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Article

Multi-temporal urban growth analysis with expansion indicators in Lucknow constituency by open-source data, India

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Research Article

Multi-temporal urban growth analysis with expansion indicators in Lucknow constituency by open-source data, India

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ABSTRACT

Urban sprawl in metropolitan cities of India is a distressing concern for planners. Not only, it is underachieved but it is neglected. This study attempts to help in understanding the gap by studying urban sprawl in 5 assembly constituencies (ACs) of Lucknow city of India, through urban growth indicators such as urban growth types (Infilling, Edge-expansion and outlying), Shannon's Entropy value and Landscape metrics (Complexity, Compactness, Centrality and Porosity). Results for these 5 ACs namely Cantonment (Cantt.), Lucknow Central (LC), Lucknow East (LE), Lucknow North (LN) and Lucknow West (LW) show that constituency has gone under a large amount of urban growth since 1985 to 2015. Amount of edge expansion in 2005–2015 is decreasing from previous duration of changes in year 1985–1995 and 1995–2005. Outlying growth of built-up area shown by formation of new patches is resulting in increase of 122.69 km² area in Built-up from 1985 to 2015, which was at first cycle (1985–1995) caused by decrease in Other and Vegetation Land Use (LU) class but after that in 1995–2005 and 2005–2015, it is mainly due to decrease in Agricultural land. Among Landscape metrics, NP (Number of Patches) and LSI (Landscape Shape Index) show upward trend from 1985 to 2015 indicating increase in compactness and complexity of patches of Built-up but ENN_MN (Mean Euclidean Nearest neighbor Distance) and AI (Aggregation Index) show either constant or negative trend. Shannon's entropy value H_n for every year is close to $\log_e(n)$ and also in increasing manner, depicting increase in Built-up area dispersion.

1. Introduction

The developing nations are facing a robust dynamic process known as Urbanisation which is land use (LU) change caused by involvement of growth of urban population (United Nations, 2019). More than 4 billion people of world population live in urban centres which are in way of becoming highly dense cities (Ritchie & Roser, 2019). Urbanisation being a unique phenomenon to each city, brings changes to its environment and socioeconomic conditional in a unique manner (Liu et al., 2016). Analysis of general trends of urbanisation and its two staged spatio-temporal pattern is an hour of need for planners of cities to understand the urbanisation process taking place in the particular city (Zhao et al., 2015). In short term, due to economic constraints, ecological and economic benefits of urban land use can be shortened but in long term, these effects are more correlated in terms of sustainable and inclusive growth of city (Luo et al., 2019). Effects of urbanisation are as local as Urban Heat Island, Biodiversity loss, and as global as Green House gases and depletion of Ozone layer (Wu et al., 2016). Studies of urban land use can be divided into 2 categories i.e. Optimisation and Simulation of

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land. Optimisation of land includes mathematical and spatial optimisation through linear modelling, GIS programming or Cellular Automata (CA) analysis of land to determine optimal Urban Land Use Structure (ULUS) whereas, Simulation of land is more about empirical analysis of Land use/Land cover (LULC) change in a city with regional environmental constraints (Luo et al., 2019). Study of urban growth and management of its infrastructure is crucial, otherwise it can lead to fragmented growth and lack of facilities at outskirts of region (Balha & Singh, 2018). Previous Land Use urban models were adaptive to widespread economical and behavioural theories but at later stage GIS approach adopted for region scale analysis proved to be much effective (Berling-Wolff & Wu, 2004). Platform like Google Earth Engine (GEE) and several other open access data platform are much more flexible in data handling and processing (Acosta et al., 2021).

Urban sprawl having no specific universally accepted definition, has been best explained by its qualitative, quantitative, and attitudinal landscape patterns. Such an attempt to best describe these characteristics was successfully made by characterising urban growth in 5 different types as in infilling, extension, linear development, sprawl and large-scale projects (Camagni et al., 2002). Raw information about infill, expansion, isolated, linear branch and clustered type of urban growth was introduced utilizing non-developed land also in change analysis (Wilson et al., 2003). Spontaneous, diffusive, organic and road influenced type of urban growth is another form to best describe change in ULUS (Berling-Wolff & Jianguo, 2004). Urban growth type was classified into basically 3 types Edge-expansion, Infilling and Outlying using equation involving common perimeter of new and old urban patch (Xu et al., 2007) and using Landscape Expansion Index (LEI), calculated by common area lying in buffer around new and old urban patches (Liu et al., 2010). An attempt to modify three growth types was made by introducing extra Ribbon type of urban patches by classifying perimeter equation into 4 classes (Shukla & Jain, 2019).

Studying urbanisation through Landscape metrics in Indian cities of unplanned concentrated growth is an effective way (Ramachandra et al., 2012). Landscape Metrics are quantitative indices representing physical characteristics of landscape of area (Huang et al., 2007; Ramachandra et al., 2019). Horizontal and vertical aspect of buildings in area, population residing in city, GDP of study area, gain or loss of arable or open space in area, are all one of factors which can be contributory in defining metrics for area (Ji et al., 2006; Jiang et al., 2007). These landscape metrics best explain centrality, complexity, compactness, density and porosity of urban patches in area (Dutta & Das, 2019; Huang et al., 2007). Landscape metrics provide better understanding of temporal changes in landscape than traditional approaches for analysis of pattern and process of urbanisation in an area (Crews-Meyer, 2002). Landscape metrics are the products of FRAGSTATS analysis (McGarigal & Marks, 1995). Indian cities have an intrinsic characteristics coupling of unprecedented population growth and urbanisation, which can be best associated with dispersion of urban form in terms of Shannon's Entropy (H_n) (Bhatta, 2009; Jat et al., 2008).

Similar studies on very few Indian cities, Indore (Kumar et al., 2007), Greater Bangalore area (Ramachandra et al., 2012), Raichur (Ramachandra & Aithal, 2013), Kolkata (Ramachandra et al., 2014), Jaipur (Sisodia et al., 2015), English Bazar Urban Agglomeration

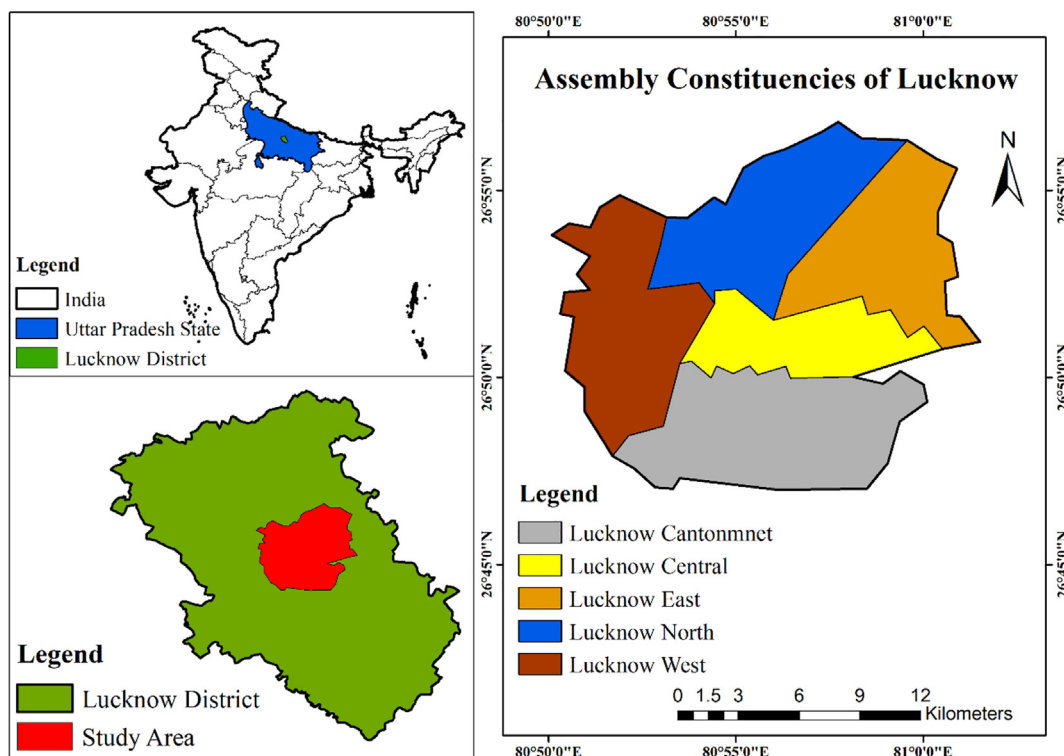


Fig. 1. Location of study area in Lucknow City.

(Dutta & Das, 2019) and Kozhikode Urban Agglomeration (Krishnaveni & Anilkumar, 2020) have been carried out. For study area of Lucknow previous studies have been carried out but only correlating population of area with urban growth (Godha, 2018; Kumari, 2015; Patel & Teli, 2019; Sridhar et al., 2019) except for morphological concentric buffer study of Lucknow city by metrics (Shukla & Jain, 2019). In this paper, analysis of urbanisation has been attempted through landscape metrics, urban growth types and Shannon's entropy values for 5 assembly constituencies of Lucknow city from year 1985–2015. Open source data of Decadal land use land cover for year 1985, 1995, 2005 and CGLS- 100 product has been used for year 2015, in achieving the results.

2. Study area

Lucknow, a metropolitan city in Uttar Pradesh state of India is chosen as study area (Fig. 1). It is one of the 100 cities ordained by Indian central government for projects under Smart City Mission. It is administrative headquarter of Lucknow District, which has 2 parliamentary constituencies in it named Mohanlalganj and Lucknow.

Study area falls in Lucknow Parliamentary constituency which is comprised of 5 Assembly constituencies (ACs) named Cantonment (Cantt.), Lucknow Central (LC), Lucknow East (LE), Lucknow North (LN) and Lucknow West (LW). River Gomati passes through almost all of 5 ACs in between of study area. Water level stands generally at 18 m below ground for Lucknow city. It receives monsoon (South West) rain near about 20th June every year and also a significant amount of rain during retreat of monsoon. Maximum temperature can reach up to 48 °C and minimum up to 1.67 °C. Population of city stands at massive 28,80,108 which is estimated to be about 47,00,000 by 2031.

3. Material and method

3.1. Data collection and processing

For classification purpose Decadal Land use/Land cover data available at ORNL DAAC has been used for year 1985, 1995 and 2005 (Roy et al., 2016) whereas for 2015 Copernicus Global Land Service: Land Cover (CGLS: LC-100) at 100 m (Buchhorn, Lesiv, et al., 2020) data has been used. Data used in this study has been listed below (Table 1).

Classified images of 1985, 1995 and 2005 are having total of 19 LU classes in Pan India classified images. These LU maps shows only 7 LU classes for Lucknow city. These 7 classes, which are merged and shown in 5 classes (NRSC, 2014) namely "Built-up", "Vegetation", "Water", "Agricultural" and "Other" for this particular study (Table 2). For Decadal Land use/Land cover data of year 1985, 1995 and 2005, an overall accuracy of classified image was found to be 94.46% for year 2005 and the Kappa accuracy of 0.9445. For year 1985 and 1995, accuracy of classified image was assumed to be same of year 2005 (Roy et al., 2016). For Copernicus Global Land Service: Land Cover (CGLS: LC-100), assessments show that the CGLS-LC100 discrete map Level 1 is mapped with $80.6 \pm 0.4\%$ accuracy. The yearly (2016–2019) maps are assessed with around 80.3–80.5% accuracy (Buchhorn, Smets, et al., 2020).

For year 2015, Copernicus Global Land Service: Land Cover (CGLS: LC-100) land use map is obtained through Google Earth Engine (GEE) services. These maps are re-projected in the corresponding geographic coordinate system World Geodetic System 1984 (WGS84) - known as EPSG: 4326 and cropped for study area only in GEE only. These CGLS: LC-100 products have 23 LU classes which area defined using the Land Cover Classification System (LCCS) developed by the United Nations (UN) Food and Agriculture Organization (FAO) (Buchhorn, Smets, et al., 2020). The classified image obtained for study area contained only 11 LU classes among 23. These 11 classes are merged and shown in 5 classes namely "Built-up", "Agricultural", "Vegetation", "Water", and "Other" for this particular study (Table 2).

3.2. Zonal analysis

As study has been conducted over 5 ACs of Lucknow city named Cantonment (Cantt.), Lucknow Central (LC), Lucknow East (LE), Lucknow North (LN) and Lucknow West (LW). These 5 ACs make Lucknow Parliamentary Constituency in its combined form. Urban growth analysis through all its agents has been studied for all 5 zones for different periods (Dutta & Das, 2019; Zhao et al., 2015).

3.3. Urban growth types

With the use of spatio-temporal analysis of urban change, three types of urban growth can be identified which are edge-expansion, infilling and Outlying (Li et al., 2013). In order to classify the urban patches in these three above categories raster pixels of Built-up classes were converted into vector polygons. Previous year patches were old built-up patches whereas built-up patches of later years

Table 1
Materials used in study.

Name	Date	Data Agency
Decadal Land Use/land Cover images	Year 1985, 1995 & 2005 (100 m resolution)	ORNL DAAC
Copernicus Global Land Service: Land Cover (CGLS: LC-100)	Year 2015 (1000 m resolution)	Google Earth Engine (GEE)
Assembly Constituency Boundaries	June 2017	Maps master

Table 2

Land use classes defined in study.

Land use class used in study	Land Use classes merged in from Decadal LULC data	Land Use classes merged in from CGLS: LC-100 products
Built-up	Built-up Land	Urban/built up
Vegetation	Deciduous Broadleaf Forest, Shrub land and Plantations	Shrubs, Herbaceous vegetation, Closed forests, Open forests
Agricultural	Cropland	Cultivated and managed vegetation/agriculture
Water	Water Bodies	Permanent water bodies
Other	Fallow Land, Wasteland and Permanent Wetlands	Bare/sparse vegetation, Herbaceous wetland

were categorised as new ones (Sun et al. 2013). A field “R”, shown in eq. (1) was defined in attribute table of polygon containing new built-up patches which will classify them accordingly into 3 categories.

$$R = \frac{L_c}{L} \quad (1)$$

where, L_c is length of common edge between old and new built-up patch and L is perimeter of new built-up patch (Xu et al., 2007). The R ranges from 0 to 1 and its get divided into 3 classes as shown in eq. (2).

$$R = \begin{cases} \text{Outlying} & ; R = 0 \\ \text{Edge-expansion} & ; 0 < R \leq 0.5 \\ \text{Infilling} & ; R > 0.5 \end{cases} \quad (2)$$

When the new built-up patch is lying in inside perimeter of old built-up patch, R becomes greater than 0.5, as length of common edge in utmost condition be equal to perimeter of new built-up patch and hence it will be called infilling (Fig. 2a), whereas when new built-up patch is lying spread at edges of old built-up patch, R lies between 0 and 0.5 and hence it will be called edge-expansion (Fig. 2b). Outlying built-up patches are those which area having no common edge from old built-up patch, so R automatically becomes 0 for it (Fig. 2c).

3.4. Landscape metrics

Landscape metrics help quantifying the properties of spatial distribution of landscape, patches and its classes. Complexity, centrality, compactness and porosity are properties which have been quantified to describe the landscape of study area (Sisodia et al., 2015).

Landscape shape Index (LSI) has been used to measure complexity of landscape as complexity denotes the irregularity in size of patches. Centrality is quantified by Mean Euclidean Nearest-Neighbor distance (ENN_MN). The Mean Euclidean Nearest-Neighbor distance (ENN_MN) measures the Euclidean distance of a patch from nearest patch in neighborhood. It may be the shortest edge to edge distance between patches of all class in landscape. Aggregation Index (AI) helps in quantifying the compactness of patches in landscape. Compactness measures the distribution of patches of alike properties which may depend upon patch shape and distance also. Number of patches (NP) shows the aggregated or fragmented growth of built-up patches in zone. Porosity is measured as ratio of open space in comparison to total built-up area in landscape. These indices can be calculated using FRAGSTATS (McGarigal & Marks, 1995) as listed in below (Table 3).

3.5. Shannon's entropy (H_n)

Shannon's Entropy (H_n) is one of the widely used index to measure urban sprawl. It provides a perspective of directional growth of urban area in 'n' zones of landscape (Krishnaveni & Anilkumar, 2020; Ramachandra & Aithal, 2013). Shannon's entropy can be calculated as below by eq. (3).

$$H_n = - \sum_{i=1}^n P_i \log P_i \quad (3)$$

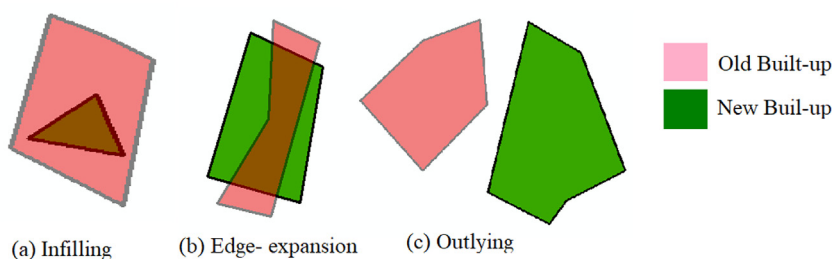
**Fig. 2.** Types of Urban growth.

Table 3

Landscape metrics used in study.

Landscape metric	Formula
Landscape shape Index (LSI) (LSI is one if patch is square but it increase without limit s edges increase in patches)	$LSI = \frac{0.25 E}{\sqrt{A}}$; Range ≥ 1 without limit where, E is sum of edge of patch (true edge or segment of edges doesn't matter) and A is total area of landscape.
Number of patches (NP) (Total number of adjacent patches if patches of class alike)	$NP = n_i$; Range ≥ 1 without limit where, n_i is number of patches for class i in landscape.
Mean Euclidean Nearest-Neighbor distance (ENN_MN) (It increases when distance between respective patches keep increasing)	$ENN_{MN} = \frac{\sum_{j=1}^n h_{ij}}{n_i}$; Range ≥ 1 without limit where, h_{ij} is Euclidean distance between patches i and j and n_i is total no. of patches present in landscape.
Aggregation Index (AI) (It is 0 when patch have no like adjacency and reaches to 100 when landscape consists of single patch)	$AI = \frac{a_{ij}}{a_{maxij}}$; Range from 0 to 100 where, a_{ij} is number of like adjacencies existing between pixels of patch j to that of i and a_{maxij} is maximum no. of like adjacency existing in landscape

where, n is the no. of zones in study area, which in this study has been 5 Assembly constituencies of Lucknow city and P_i is the proportion of built-up area in the zone, so P_i can be describes as ratio of built-up area to the total area of zone. Shannon's entropy ranges from 0 to $\log_e(n)$ and depicts distribution of built-up area in zone. Higher the H_n value, i.e. nearer the H_n value to $\log_e(n)$, more is the dispersion in built-up of zone depicting characteristics of urban sprawl in zone.

4. Results

4.1. Land use change

4.1.1. Land use change direction

LU classified data were already made available for year 1985, 1995 & 2005 through ORNL DAAC and CGLS: LC-100 products as classified LU maps for year 2015. These maps were analysed per need of study and reclassifies into 5 basic classes which are needed in a study area for landscape analysis. These Land Use classes being “Built-up”, “Vegetation”, “Water”, “Agricultural” and “Other” area shown in below image for year 1985, 1995, 2005 & 2015 (Fig. 3).

Land use in study area has gone some vast changes over years from 1985 to 2015. Built-up has increased from acquiring 28.1% of study area in year 1985 to 77.4% in year 2015. North, East and West Lucknow constituencies have been dominant in the built-up increase over in year 1985–1995 with conversion of “Other” to “Built-up” LU class but Cantonment saw conversion of “Vegetation” to “Built-up” LU class massively in the same period. The increase in built-up is due to change of “Other” land use class, which contains classes like fallow or barren land suitable for conversion by construction.

In the last year 2015, mid Built-up some Vegetation is present in Cantonment and Central Lucknow constituency, it is due to construction of an urban park by name of Janeshwar Mishra Park (Asia's second largest Park) in Lucknow Central AC and increased

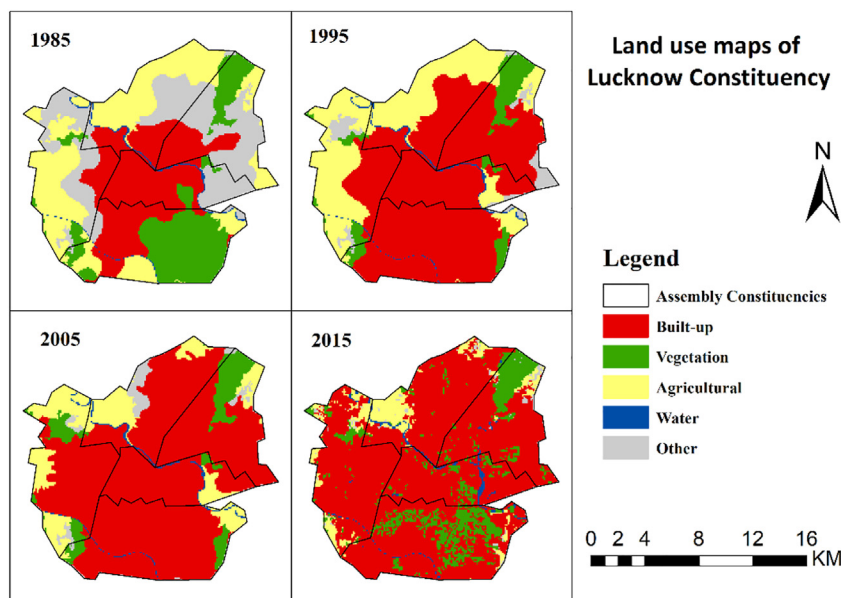


Fig. 3. Land use map of study area from year 1985–2015.

plantation at left spots of constructions in Lucknow Cantonment AC in between 2005 and 2015. Removal and cleaning of deposits from Gomati River and Kathauta Lake in Lucknow West AC is also a major factor in increase of water area as LU class in study area. Decrease in “Other” LU class from 24.1% of study area in 1985 to 1.1% in year 2015 shows conversion of “Other” LU class to “Built-up” LU class. Vegetation and agricultural LU class has also gone under deterrent over the years but agricultural land has taken more decrease i.e. 27.3% in 1985 to 7.1% in 2015 in comparison to vegetation which is 18.6% in 1985 to 13.3% in year 2015 (Fig. 4).

4.1.2. Land use magnitude

Change in LU classes area wise (km^2) over duration 1985–2015 is shown in table (Table 4). Built-up LU class which has gone massive gain has been most due to loss in “Other” LU class and that too in change duration 1985–1995 (Fig. 5). In the change duration 1995–2005 “Agricultural” LU class was converted to “Built-up” at most (38.71%) culminating a total area of 24.18 km^2 as loss towards built-up up to year 2005.

Loss of “Vegetation” towards gain of “Built-up” has never been prominent in any change duration 1985–1995, 1995–2005 and 2005–2015. It remained second at top in loss among 5 LU classes of study area for all 3 change durations but in change towards “Built-up”, “Vegetation” LU class remained at third from top among 5 classes in study area from year 1985–2015 (Fig. 6). Cantonment (Cantt.) AC is having largest Built-up gain in from 1985 to 1995 and after that it remains almost similar up to 2015. Same pattern is seen in Lucknow East (LE) AC. Lucknow North (LN) and Lucknow West (LW) assembly constituencies of Lucknow are having increase in “Built-up” LU class in all durations continuously. Lucknow Central AC is having a little increase in its Built-up percentage only once that too in 1985–1995 after that, it is almost same (Fig. 7). LE and LW both constituencies are having largest percentage of their area as “Other” LU class which in turn gets converted to Built-up over the years from 1985 to 2015. Cantonment AC lost largest percentage of vegetation among its area but Central and West AC retained its vegetation percentage almost exact as in year 1985 to year 2015. North AC is one among all ACs having lowest percentage of its area as vegetation which remains same throughout the study period from 1985 to 2015 (Fig. 7).

Lucknow North (LN) and Lucknow West (LW) ACs are contributing towards urbanisation in year 2015 by change of “Agricultural” to “Built-up” LU class. “Vegetation” to “Built-up” change is most from Cantonment AC of Lucknow. “Other” LU class is changing to “Built-up” in Lucknow North, East and West (LN, LE and LW) ACs. Lucknow Central is the only one with one unchanged towards urbanisation in fact, it is enriched in built-up towards year 2015.

4.2. Urban growth types

Edge-expansion, Infilling and outlying urban growth types, all 3 types are found in urban expansion from 1985 to 2015 in Lucknow study area (Fig. 8). In all 3 change durations, edge-expansion type of urban growth is dominant over other two outlying and infilling.

Outlying type of urban growth is only seen in duration 2005–2015, which means new urban patches formed only in this duration. Other previous durations, 1985–1995 and 1995–2005 has abundance of edge-expansion type of urban growth and only an insignificant patch of either outlying or infilling respectively (Fig. 9).

In period 1985–1995, edge-expansion occurred in all 5 assembly constituencies. It happened as process of urbanisation just started taking place in central part of Lucknow city at the time, which is the study area itself. People started migrating to this area because it is capital of Uttar Pradesh state and all governmental institutes and administrative offices are located in this part of state. In period 1995–2005, edge-expansion occurred but lesser in amount from previous change period and in less constituencies also. Same pattern is seen in period 2005–2015. Amount of urban growth is lesser in 2005–2015 from previous one and also in lesser number of constituencies. In fact, only Lucknow North and Lucknow West are 2 constituencies, which see outlying patches of urban growth for study area. After 2005, due to change in policies of state towards greening of areas, more parks have been developed, more area has been acquired to accommodate new rural population in boundary of LDA (Lucknow Development Authority), which resulted in new settlements over duration of 2005–2015 in form of outlying patches as new colonies were being formed.

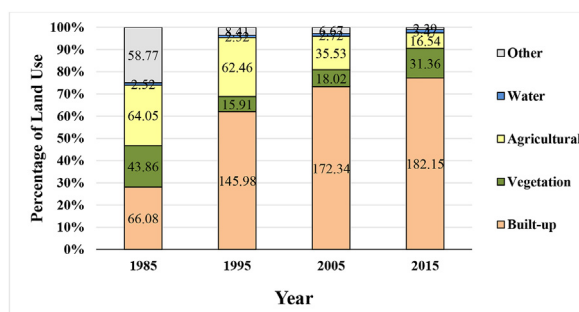
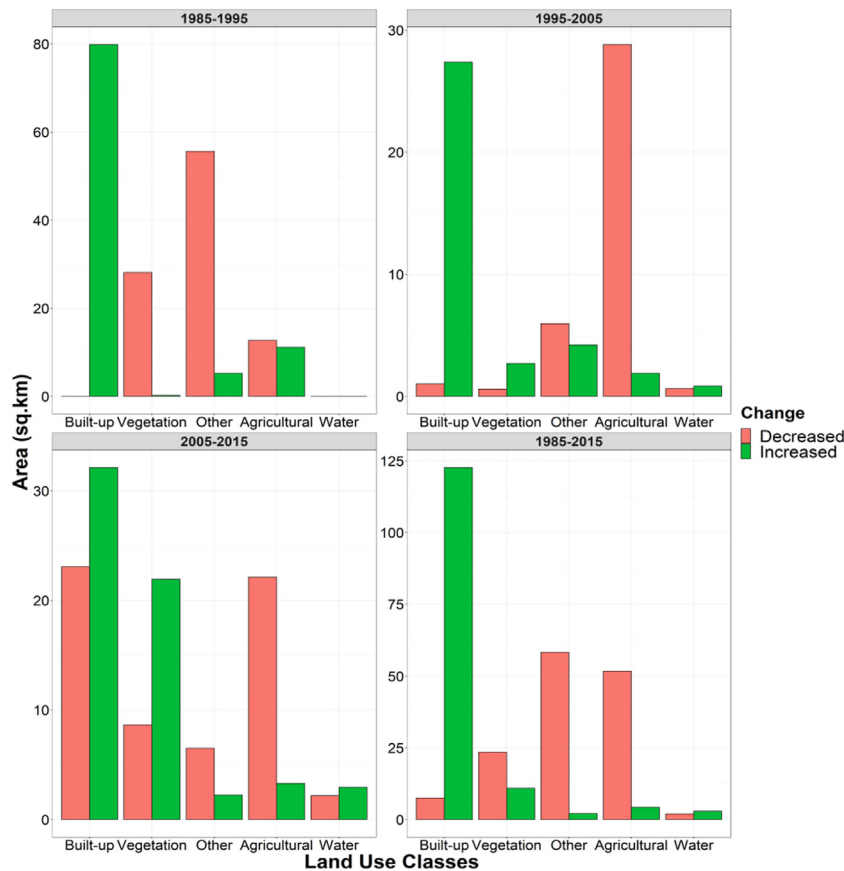


Fig. 4. Land use change in study area from year 1985–2015.

Table 4Landuse change (km^2) from year 1985–2015.

LU Classes	Built-up	Vegetation	Agricultural	Water	Other	1985
Built-up	58.58	5.44	0.56	1.44	0.06	66.08
Vegetation	21.93	20.38	1.04	0.17	0.33	43.85
Agricultural	46.51	2.72	12.12	0.78	1.71	63.84
Water	1.51	0.07	0.39	0.53	0	2.50
Other	52.74	2.67	2.31	0.55	0.29	58.56
2015	181.27	31.28	16.42	3.47	2.39	91.90

**Fig. 5.** Gain and loss in land use of study area in different durations.

4.3. Landscape metrics

Number of Patches (NP) is increasing for all ACs from year 1985–2015. Among ACs Lucknow central is having most no. of NP. NP shows density of patches. Lucknow North and Lucknow West are having least NP, indicating less no. of Built-up patches hence, less urbanisation in these ACs. LSI shows complexity of patches. All ACs are having almost same LSI but in increasing pattern from year 1985–2015. Lucknow West is having very large LSI value in year 2015, which is due to generation of new built-up patches in this AC in form of outlying patches in year 2015. ENN_MN showing centrality of patches is following exact opposite pattern across years in all 5 ACs. As no. of patches increase or decrease in ACs over year from 1985 to 2015, new patches are lying at more or less distance from each other respectively. ENN_MN is largest for Cantonment AC in year 1985, which is because of more area of Cantonment AC being filled with vegetation, hence whatever little amount of built-up patches were present, it was with much more distance than in coming years. It happened due to already existing built-up patch in the study area, so whatever new vegetation area have been formed in form of urban parks, they will be far away from existing built-up patches only. AI is almost same in number for all ACs even overall years. It is close to 100 (92–98) for all patches existing in study. AI depicting compactness of patches, is indicating that almost every AC in each year is comprising of 1 large built-up patch in it (Fig. 10), as being central part of Lucknow District, study area always had a pre-existing patch of built-up area in its boundary.

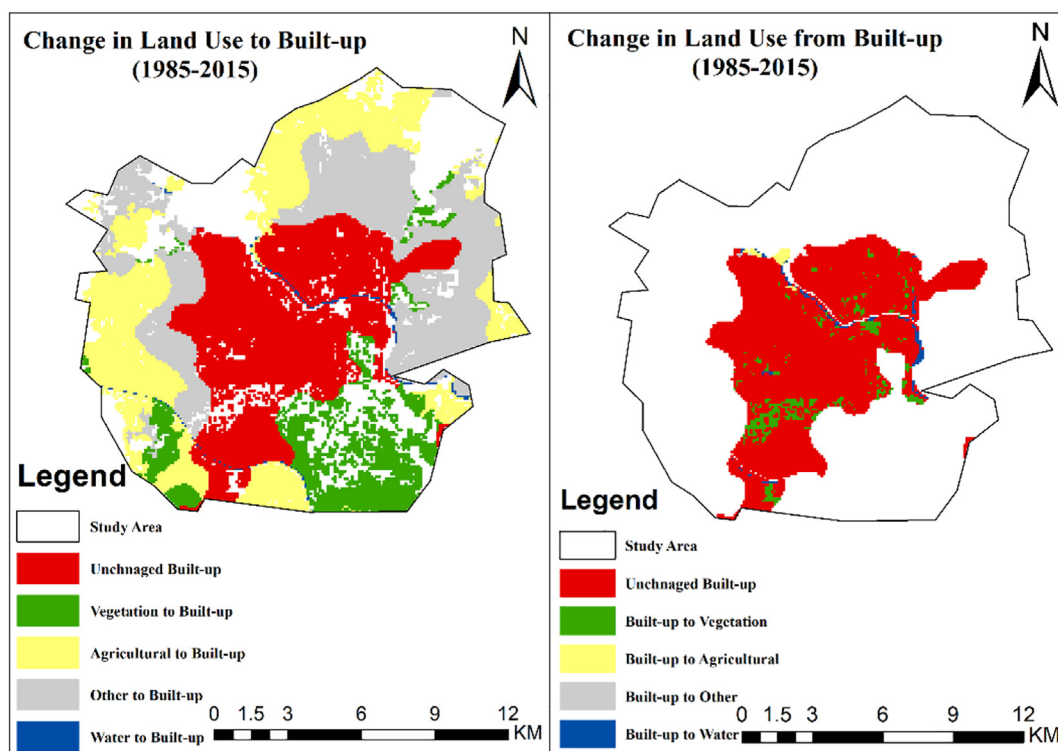


Fig. 6. Gain and loss of Built-up from year 1985–2015.

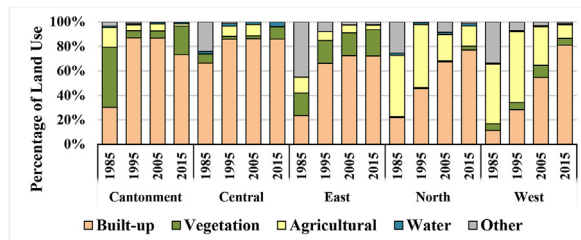


Fig. 7. Land use change (%) in different assembly constituencies.

4.4. Urban sprawl

Shannon's entropy value (H_n) is used for analysis for urban sprawl in study area of Lucknow. In all years from 1985 to 2015 Lucknow is having entropy value close to $\log_e(n)$ which is equal to 1.609 for Lucknow and its 5 ACs. Entropy value increases from 1.544 to 1.604 in year 2015. Since, Shannon's entropy value (H_n) shows dispersion when close to $\log_e(n)$, Lucknow can be said having dispersed type of urban growth in all years. In year 1995 entropy value decreases a very little bit to 1.531 and then closes at 1.604 equal to 2015, indicating increase in dispersion of urban growth over years. Forming of new outlying patches is main cause of this dispersion in study area. If it would have been in form of edge expansion type of urban growth then obviously, urbanisation would have been of compacted growth but more and more outlying patches of built-up area causing the urban growth in Lucknow Constituencies to be dispersed.

Shannon's entropy value (H_n) for all 5 ACs is shown (Fig. 11). Cantonment AC is having highest value of entropy indicating most dispersed growth of built-up in it. Lucknow West AC has compacted urban growth in year 1985 which keeps dispersing to year 2015 continuously. Lucknow Central has dispersed built-up patches first in year 1985 but it kept getting compacted to year 2015 continuously.

5. Discussion

The study collaborates all the major urban growth indicators for an area but in a very brief analysis. Decadal Landuse data used in study has been most useful. Remote sensing data used for classification of 2015 data is also done through very popular and effective

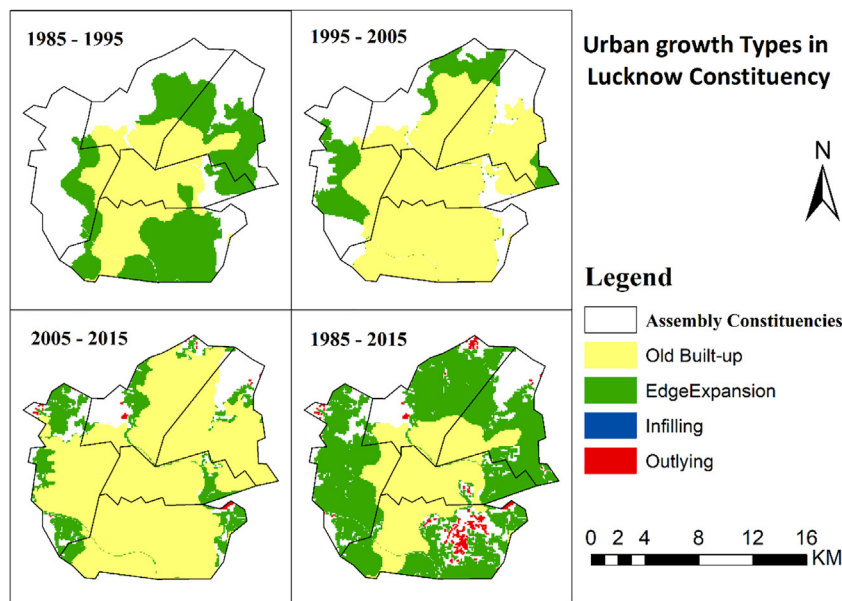


Fig. 8. Different Urban growth types in study area from 1985 to 2015.

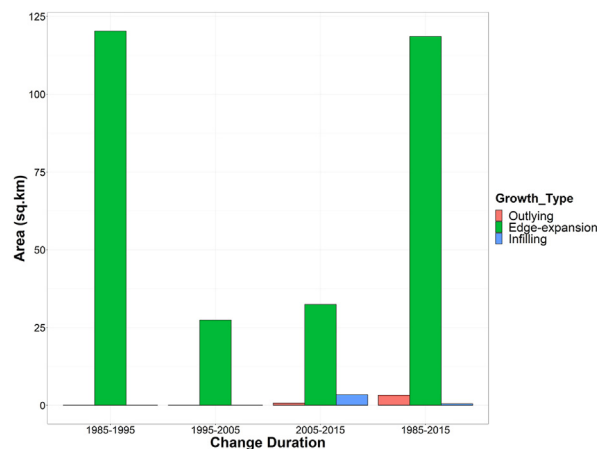


Fig. 9. Magnitude of Urban growth types in different durations from 1985 to 2015.

Maximum Likelihood classification hybrid approach. Constituency data used for zonal categorisation of study area proved to be useful as each assembly constituency (zone) found to be possessing unique urban growth characteristics. Only after analysing urban growth patterns of zones of a city only, comment on growth pattern of the whole city can be made.

Study found all the urban growth indicators to be inter-connected. Generation of Outlying built-up pixels in Lucknow West AC is causing increase in number of patches (NP), Decrease in AI and ENN_MN and increase in Shannon's entropy value for this AC. Cantonment AC is having largest percentage of vegetation in year 1985 corroborating to least NP, highest ENN_MN in same year. Study shows that Lucknow is having a much dispersed urban growth from 1985 to 2015. Loss of Vegetation is a contributing factor in increase of built-up from year 1985–2015 in Lucknow but not more than Agricultural or Other land in study area as formation of new urban parks has certainly helped in some increase of greenery in study area but still not up to optimum level. Lucknow West AC is having largest urbanisation form year 1985–2015 in percentage (69.67%) and area (34.91 km²) wise both.

Whole area of study is found to be completely urbanised in year 2015 by 77.4%, which is problematic situation for planners to counteract ever increasing population in Lucknow city by providing suitable area for new settlers in the city boundary. Only 13.4% of total area of study as vegetation is also a worrisome situation for planners which needs to be taken care of. Judicious use of remaining part of study area is need of time, as it can go to contribute in growth of urban extent or improvement in green access to its citizens. Sudden presence of outlying built-up patches in duration 2005–2015 indicates the start of more dispersed growth in already urbanised study area.

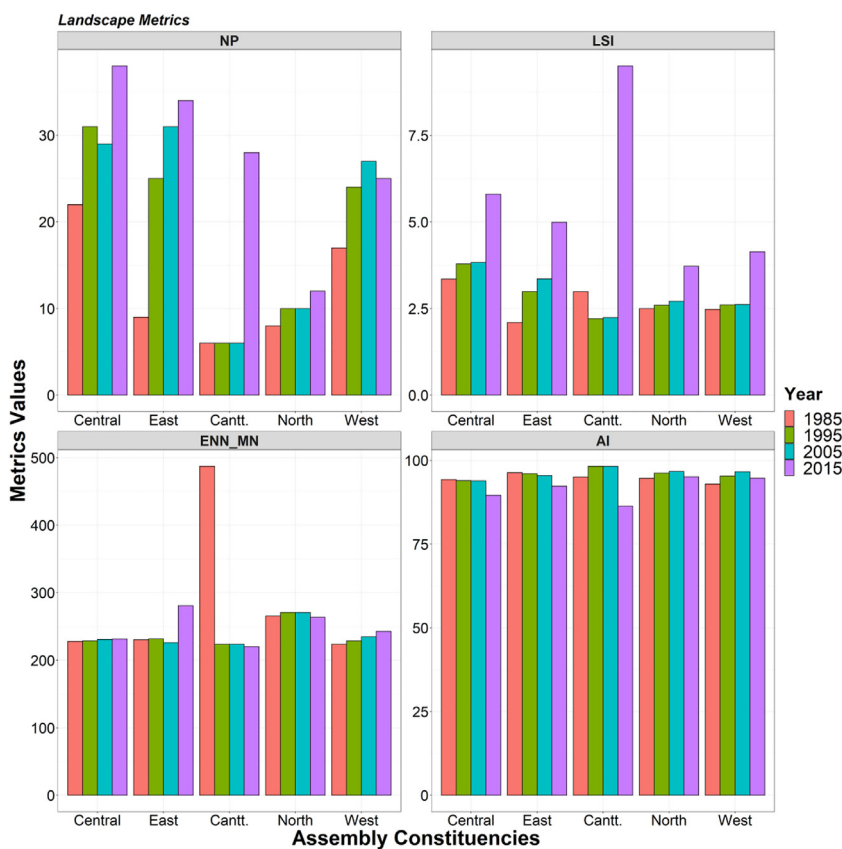


Fig. 10. Landscape metrics for assembly constituencies in year 1985–2015.

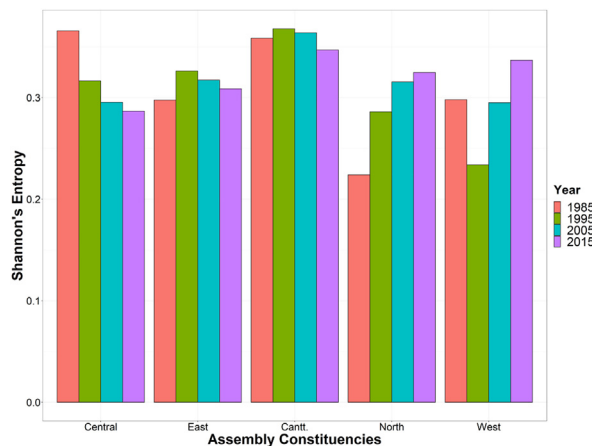


Fig. 11. Urban sprawl in assembly constituencies in years from 1985 to 2015.

6. Conclusions

Study establishes the importance of Landscape metrics, Shannon's entropy and Urban Growth types in analysis of urbanisation in any city. These parameters are certainly quantitative in nature but its interpretation when connected with physical presence of land use at ground level, certainly provides a magnificent view of urban extent. All 3 parameters in connection can wholly describe a city how it will lie in terms of urbanisation in upcoming year or decades. Zonal analysis is found to be helpful in indicating magnitude and direction of urbanisation in study area, which in turn characterised the urbanisation pattern of whole city. Spatio-temporal analysis helped in analysing the characteristics of urban growth over three change durations of 1985–1995, 1995–2005 and 2005–2015. Presence of

outlying patches in Lucknow West is indicating the direction of urbanisation which will take place in nearby future in city area.

Rapidly urbanising cities like Lucknow need a master plan of pre-established urban growth zones so that new built-up patches don't get dispersed over the years, as study found it to be. Dispersed urban growth although will be helpful in mitigation of several factors of urban dynamics like Urban Heat Island (UHI) effect (Qiao et al., 2020) and better access to greenery in form of Urban Green Space (UGS) but will also make it difficult to laydown communication networks all over city for municipal corporation or planning department of cities.

Declaration of competing interest

We declare that there is no conflict of interest involved in this research.

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