zhao *et al*. 2018). These studies were conducted in ArcGIS 10.3 to determine the relative impact of socioeconomic, infrastructure, and environmental elements. The spatial correlation and model accuracy were assessed using Global Moran's I and Local Moran's I statistics.

Figure 2

Methodological Flow of Data Processing



Results and Discussions

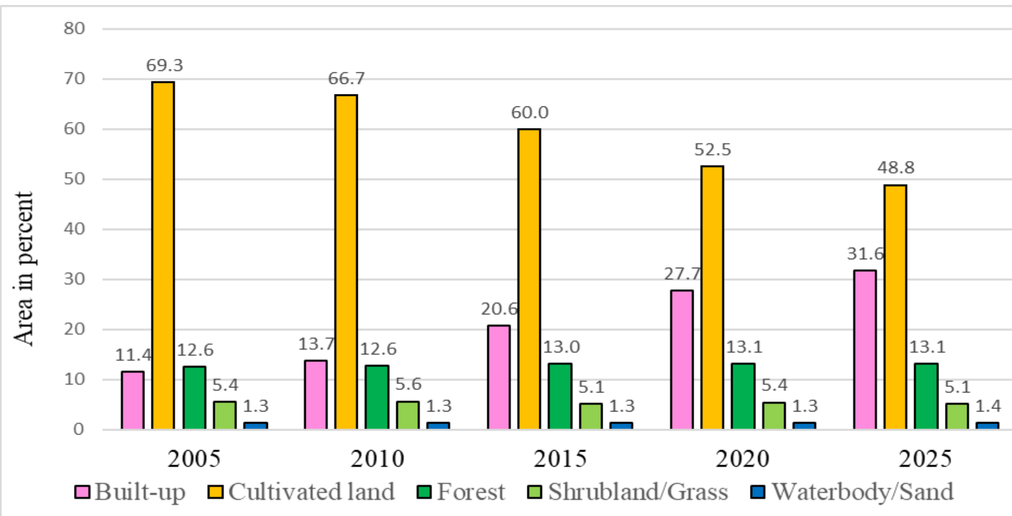
Spatial and Temporal Distribution of Land Use and Land Cover

Among the five-land use and land cover (LULC) types identified in the research area, cultivated land, forest, and built-up areas became the most common. Cultivated land became the most common land use during the study period. It occupied 69.27% of the entire area in 2005 but possesses rapidly reduced to 48.82% by 2025. This reduction mainly occurred by the transformation of agricultural land into built-up regions. The most significant loss happened between 2010 and 2015, when cultivated land decreased from 66.70% to 59.98%, along with a period of increasing urbanization and infrastructure development.

As a result, built-up areas expanded significantly over the years. The number of them increased from 11.43% in 2005 to 31.64% in 2025, with a particularly high increase observed between 2010 and 2015 and 2015 and 2020. In 2025, however, built-up land became the second-biggest LULC type, which indicates a substantial shift toward urban land use within the municipality.

Figure 3

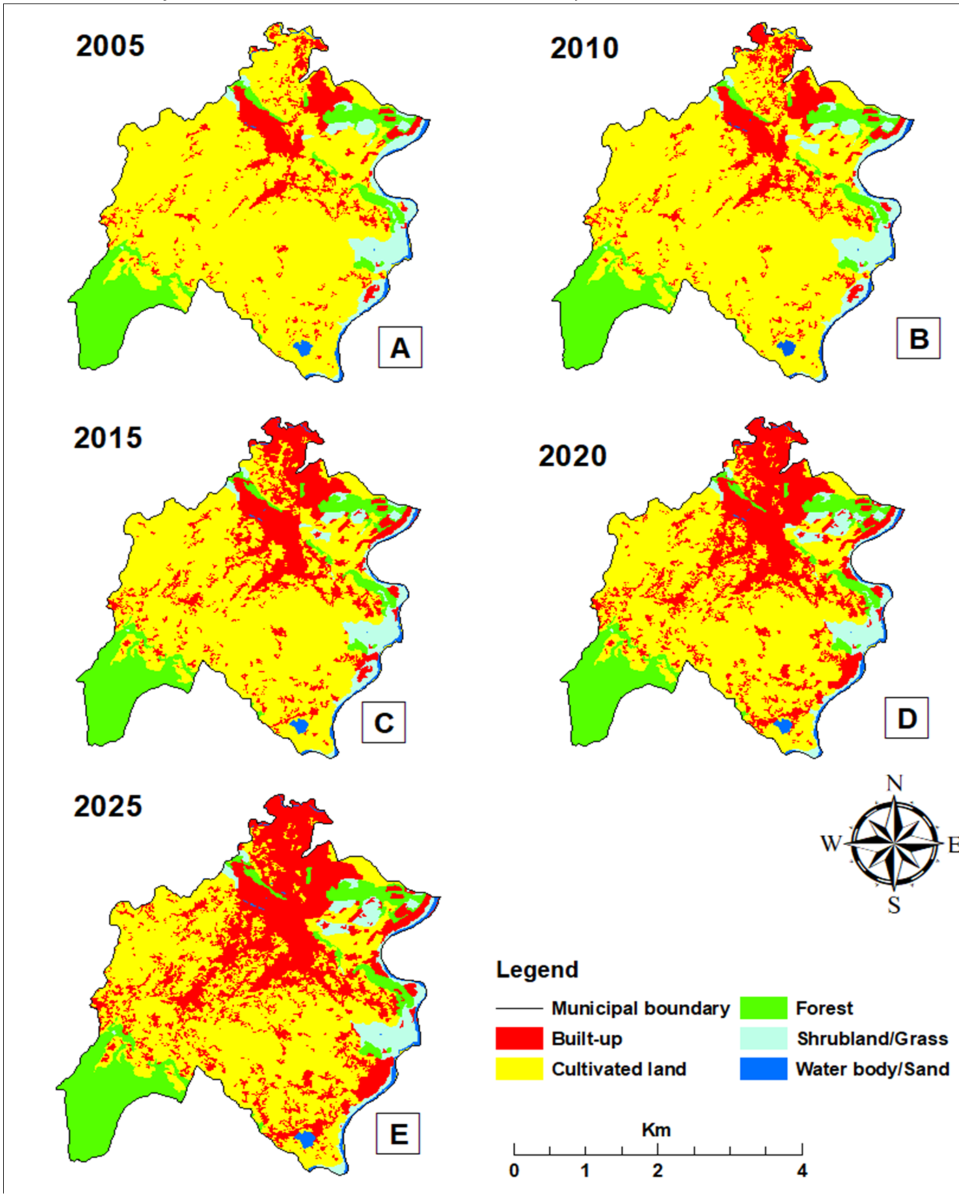
Distribution of Land Use and Land Cover in the Year of 2005, 2010,2015, 2020, and 2025



Forest cover remained constant during the study period, with small modifications and a small increase from 12.55% in 2005 to 13.05% in 2025. Whereas, Shrubland and grassland showed minimal change, with a small decrease from 5.43% to 5.12%, which suggests small change to built-up land. Similarly, water bodies and sand regions observed low change, increasing slightly from 1.32% to 1.36%, indicating minor human disturbance in these land cover types (Figure 3).

Figure 4

Distribution of Land Use/Land Cover in the Study Area



Source: Google Earth Image.

Land Use and Land Cover Change

Between 2005 and 2025, the built-up areas increased by 298.39 ha, or 20.21%. During the same time, the cultivated land declined by 301.74 hectares (20.45%) that indicates a significant shift of agricultural land to urban use. While forest cover remained almost same that increased by 7.47 ha (0.50%). Additionally, the shrubland and grassland lost 4.52 ha (0.31%), while water bodies and sand areas rose by only 0.55 ha (0.04%). Overall, these changes illustrate municipality gradual change from an agricultural productive land to growing urbanization (Figure 4 and Table 1).

Table 1

Land use and Land Cover Change in Kirtipur Municipality from 2005 to 2025

Land use type	Year					
	2005-2015		2015-2025		2005-2025	
	Area (ha)	%	Area (ha)	%	Area (ha)	%
Built-up	135.94	9.21	162.45	11.00	298.39	20.21
Cultivated land	-137.01	-9.29	-164.73	-11.16	-301.74	-20.45
Forest	7.20	0.49	0.27	0.01	7.47	0.50
Shrubland/Grass	-5.02	-0.35	0.50	0.04	-4.52	-0.31
Waterbody /Sand	-0.94	-0.06	1.49	0.10	0.55	0.04

Source: Pakhrin, 2025.

Patterns of Built-up Area Expansion

Built-up and Population Change

The ward-level study shows that the development of built-up areas generally followed population growth. However, the process of land shift frequently exceeds the rate of demographic change (Table 2). The four wards 2, 4, 5, and 6 noticed significant rises in built-up land with Ward 2 having the fastest growth rate (410.14%). whereas other wards, such as Ward 8, experienced relatively moderate population growth (2.14%) but significant increases in built-up areas (157.28%). This pattern indicates that urban expansion is influenced by infrastructure (road, health centers, etc.), institutional development (University, banks, etc.), and efforts of planned projects rather than population growth alone. The linear regression confirms a moderate relationship between population and built-up change ($\beta = 1.2293$, $R^2 = 0.50$), which shows that other factors also contribute a substantial impact on the spatial dynamics of urban growth (Figure 5).

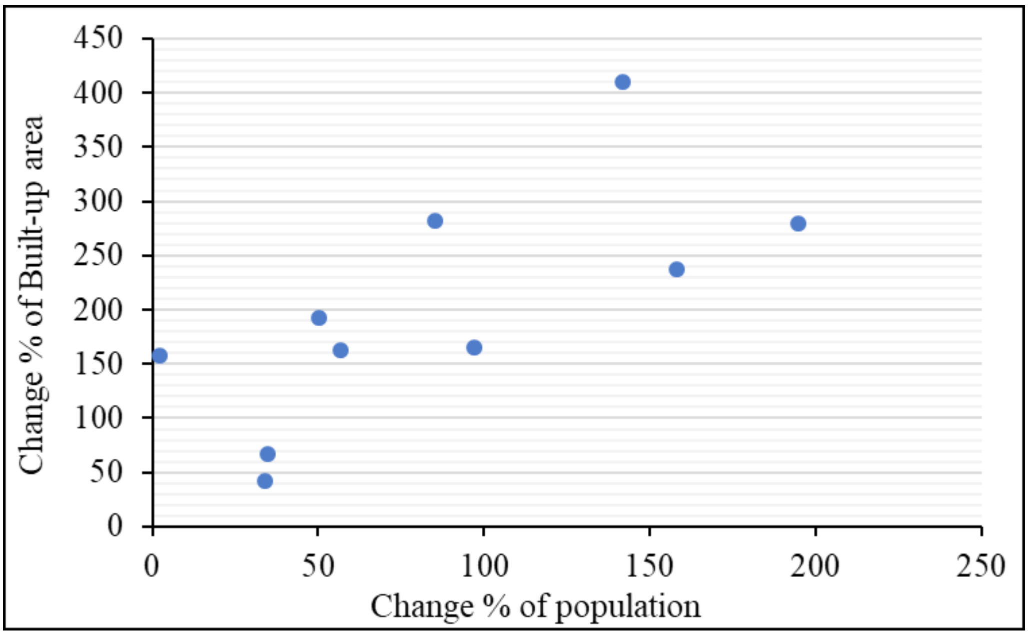
Table 2

Population and Built-up Area Change in the Study Area (2005-2025)

Ward	(2005-2025)	
	Changed % Pop	Changed % built-up
1	56.62	162.75
2	141.95	410.14
3	33.80	41.63
4	158.18	237.20
5	194.54	280.19
6	85.28	282.66
7	97.00	165.08
8	2.14	157.28
9	50.19	192.66
10	34.86	66.64

Figure 5

Relationship Between Built-up Area and Population



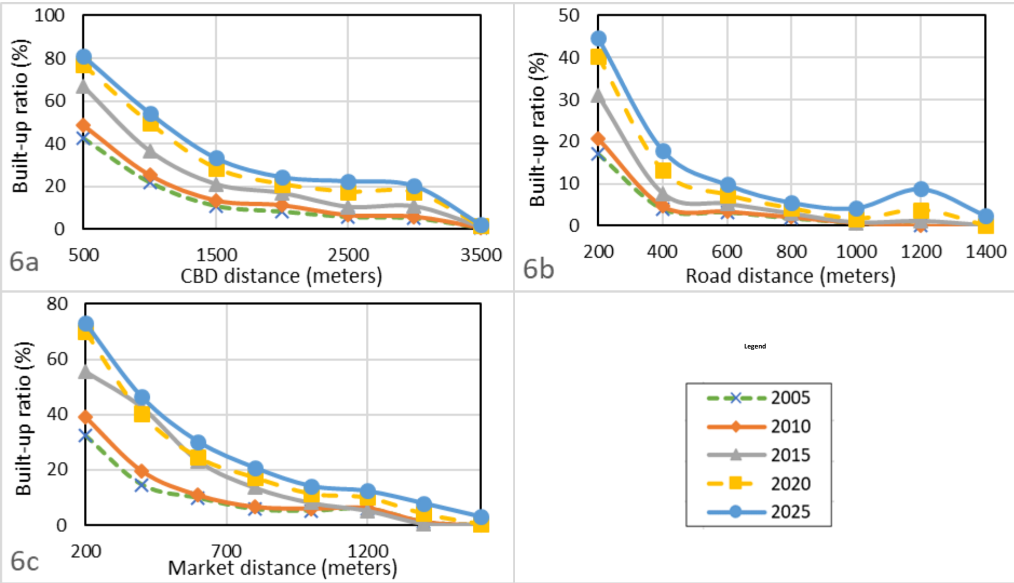
Built-up Distribution by Proximity to the CBD

Development intensity declined with distance from the CBD. Areas within 500 m of the CBD increased from 42.44% built-up in 2005 to 81.03% in 2025 which represent

5.2 times of growth magnitude whereas peripheral zones experienced slowly gradual growth. This gradient highlights the central role of the CBD in urban expansion and the outward-radiating pattern of development (Figure 6a).

Figure 6

(6a) Aerial Distance (meter) from CBD and Percent of Built-up Area, (6b), Road Distance (meter) from CBD and Percent of Built-up Area, and (6c) Distance to Markets (meter) and Percent of Built-up Area from 2005-2025



Built-up Area Distribution by Distance to Major Roads

The highest built-up area density occurred within in 200 meters of major roads increasing from 17.11% in 2005 to 44.60% in 2025. This represent the growth magnitude is 2.6 times increased over 20 years which indicating rapid urbanization in this zone. More distant zones also experienced growth due to improved connectivity through secondary roads, demonstrating that road networks facilitate both adjacent and corridor-oriented urban expansion (Figure 6b).

Built-up Distribution by Distance to Markets

Urban expansion showed an interesting distance-decay pattern around markets. In 2005, the built-up area was 19.51 percent within 500 meters of markets, increasing to 51.87 percent by 2025. This result showed that only about one-fifth of land near markets was built-up whereas by 2025, this grew to more than half showing rapid urban expansion and densification around market areas. Growth was significant up to 1,500 meters, while areas beyond 2,000 m remained largely undeveloped, demonstrating the strong influence of commercial hubs on local land conversion (Figure 6c).

Built-up Distribution by Slope

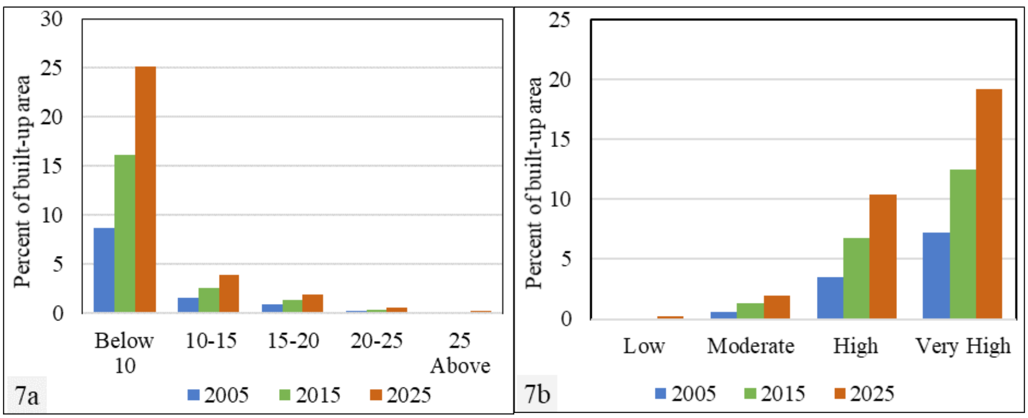
Built-up development focused mainly on less steep slopes and areas with slopes less than 10 observed a significant rise in built-up covering, which rises from 8.68% in 2005 to 25.20% by 2025. Moderate slopes that varied from 10° to 15° showed substantial growth, but at lower rates. However, places with slopes greater than 15° showed comparatively little development and highlighting the topography restricting role on urban expansion (Figure 7a).

Built-up Distribution by Solar Radiation

Built-up areas concentrated in the areas with more solar exposure and the regions with extremely high solar exposure noticed an increase in built-up covering from 7.25% in 2005 to 19.17% in 2025, and regions with high solar exposure increased from 3.53% to 10.35% during the same period. However, places with less solar exposure observed relatively slow growth. This pattern indicates that environmental suitability influences settlement distribution and urban development (Figure 7b).

Figure 7

Percentage of Built-up Area by Slope Degree (7a) and by Sun Exposure (7b) (2005, 2015, 2025)

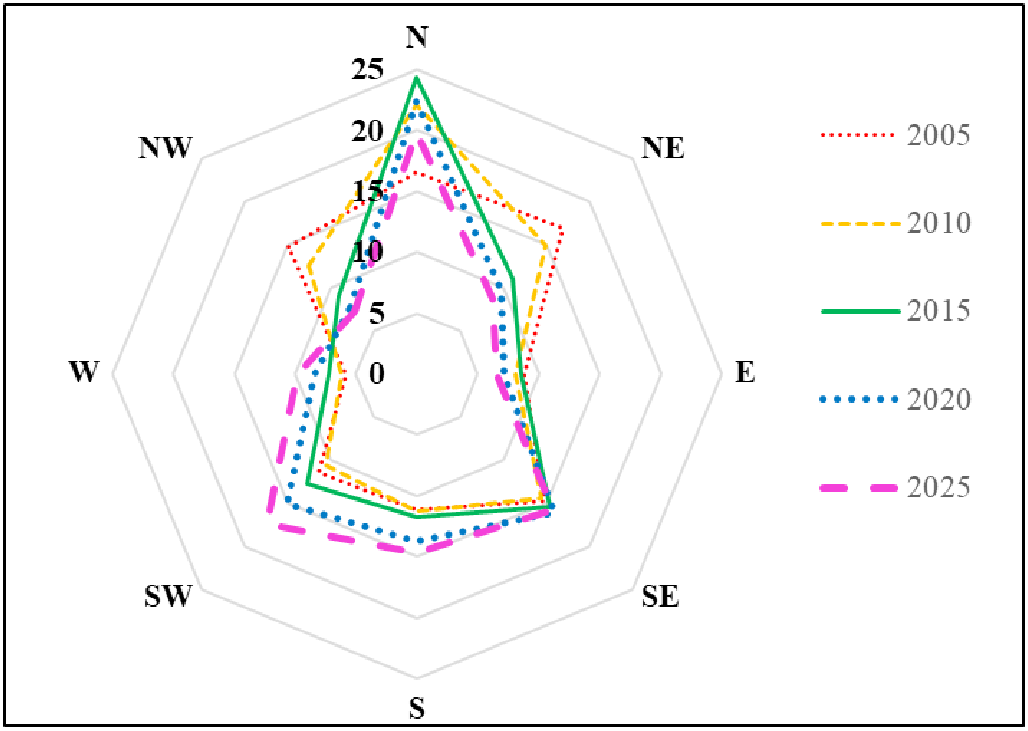


Directional Patterns of Urban Expansion

The directional analysis shows a definite shift in urban expansion from the north to the south of the studied area over the years. In 2005, the northern regions (North, North-East, and North-West) represented 48.23% of the total built-up area, however, by 2025, this proportion decreased to 35.83%. whereas, the southern areas (South, South-East, and South-West) experienced significant growth, growing from 37.23% to 47.85% during the same period. The eastern and western regions experienced comparatively little changes. This shift in direction represents differences in land availability, accessibility, and infrastructure development, particularly important transportation corridors. In general, the results show the gradual geographical shift of urban growth inside the municipality during the last two decades (Figure 8).

Figure 8

Percentage Distribution of Built-up Land Across Directions (2005-2025)

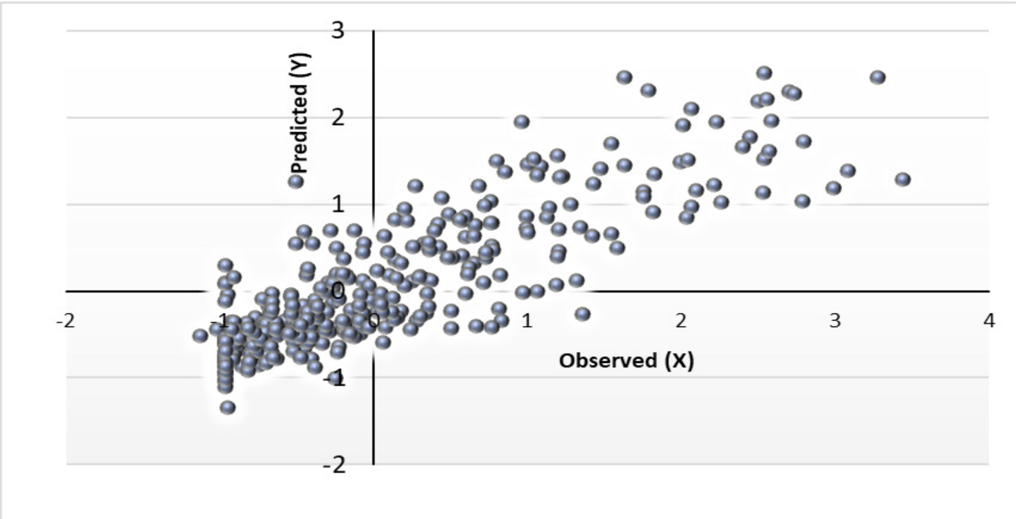


Spatial Dependency of Built-up Area Changes

The geographically weighted regression (GWR) model describes 73% of the spatial variation in built-up land change ($R^2 = 0.73$), which shows the impact of both accessibility and bio-physical factors (rivers, slopes, aspects etc) in urban expansion. The closeness to road networks and public facilities possessed an important beneficial effect on built-up expansion in the central and southern valleys. However, the steep slope, close to rivers, and sun radiation restrict growth in the surrounding hilly regions. The model validation findings showed high predictive ability, highlighting the significance for including local spatial variation for studying urban growth dynamics (Figure 9).

Figure 9

Observed Versus Predicted Values of Built-up Change



The model validation findings demonstrated high predictive ability, underscoring the importance of incorporating local spatial variation in studying urban growth dynamics. Figure 9 shows the predictive accuracy of the GWR model. The distribution of points with an upward trend from left to right indicates that the model captures the overall pattern in the variables. Many points clustered around an implied 1:1 line, suggesting reasonably good predictive performance of the model. Prediction values are more compressed at lower observed values, while there is a noticeable spread of predicted values at higher observed values. It means under- and over-prediction at extreme observed values.

Conclusion

Kirtipur Municipality's land use and land cover (LULC) experienced major transformations between 2005 and 2025, with agricultural lands changing to urban areas. In 2025, built-up regions occupied about one-third of the total municipal area. This development occurred mostly by the conversion of cultivated land, but forest cover, shrubland, and water bodies remained unchanged by the research time. The growth of cities focused primarily on flat slightly sloped terrain with increased sun exposure, as well as areas close to major road networks, the central business district (CBD), and markets. The spatial framework of urban expansion further demonstrated a constant directional shift over time.

Early development focused on institutional and historic centers in the northern sectors, with outward expansion into agricultural regions in the south and southwest of the municipality. These developments are influenced by a variety of reasons, including institutional growth, particularly the expansion of Tribhuvan University, as well as population growth/migration, infrastructure (near the east-west highway and influence of Tarai fast track road development), and broader sociocultural transformations. The geographically weighted regression (GWR) model showed that for 73 percent of the spatial variation in built-up expansion, highlighting the combined significance of accessibility and environmental factors in driving urban growth patterns.

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