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Examining Trend and Characteristics of Urban Sprawl in Kathmandu Valley

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Abstract
This paper examines the spatiotemporal pattern of urban growth in Kathmandu Valley between 2000 and 2020 using land use change analysis and spatial metrics technique. The study demonstrates that urban growth in the Valley during the study period is characterized by increased densification in the central or more urbanized areas through infill development followed by increased fragmentation of built-up area in the fringe areas indicating sprawl. Between 2000 and 2010, the built-up area increased by 2.38 times whereas population increased by 1.57 times during the same period, which indicates a sprawl pattern of urban growth. Likewise, between 2010 and 2020, the built-up area increased by 4.68 times compared to a projected rise in population by 2.47 times, indicating further sprawl development in the peri-urban areas. The fragmentation of lands in the peri-urban areas has further resulted into heterogeneous land use combinations. However, due to increase in infill development, the neighborhood distances between built-up patches are decreasing, indicating possible increment in homogeneity in favor of built-up area in the future.

Keywords
Land use change, spatial metrics, urban sprawl, urbanization spatial pattern

1. Introduction

From one of the least urbanized countries in Asia, Nepal in recent years has emerged as one of the most rapidly urbanizing countries in the world. As of 2011, only 17.1% of its population lived in 58 designated urban areas with an inter-censual urban growth rate of 3.43 [1]. With the number of designated urban areas escalated to 293 in recent years, the level of urbanization is also expected to have jumped rapidly. As the main political and administrative centre, a major tourist gateway, and an economic hub, the Kathmandu Valley has remained for long as the largest urban region in Nepal, comprising of two metropolitan cities, 18 municipalities and some wards of two rural municipalities, covering an area of 721.87 sq. km. The Valley recorded a population of 2,468,316 in 2011, which accounted for nearly 22.4% of national urban population [2, 3]. The Valley population grew at an annual growth rate of 4.63% between 2001 and 2011.

The rapid urban growth can be attributed to various socio-political, economical and development of factors i.e., driver of changes and these drivers have had significant influence since 1970's and lack of effective planning and its implementation can be attributed to the urban sprawl observed in Kathmandu Valley. With expansion of roads linking Valley with other parts of country, economic opportunities, political and security issue after the Maoist insurgency from mid-1990s to mid-2000s, the Valley population grew rapidly with horizontal outward growth in the peri-urban areas to accommodate the increasing population, as central areas were already densely developed [3]. This high population influx, along with heterogeneous land use environment, has resulted into various environmental and social problems such as water shortage, lack of functional open spaces, pollution, and congestion, among others. Hence, though urban sprawl has resulted into affordable and cheaper housing in the Valley, the cost of sprawl has outnumbered the benefits.

Various driving factors have induced rapid urban growth in the Valley resulting to significant transformation of physical as well as social environment of the urban areas. Until 1980's, municipalities of the Valley had distinct urban boundaries and plenty of open and green space in between them. However, at present built-up areas in those municipalities have since aggregated into a large metropolitan area where cultivated lands and open spaces have been aggressively converted for residential purpose resulting into insufficient open spaces and further environmental degradation [4]. In the past, the Ring Road acted as the urban –rural boundary to a certain extent but sprawl development in peri-urban areas has resulted into inefficient and incompatible land use and haphazard land subdivision often led by informal land developers, requiring large investments for infrastructures development. Therefore, it is important to monitor the trend and characteristic of urban growth so that appropriate regulations can be imposed for planned urban expansion. The objective of this paper is to examine the trend and characteristics of urban sprawl in Kathmandu Valley through analysis of land use change and spatial metrics.

2. Literature Review

The term 'urban sprawl' was coined in 1937 by Earle Draper, the then Director of Planning at the Tennessee Valley Authority during a national conference of planners, referring it as an unaesthetic and uneconomic settlement form [5]. However, urban sprawl now involves various and conflicting views regarding its definition, measurement, causes as well as benefits and costs. While environmental activists and urban planners, among others, are concerned with the environmental and social aspects of sprawl, most urban economists prefer less value-laden terms such as urban decentralization, viewing it as an outcome of free market choices [6]. The form of development most often characterized as sprawl includes (i) leapfrog or scattered development; (ii) commercial strip or ribbon development; (iii) large expanses of low density or single-use development as appeared in Florida's anti-sprawl rule [7]. Florida's anti-sprawl rule also states indicators of sprawl which includes (i) poor accessibility, which refers to poor residential accessibility and poor destination accessibility due to increased distance between home and out of home activities which is usually resulted due to scattered, strip and low-density single use developments; (ii) lack of functional open space, as preserving large open spaces becomes difficult in presence of uniform low density of built forms with privatized open spaces [7]. In the case of Kathmandu Valley, sprawl is often manifested in the form of scattered development.

3. Methodology

The research falls under positivist paradigm, as the researcher is objective and concerned with acquiring knowledge through direct observations. In positivism, importance is placed on objectivity and evidences so that a researcher's analytical capabilities aren't corrupted [8]. The research objective of this paper relies on inductive method for reasoning and rationalizing for studying the trend and characteristics of urban growth in general and spatiotemporal change in built-up area, as it involves drawing conclusions from the observations made. Hence, quantitative methods such as remote sensing technique and spatial metrics were used for collection and analysis of the data.

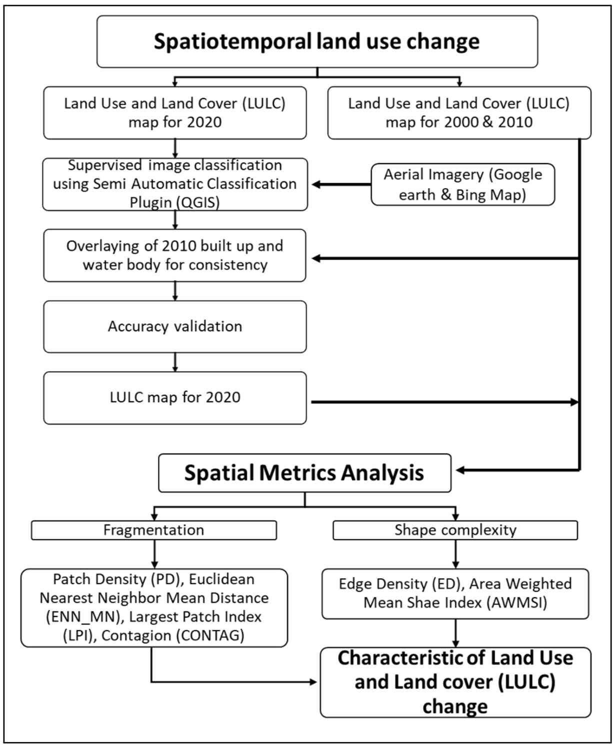

Figure 1: Theoretical Framework

To examine the spatiotemporal changes in built-up area, remote sensing technique was used. According to Lambin and Geist (2003), remote sensing is a commonly accepted technique for change detection [4]. Remote sensing provides spatially consistent data sets that cover large areas with both high spatial details and high temporal frequency [9]. Sentinel 2 image (resolution of 10m) of Kathmandu Valley was processed to prepare the LULC map of Kathmandu Valley and detect the spatiotemporal change in built-up area since 2000. The description of datasets used in this study is summarized in Table 1.

Table 1: Summary of datasets used in this research

Data type	Year	Resolution /Scale	Source
Raster Layer and Satellite Imageries			
Sentinel-2	2020	10m	Copernicus Open Access Hub
Aerial Imageries	2000		Google Earth and Bing Map
Land Use Map	2000		KVTDC (2006)
Vector Layers			
Land Use Map	2000	30m raster	UNDP (2013)
Land Use Map	2010	30m raster	UNDP (2013)
Land Use Map	2015		KVDA (2015)

Table 2: Land Use and Land Cover (LULC) Classes

Class	Description
Built-up	Structures of all types, roads within settlements, industries, institutions, special zones, WHS, airport and bus park
Cultivated	Croplands, temporary grasslands
Forest	Tree covered area
Barren land	Vacant land, open areas, and fallow lands
Water body	Rivers, Flood plain, Ponds (man-made and natural)

Note: Industries, WHS, Institutions, Special Zone, Airport and Bus Parks were overlayed on LULC maps of 2000, 2010, and 2020 based on land use map prepared by KVTDC (2000) and land use map prepared by KVDA (2015), Google and Bing aerial imageries as fragmentation within these zones cannot be considered as urban sprawl.

In this study, pixel-based approach was used to detect the LULC change pattern where the pixels of the raster image were classified based on the pixel reflectance value using Semi-Automatic Classification Plugin (SCP) in QGIS. Supervised image classification technique was used where a minimum of 100 training sites were selected for five land use categories namely, (i) built-up, (ii) cultivated, (iii) forest, (iv) barren and (v) water bodies (Table 2), and were classified using minimum distance algorithm in SCP. Accuracy assessment of the prepared LULC map of 2020 was conducted by taking 50 samples for each class where overall accuracy of 93.03% and kappa value of 0.892 were obtained. According to Anderson (1971), the minimum level of interpretation accuracy in the identification of LULC categories from remote sensor data should be at least 85% [10]. Additionally, various kappa values reflect degrees of agreement in the following manner: less than 0: no agreement; 0–0.2: slight; 0.2–0.41: fair; 0.41–0.60: moderate; 0.60–0.80: substantial; and 0.81–1.0: almost perfect agreement.

Table 3: Description of spatial metrics

Spatial Metrics	Description
Patch Density (PD)	PD equals the number of patches of the corresponding patch type per 100 ha. of total landscape area and measures fragmentation of the area
Euclidean Nearest Neighbor Mean Distance (ENNMN)	ENNMN is the distance mean value of all patches of a land use to the nearest neighbor patch of the same land use based on shortest edge to edge distance and measures isolation/ proximity
Largest Patch Index (LPI)	LPI equals the area of largest patch of the corresponding class divided by total area covered by that class, multiplied by 100 and measures dominance
Contagion (CONTAG)	Contagion measures interspersion of patch type i.e., the intermixing of units of different patch types as well as patch dispersion i.e., the spatial distribution of a patch type across the landscape
Edge Density (ED)	ED equal the sum of the lengths of of all edge segments involving a specific class per ha. of the total landscape area and measures the fineness or coarseness of each patch in the landscape
Area Weighted Mean Shape Index (AWMSI)	AWMSI is the area weighted normalized patch perimeter to area ratio in which complexity of patch shape is compared to a standard shape (square) of the same size

Source: [11]

For spatial metrics analysis, the vector layers of LULC maps of 2000 and 2010 (originally prepared using LANDSAT 30m resolution) were converted to raster images with resolution of 30m. Similarly, the LULC map of 2020 (10m resolution) was converted to 30 m resolution for uniformity among the maps. The maps were imported in FRAGSTAT in QGIS where spatial metrics listed in Table 3. were calculated to assess the patch fragmentation, complexity and compactness.

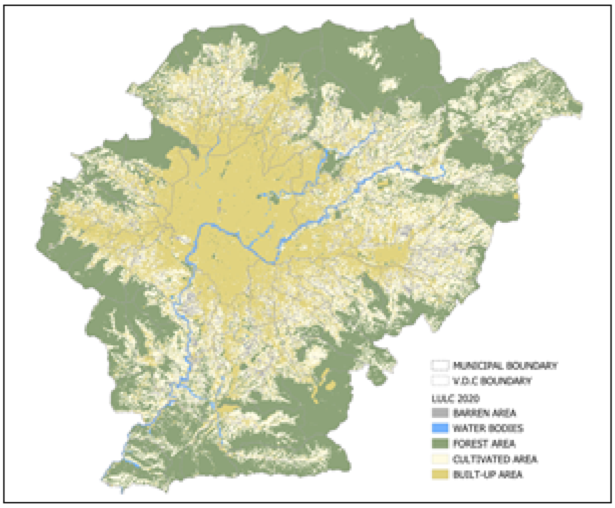

Figure 2: Land Use and Land Cover map (2020) of Kathmandu Valley (Source: author)

4. Results

4.1 Trend of urban growth in Kathmandu valley

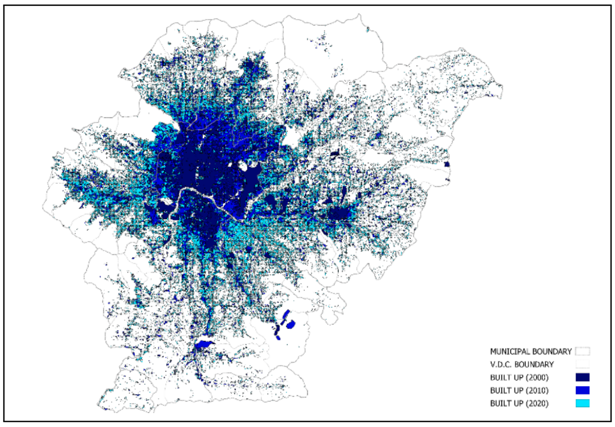

Figure 3: Built up change in Kathmandu Valley from 2000- 2020 (Source: Author)

Changes in land use, primarily from agriculture and vegetation to built-up area, are the most apparent sign of urban growth [3]. Until 1980's, built-up areas in Kathmandu Valley were limited to traditional settlements of the Kathmandu, Lalitpur and Bhaktapur districts whereas outward expansion began in early 1990's with further expansion in 2000's along the major roads that linked core areas with the outskirts replacing the fertile farmlands [4].

Table 4: Summary of land use and land cover change in the period 2000–2020

Class	Unit	2000	2010	2020
Barren	ha.	4157.37	630.72	2854.53
	%	5.76	0.87	3.95
Water	ha.	878.58	862.83	873
	%	1.22	1.2	1.21
Forest	ha.	32191.74	26725.86	28782.36
	%	44.59	37.02	39.87
Cultivated	ha.	30603.51	33601.23	19246.41
	%	42.39	46.54	26.66
Builtup	ha.	4363.47	10374.03	20438.37
	%	6.04	14.37	28.31
Total	ha.	72194.67	72194.67	72194.67
	%	100	100	100

Table 3 summarizes the trend of LULC change in Kathmandu Valley from 2000 to 2020. The built-up area increased by 2.48 times from 4363.47 ha in 2000 to 10373.03 ha in 2010. Between 2010 and 2020, the built-up further increased by 1.97 times to 20438.37 ha. The 2000-2010 period coincided with the decade-long Maoist insurgency which led to massive migration to the Valley and consequent boom in the housing market. During this period, significant development of scattered, low-density built-up area can be observed outside the then five municipalities [3]. The growth in built-up area continued in the 2010-2020 period as well with scattered, low-density development extending towards the outskirts of Kathmandu Valley. Overall, from 2000 to 2020, the total built-up area in the Valley increased by 4.68 times at the cost of other land use categories.

4.2 Growth in population and built-up area

Figure 4 demonstrates the trend of growth in population and built-up area from 2000 and 2020. The population for year 2001 and 2011 is obtained from the respective National Census data while the population for 2021 is geometrically projected at the rate of 4.63% [3]. From Figure 4, it is evident that the built-up area has increased more rapidly relative to the population growth. While the population increased by 1.57 and 2.47 (projected) times between 2001-2011 and 2011-2021 respectively, the built-up area has increased by 2.37 and 4.68 times during the respective periods. The rapid increase in built-up area relative to the population growth suggests low density development which is a major indicator of urban sprawl.

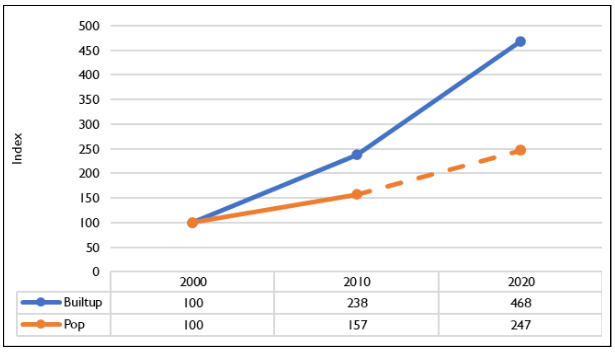

Figure 4: Population and built-up growth trend

Note: Population was geometrically projected for 2021 with 4.63% [3]; Population data is for years 2001, 2011 and 2021.

4.3 Spatial metrics analysis of Kathmandu Valley

Spatial metrics help in examining the characteristics of spatial urban growth in detail, which leads to a better understanding of urban sprawl. In figure 5, from 2000 to 2010, the PD of built-up area had increased moderately while a steep increase was observed between 2010 and 2020, indicating increase in fragmentation. By 2010, the central area of Kathmandu Valley had already reached saturation in terms of built-up area, so this suggests diversion of further development towards peri-urban areas of the Valley. The decrease in the PD of the cultivated area as observed in 2010 is due to the conversion of barren and forest patches to the cultivated patches followed by consolidation. Further fragmentation of cultivated area from 2010 to 2020 is attributed to an increase in built-up patches in peri-urban areas. From 2000 to 2020, the ENNMN of built-up patches was found to have decreased, suggesting an increase in the proximity between built-up patches due to infill development as well as an increase in the number of built-up patches. An increase in the proximity between cultivated patches can be observed, which can be attributed to increased fragmentation of the cultivated area patches the built-up area. The intermixing of patches was also found have decreased during the 2000-2010 period. This coincides with period when the built-up area in the urbanized areas of the Valley had already reached saturation along with significant conversion of barren and forest into cultivated patches. Further increase in intermixing of patches from 2010 through 2020 was resulted due to increase in built-up area patches in peri urban areas, which fragmented forest and cultivated areas. The LPI of cultivated patches was found to have increased in 2010 with significant conversion of barren and forest patches, consolidating and enlarging cultivated patches. On the other hand, the LPI of built-up area patches was observed to have increased steadily from 2000 through 2020, indicating consolidation of built-up area patches in the central areas of the Valley due to infill development.

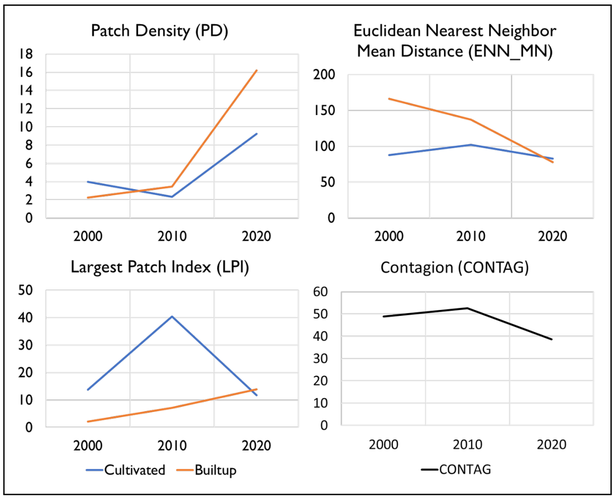

Figure 5: PD, ENNMN, LPI and CONTAG measuring patch fragmentation of Kathmandu Valley

The Edge Density (ED) and Area weighted mean shape index (AWMSI) measure shape complexity and irregularity respectively. In figure 6, the ED of cultivated area patches was found to have decreased between 2000 and 2010 before increasing from 2010 to 2020.This is because of a decrease in the number of cultivated patches in 2010. Similarly, the ED of built-up area patches was observed to have increased from 2000 through 2020 in correspondence to the increased number of built-up patches. Similarly, the AWMSI was observed to have increased for built-up area patches from 2000 through 2020, which suggests patches getting less compact and more complex probably due to infill development connecting the patches. Similarly, AWMSI of cultivated area patches was observed to have increased in 2010 due to massive conversion of barren and forest patches to cultivated patches connecting the patches, making their shape more complex.

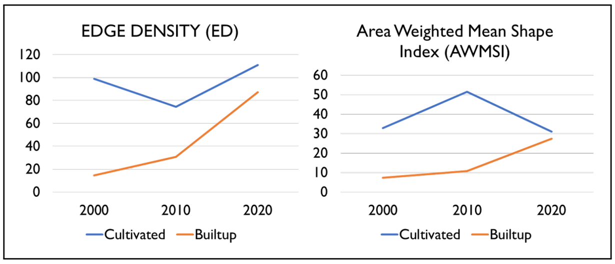

Figure 6: ED and AWMSI measuring patch shape complexity of Kathmandu Valley

4.4 Cross-sectional spatial metrics analysis of Kathmandu Valley

Cross-sectional spatial metrics analysis was conducted along north-south and east-west axes with Tinkune area as the central location to assess the change in spatial metrics across the Valley (Figure 8) using 1 km by 1 km grids.

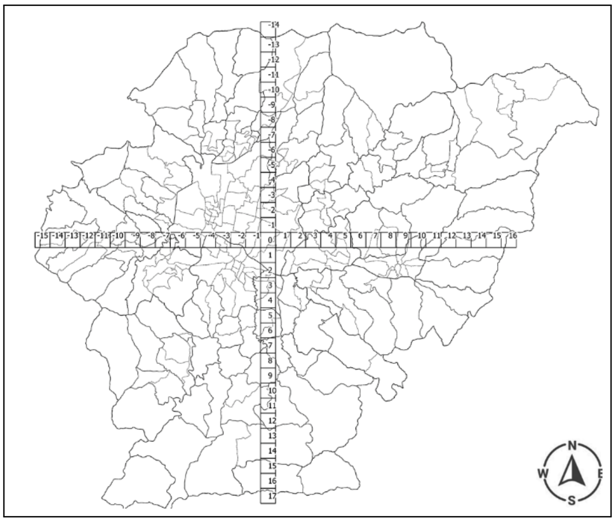

Figure 7: North-south and east-west cross-sectional spatial metrics analysis of Kathmandu valley

4.4.1 North-south cross-section

In 2000 (figure 8), the central areas of the Valley from Pipalbot (grid -6) to Balkumari (grid 2) along the north-south cross-section was observed to have experienced comparatively more fragmentation than the remaining areas along the cross-section. Along with high fragmentation, the proximity between the neighboring built-up area patches was also found to be low. However, in 2010, the PD was found to have decreased significantly in the stretch from Pipalbot through Balkumari area, resulted from infill development that further decreased the built-up area patches as well as reduced the distance between them. However, the PD increased in the surrounding areas of Kathmandu Metropolitan City (K.M.C.) i.e., from grids (-7 to -11) and grids (3 to 9) due to shifting of development in these areas as land availability began to decrease in the central areas.

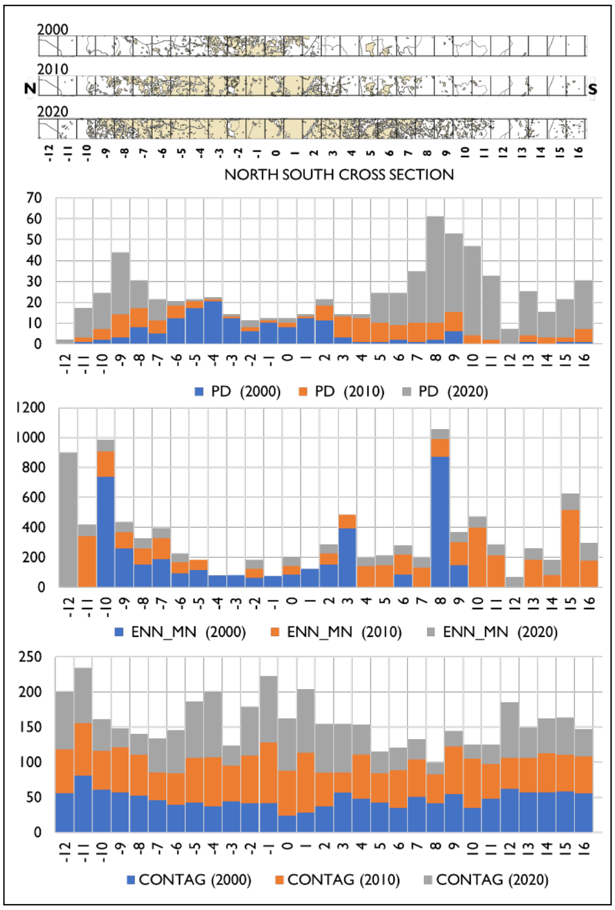

Figure 8: PD, ENNMN and CONTAG analysis along the north-south cross-section of the Valley

Along with emergence of new built-up patches, the mean neighbor distance between the patches were also found to be decreasing in the peri urban areas. By 2020, the built-up patch density had further decreased in the central area and aggressively increased in peri-urban area significantly in grids (-8 to -11) and grids (5 to16). The mean neighbor distance in these areas was found to have decreased further indicating scattered development in these areas. Likewise, with larger built-up patches within Kathmandu Metropolitan City in 2000, the land use was more heterogeneous in the central area. However, with an increase in built-up within the urban core, land use was observed to be more homogeneous in 2010 and 2020 while the areas surrounding KMC showed increasing trend of intermixing along the cross section as shown by CONTAG chart.

4.4.2 East-west cross-section

In 2000, the PD was found to be high within the K.M.C. as well as the western outskirts of K.M.C. such as Tinthana, Satungal, Naikap and Balumbu i.e., grids (-5 to -10) along the Tribhuwan highway (figure 9). The mean neighbor distance between built-up patches was also found to be low indicating scattered development. In 2010, the PD was found to have reduced in these areas. However, the PD had comparatively increased in the eastern outskirts of K.M.C. along the cross-section i.e., grids (3 to 15). Along with the increased number of patches, the mean distance between built-up area patches had also decreased in these areas. In 2020, the PD was found to have increased aggressively in the eastern peri-urban areas in Kathmandu Valley along with a dip in PD in Madhyapur Thimi (grid 5) area which consisted of Bode Planning area. The mean distance between the neighboring patches was also found to have decreased further in 2020 as a result of emergence of new patches in peri-urban areas and infill development in central area of the valley.

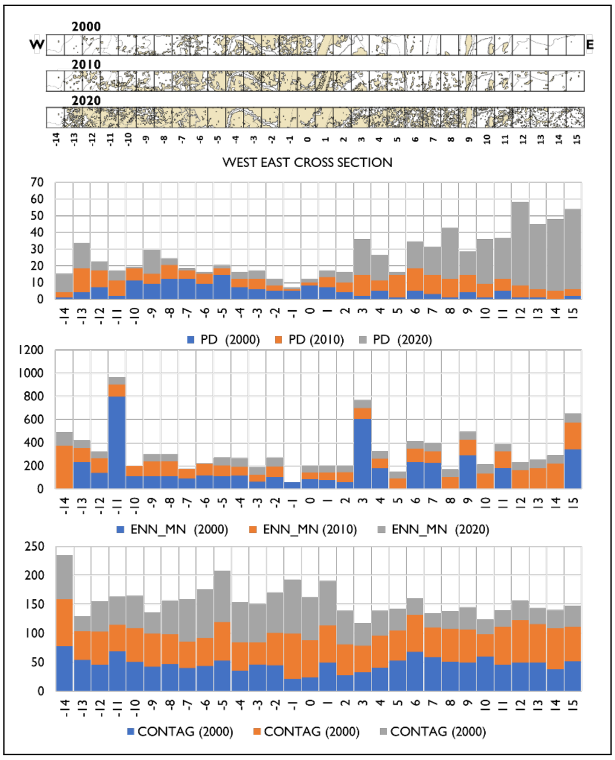

Figure 9: PD, ENNMN and CONTAG analysis along the east-west cross-section of the Valley

Likewise, in 2000, the intermixing in land use was found to be high in central part of the Valley given high PD in this area. Between 2010 and 2020, the land use in the central parts of the Valley had become more homogeneous while peri-urban areas had become more heterogeneous.

5. Discussion

The spatiotemporal land use change and spatial metrics analysis demonstrates that the built-up area which was concentrated in the central area of the Valley in 2000 had expanded aggressive towards the peri-urban areas in the Valley by 2020. The built-up area had increased more rapidly compared to the increase in the population indicating low density development in the peri-urban areas of the valley– the population had increased by 2.47 times from 2001 to 2021 while the built-up had increased by 4.68 times in from 2000 to 2020. Similarly, from the spatial metrics technique, the characteristics of the urban sprawl were analyzed. While the concentration of built-up had increased in the central areas of the Valley with infill development as indicated by increasing LPI, scattered development continuously increased in peri-urban areas from 2000 to 2020. Due to scattered development in cultivated and forest area, the heterogeneity in land use increased during the study period. However, despite increase in sprawl development, results show that infill development is also continuously occurring in the Valley. While infill development promotes densification, haphazard infill development can also result into inefficient and incompatible land use, requiring large investments for infrastructure development. Formulation and implementation of appropriate land use regulations that are adjusted dynamically and simultaneously with population growth and built-up growth is necessary to direct the urban change to an efficient and compatible land use [3, 12].

6. Conclusion

In this study, we investigated the spatiotemporal patterns of urban growth in the Kathmandu valley using land use change and spatial metrics techniques. Results show the occurrence of both sprawl and infill development occurring in the Kathmandu Valley. Despite some benefits, the cost of sprawl is high, and although infill development is expected to mitigate the effects of sprawl to some extent through densification, improper management of infill development could also lead to inefficient and incompatible land use. The quantitative analysis of the urban growth trend and pattern presented in this paper could help urban planners and researchers to understand land use change dynamics in the Valley to formulate compatible land use zonings, transportation policies, development control and investment plans.

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References

[1] MoUD. *National Urban Development Strategy*. Government of Nepal, MoUD, 2017.

[2] Nepal CBS. National population and housing census 2011. *National Report*, 2012.

[3] D. Irwin, S. Basnet, G. S. Gawadi, R. M. Pokharel, P Paudyal, T. R. Adhikari, S. Duwal, B. Rakhal, and D. Tamang. *Urban Growth Trends and Multi-Hazards in Kathmandu Valley*. Kathmandu Valley Development Authority (KVDA) and UNDP, 2016.

[4] Asif Ishtiaque, Milan Shrestha, and Netra Chhetri. Rapid urban growth in the kathmandu valley, nepal: Monitoring land use land cover dynamics of a himalayan city with landsat imageries. *Environments*, 4(4):72, 2017.

[5] Suinyuy Derrick Ngoran. *Socio-environmental impacts of sprawl on the coastline of Douala: Options for integrated coastal management*. diplom. de, 2014.

[6] Stephen Malpezzi and Wen-Kai Guo. Measuring "sprawl": alternative measures of urban form in us metropolitan areas. *Unpublished manuscript, Center for Urban Land Economics Research, University of Wisconsin, Madison*, 2001.

[7] Reid Ewing. Is los angeles-style sprawl desirable? *Journal of the American planning association*, 63(1):107–126, 1997.

[8] Jane Ritchie, Jane Lewis, Carol McNaughton Nicholls, Rachel Ormston, et al. *Qualitative research practice: A guide for social science students and researchers*. sage, 2013.

[9] Rajesh Bahadur Thapa and Yuji Murayama. Examining spatiotemporal urbanization patterns in kathmandu valley, nepal: Remote sensing and spatial metrics approaches. *Remote Sensing*, 1(3):534–556, 2009.

[10] James Richard Anderson. *A land use and land cover classification system for use with remote sensor data*, volume 964. US Government Printing Office, 1976.

[11] Kevin McGarigal. *FRAGSTATS: spatial pattern analysis program for quantifying landscape structure*, volume 351. US Department of Agriculture, Forest Service, Pacific Northwest Research Station, 1995.

[12] Kirti Kusum Joshi and Tatsuhito Kono. Optimization of floor area ratio regulation in a growing city. *Regional Science and Urban Economics*, 39(4):502–511, 2009.