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Urban dynamics assessment of Ghaziabad as a suburb of National Capital Region, India

Juhi Priyanka Horo · Milap Punia

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Abstract With the realisation of the substantial changes made by Homo sapiens on earth dynamics; initiated a proposal of geological time scale ahead of the Holocene named as the Anthropocene, i.e., the Human Age. The conditions of the Anthropocene have redacted in a way by the optical modes of analysis; being made through data interpretation, changes experienced through satellite imagery, the consistent updating of climatic change, and the altered man–environment relationship across ages. Urban spatial areas have expanded in an accelerated speed during the last few decades, and rates of urban population growth are higher than the overall growth in most cities because urban areas are the locus of economic activity and transportation nodes. The study focuses on the increasing burden on the metropolitan cities like Delhi National Capital Region (NCR) of India—thereby inducing analogous effects over the suburban conurbation through ceaseless outgrowths. These patterns of urban densification and internal modifications are of major concern to sustainable development because they represent the physical manifestations of a range of social, economic, cultural, and political dimensions associated with urban dynamics. Considering the altered man–environment relationship; this paper deals with the urban assessment of Ghaziabad for the years—2001, 2006, 2011, and 2015. It further focuses on the directional change of the region as a suburb of NCR in context with buffer zone analysis and Shannon's entropy approach.

Keywords Shannon's entropy · Ghaziabad · Ward · Homogeneity · Heterogeneity · Zones · Direction

Introduction

Humans are the dynamic actors of the planet and their actions cause several transformations in the environment, from earth's biological, geological, and chemical cycles to the evolution of life. They are capable to affect the abiotic life as well. Human activity has made a subsequent impression on the environment globally, that suggested for a period of human dominance over the planet in 2008, i.e., the Holocene Epoch. However, the incidences of perpetual potency evoke a composite form of the epoch, far different from the stratigraphic delineation of the geological time scale that manifests the much more complex evidence of human activities (Lewis and Maslin 2015; Monastersky 2015). Following the lead of Nobel laureate Paul Crutzen, one of the discoverers of the chemistry behind stratospheric ozone depletion, in 2002, scientists and researchers have adopted the new term Anthropocene to refer to the planet dynamics driven by human forces (Davis

J. P. Horo · M. Punia (✉)
Centre for the Study of Regional Development (CSRD), Jawaharlal Nehru University (JNU), New Delhi 110067, India
e-mail: milap.jnu@gmail.com

and Turpin 2015). It is based on the idea that human forces are traversing the global ecosystem functions, the level beyond which the earth will cease to replenish and will incur devastating consequences. The remarkable transgression from the Holocene to Anthropocene from where the species that had to obey the changes of nature to the same, being a driving force of altering the environment, remains an abstract concept to be formalized (Steffen et al. 2011; Zalasiewicz et al. 2011; Biermann 2014). These interferences call for a new perspective. One such new perspective is a newly emerging paradigm in the social sciences, "Earth System Governance" (Biermann 2007; Biermann et al. 2009). The earth system governance paradigm is a response and a reaction in the social sciences to the notion of the Anthropocene (and related concepts such as Earth System analysis). The assessment has been designed to contribute to the 2012 United Nations (UN) Conference on Sustainable Development at Rio de Janeiro, which will focus on the institutional framework for sustainable development and possible reforms of the intergovernmental governance system (Biermann et al. 2012; UN 2015). It accepts the core tenet of the Anthropocene, i.e., the understanding of the Earth as an integrated, interdependent system transformed by the interplay of the human and non-human agency. The focus of earth system governance is not 'governing the Earth', instead, it is about the human impact on planetary systems for the conceptualization is based on the emergence of the 'Anthropocene' and the 'End of environmentalism' (Biermann 2014). The present era evokes these forces as both global and local, and that they impinge simultaneously on several different crucial earth systems.

Urban landscapes change over time as the new urban fabric is added and as the existing fabric is internally modified (Rashed et al. 2005). Urban spatial areas have expanded in an accelerated speed during the last 5 decades, and rates of urban population growth are higher than the overall growth in most countries because urban areas are the locus of economic activity and transportation nodes (Masek et al. 2000). Expanded urbanised areas encroached on surrounding valuable natural lands such as paddy fields, forestlands, and wetlands (Xu et al. 2000). These patterns of urban densification and internal modifications are of major concern to sustainable development because they represent the physical manifestations of a range of social, economic, cultural, and political dimensions associated with urban dynamics. With the advent of rapid urbanisation, it has become extremely necessary to study vulnerability assessment of these areas (Roy 2009).

India is the second most populous country in the world, with over 1210 million people; constituting 17.5% of the global population (Census of India 2011). On a path of accelerated urbanisation, India is going through substantial changes in its land cover and land use. A dualistic character of Indian cities has been observed by Punia and Singh (2011), i.e., at the macro level, India's urbanisation is slowing down whereas, on the other hand, it is expanding in class-I cities. According to Kundu (2006), the process of urbanisation in India is largely city oriented. In the past 2 decades, the area covered by Indian cities has expanded by a staggering 250%, occupying an additional 5000 km^2 of India's surface with concrete, asphalt, and glass (Nagendra et al. 2013). India contains three of the world's ten largest cities: Mumbai, Delhi, Bengaluru, and Kolkata—as well as three of the world's ten fastest growing cities: Ghaziabad, Surat, and Faridabad (Nagendra 2015). This massive urbanisation will pose large-scale challenges for urban resilience and sustainability, especially for the poorest and most vulnerable: the urban poor, migrant workers, and traditional village residents.

Human beings construct their own space with the effect of interactions with the environment and endowments associated with it. The harmful effects of the degradation of ecosystem services (the persistent decrease in the capacity of an ecosystem to deliver services) are being borne disproportionately by the poor, are contributing to growing inequalities and disparities across groups of people, and are sometimes the principal factor causing poverty and social conflict. They tend to be directly reliant on ecosystem services and most vulnerable to changes in those services. On a path of accelerated urbanisation, Indian cities are going through substantial changes in their land cover and land use. In the past 2 decades, the area covered by Indian cities has expanded by a staggering 250%, occupying an additional 5000 km^2 of India's surface with concrete, asphalt and glass (Nagendra et al. 2013). India contains three of the world's ten largest cities—Mumbai, Delhi, Bengaluru, and Kolkata—as well as three of the world's ten fastest growing cities:

Ghaziabad, Surat, and Faridabad (Nagendra 2015). This massive urbanisation will pose large-scale challenges for urban resilience and sustainability, especially for the poorest and most vulnerable: the urban poor, migrant workers, and traditional village residents.

Study area

To analyse the urban environment and the socio-ecological sustainability, the study has incorporated ward level analysis for Ghaziabad for 2001, 2006, 2011, and 2015. Mapping the urban sprawl gives an incentive to identify the natural resources and their changes in due course of time. It also provides a picture where it helps in finding the location of sprawl and helps to provide the ecologically threatened areas (Sudhira et al. 2003a). The use of impervious surfaces to determine the areas of built-up provide a concrete measure of development (Barnes et al. 2002). The regional level study has been brought into focus taking the study area of Ghaziabad of Uttar Pradesh. The region is analysed ward-wise; comprising of 80 wards. The city perspective of Ghaziabad has encountered urban growth; however, the impact of the sprawl is different across years in the region that will be unfolded in the succeeding section. Ghaziabad has registered a high growth rate, i.e., 70.22% (Census of India 2011). Taking environmental concerns into considerations and socio-ecological sustainability and with the implication of urban growth on the environment, city perspectives of Ghaziabad are taken into consideration (Fig. 1).

Administrative and demographic transformation of Ghaziabad (UP) over years

The state of Uttar Pradesh (UP) constitutes the largest population under its territory, with 16.51% of India's total population and merely 11.80% of India's urban population, but fourth in terms of area, after Rajasthan, Madhya Pradesh (MP), and Maharashtra (Census of India 2011). UP holds 199,812,341 population constituted of 52.29% males, and 47.71% females as against 1,210,569,573 of India's population constituting 51.47% males, and 48.53% females in 2011 (Census of India 2011). Uttar Pradesh consists of 71 districts out of which Ghaziabad is at third rank with 2.34% of total state's population. In terms of growth rates, Bahraich holds the first position with a growth rate of 46.48% in the decade of 2001–2011 (Census of India 2001). Though Bahraich is held at first position, it does not contribute much in terms of its share in state's total population. Second is Ghaziabad with a growth rate of 42.27%. However, it stands second in terms of its growth rate, it is ranked third in terms of its share of the population.

The Table 1 represents the level of urbanisation of top 10 districts in UP. Ghaziabad is held at first rank with 67.55%. Ghaziabad ranks third in terms of its population, and second in terms of its growth rate.

Ghaziabad district was formed as a separate district out of Meerut on 14th November 1976 with a spread over 1179 sq. km. The district is surrounded by Meerut and Baghpat to the North, Jyotiba Phule Nagar to the East, Gautam Buddha Nagar, and Bulandshashar to the South and Delhi to the South-West. The district is traversed by River Yamuna, Ganga, Hindon, and Kali. Delhi, the Capital of India, forms a part of NCR. However, the territory of NCR also includes Baghpat, Gurgaon, Sonepat, Faridabad, Ghaziabad, Noida, and Greater Noida constituting a population of 21,753,486 (Census of India 2011).

Ghaziabad city is a growing satellite town governed by the Municipal Corporation which comes under Ghaziabad Metropolitan Area (Ghaziabad Nagar Nigam, n.d.). It constitutes a population of 1,648,643 with the male population of 874,607 and female population of 774,036 within an area of 210 sq. km (ibid). Ghaziabad Metropolitan Area constitutes a population of 2,358,525 out of which 1,256,783 are males and 1,101,742 are females (Census of India 2011). In terms of literate population, Ghaziabad Metropolitan Area possesses 93.81% of the literate population, male population constitutes 91.05% of literacy and female population constitutes 96.95% of literacy.

The status of Ghaziabad, former recognised as a Municipal, was upgraded to Municipal Corporation or Ghaziabad Nagar Nigam on 31st August 1994 following the 74th Constitutional Amendment Act 1992 (Ghaziabad Nagar Nigam, n.d.). Ghaziabad city, over a period of time, provided with a series of management institutions, engineering colleges, physiotherapy institutes, and dental colleges. In terms of transportation, Delhi Metro provides services up to Dilshad Garden which is located in the suburbs of the city. The Blue

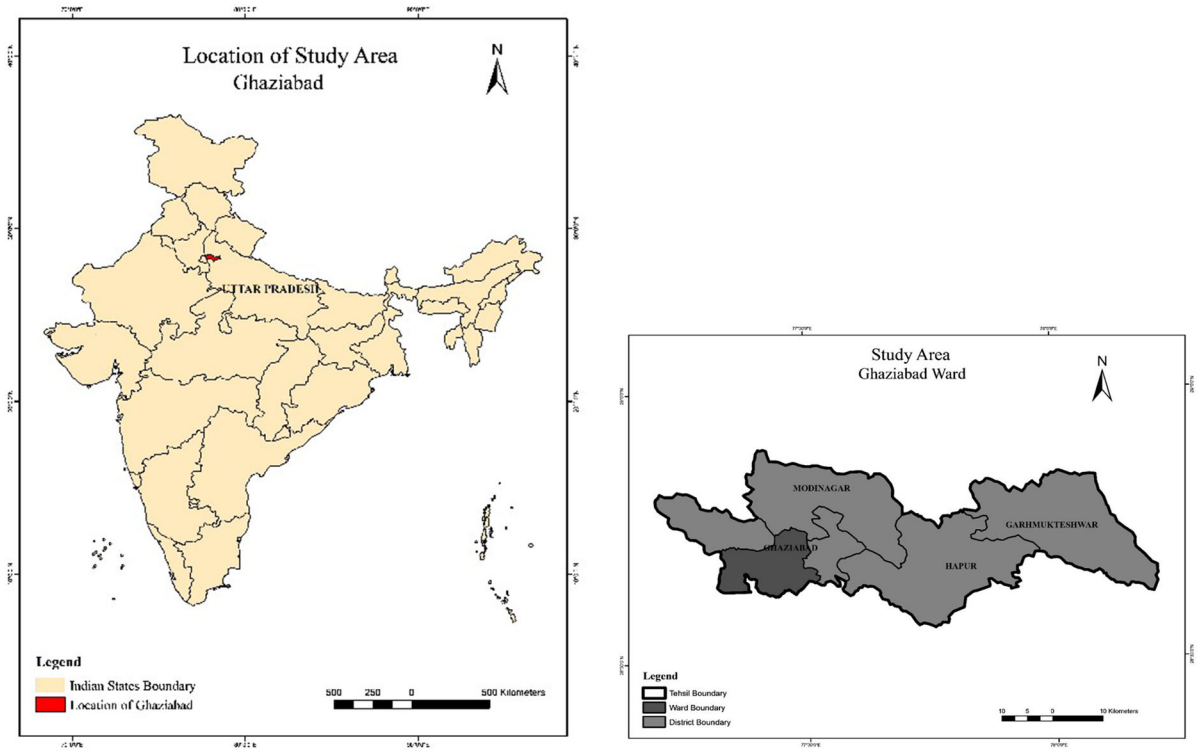

Fig. 1 Location of study area in the map of India (Ghaziabad ward). *Source*: Administrative Atlas of Uttar Pradesh 2011

Table 1 Percentage of urbanisation of top 10 districts of Uttar Pradesh. *Source*: Census of India 2011

District	Percentage of urban to total population
Ghaziabad	67.55
Lucknow	66.21
Kanpur Nagar	65.83
Gautam Buddha Nagar	59.12
Meerut	51.08
Agra	45.81
Jhansi	41.70
Bareilly	35.26
Firozabad	33.35
Aligarh	33.13

line extends out to Vaishali and Kaushambi (Das 2011). The national highway numbers 24 and 58 are thriving for commercial developments along with the residential developments (Tiwary 2011). The road traffic and highways ministry have planned to widen the 20 km NH-24 between Delhi border and Dausa. At present, this national highway is 4 lanes and is expected to accommodate population along with it occupying the areas of Indirapuram and Crossings Republic, two big sub-cities of Ghaziabad (Ghose 2011). According to the Raaji ("The Times of India," 2006), this city has been considered among the 10 most dynamic Indian cities around the world.

The growth rate of Ghaziabad Urban Agglomeration (UA) has been found constantly increasing with the proceeding years. However, the growth is positioned toward the positive side, the growth rates have been fluctuating over the decades, i.e., 1901–1911,

Table 2 Population and Growth Rate of Ghaziabad UA since 1901. *Source*: Various decades, Census of India

Year	Population	Growth rate (percentage)
1901	11,275	–
1911	11,304	0.26
1921	12,343	9.19
1931	18,831	52.56
1941	23,834	26.57
1951	43,745	83.54
1961	70,438	61.02
1971	137,033	94.54
1981	287,170	109.56
1991	511,759	78.21
2001	968,521	89.25
2011	1,648,643	70.22

1911–1921 has shown a comparatively low increase (Table 2).

However, since 1921–1931 onwards the UA has registered an increasing population but at a fluctuating growth rate. The decade from 1941–1951 (83.54%), 1961–1971 (94.54%), 1971–1981 (109.56%), and 2000–2001 (89.22%) have registered more than 80% of growth rate, 1971–1981 even crossed 100% nearly doubling the population previous decade (1961–1971). The decade between 2001 and 2011 has registered 70.22% of growth rate which though is positioned lower than the decade of 1991–2001 but shows evidence of growth.

Objectives

Indian cities replicate the growth model of the international urbanised economies in order to battle in the pace of world competency. Roy (2011) in "The Economic Times" provides detailed stipulations about Ghaziabad informing a long way to become a part of NCR backbone. He calls Ghaziabad as "the target of mismanaged civic infrastructure planning, development, funding, and execution". The issues of swanky apartments and nonexistence of roads remains a horrifying fact of the city. Taking under considerations the growing importance of Ghaziabad as a suburb of NCR, the dire consequences of exclusive growth as means of decongesting the metropolitan areas need to be examined in terms of use of satellite imagery to overview the changes in urban dynamics of Ghaziabad across years. This will also facilitate to analyse the impacts of urban growth and association of locally situated constituents of urban growth. The further research focuses on the zonal and directional change of urban growth in Ghaziabad to validate the trend of decongestion of the city.

Database

The following research dealt with several reports provided by the Census of India. These include District Census Handbook (DCH) and Primary Census Abstract (PCA), Ghaziabad, for the decades of 2001 and 2011. The Census of India provides data on the decadal basis, so the recent data present and used in this research as secondary sources is up to 2011. Apart from the demographic data, remote sensing datasets have been used. The satellite datasets acquired are from Landsat-4 and Landsat-8 (USGS Earth Explorer) and LISS-III (IRS-P6) for the years of 2001, 2006, 2011, and 2015. The software used in the processing of large datasets of the research includes Arc Map 10.2.2, Erdas Imagine 2014, Microsoft Excel, and Microsoft Word.

Methodology

As per the objectives mentioned and research questions framed, following methodology have been put forward for the research:

1. Shannon's entropy index (form and type of urban growth)

To delineate the urban growth, Shannon's entropy was computed for different areas. The Shannon's Entropy was first used by Yeh and Xia (2001) to compute the urban sprawl phenomena (Sudhira et al. 2003a, b). The Shannon's entropy (Hn) is given by:

$$H_n = -\sum P_i \log_e(P_i)$$

where P_i = proportion of the variable in the *i*th zone (e.g. proportion of built-up area in each ward), n = total number of zones (e.g. total number of wards)

The value of entropy ranges from 0 to log n. The value of 0 indicates that the distribution is very compact and homogenous, while values closer to log n

reveal that the distribution is much dispersed and of varied types. Higher values of entropy indicate the occurrence of sprawl.

2. Range of Shannon's entropy values

The value of Shannon's entropy ranges from zero (0) to infinity. In this case, including the regions of Ghaziabad, the range is between 0.400 and 1.800, so the number of a range is prepared accordingly. These palettes were chosen from the available colours in Arc Map 10.2.2 (Table 3).

3. Land use and land cover change detection

Unsupervised Classification is a method of sectorization of multispectral features captured by the sensors based on the reflectance of different surface features represented in the form of DN (Digital Number) values in each pixel. Such type of classification is important when the land cover is not well-known or undefined. It is to be used in order to detect the land use and land cover change detection of the study area with the help of remote sensing imagery. The classification is completely performed over the DN values. The change detection shall be categorised under following classes: 'Built-up' refers to human settlements, impervious surfaces, building, houses etc. They appear in different shades of sky blue in satellite images. 'Agriculture' is the crop production area including both irrigated and non-irrigated tracts. They appear in shades of light red in satellite images. 'Fallow land' is the cropland not seeded for a season. This is done to retain the soil fertility or to practice crop rotation. They appear greyish-green in satellite images. 'Vegetation/Forest' is an assemblage of plant species. They appear in dark red in satellite images. 'Barren land/Waste land' is the land which has the potential to develop vegetation or agricultural practices but is somehow restricted due to varying factors. They appear in shades between light blue and white in satellite images. 'Water-bodies' are the tracts of wet resources. They appear in shades from navy blue to dark navy blue in satellite images (Fig. 2).

Table 3 Range and palette for Shannon's entropy values. (Color table online)

Range	Palette	Name
< 0.400		Tzavorite green
0.401–0.500		Lemongrass
0.501–0.600		Light apple
0.601–0.700		Medium key lime
0.701–0.800		Fern green
0.801–0.900		Yucca yellow
0.901–1.000		Topaz sand
1.001–1.100		Medium yellow
1.101–1.200		Autunite yellow
1.201–1.300		Solar yellow
1.301–1.400		Rose quartz
1.401–1.500		Medium coral light
1.501–1.600		Medium coral
1.601–1.700		Rose dust
1.701–1.800		Tulip pink

Assessment of urban growth of Ghaziabad ward in temporal and spatial extent (2001–2015)

The Ghaziabad Nagar Nigam consists of 5 administrative zones:

1. City zone
2. Kavi Nagar zone
3. Vijay Nagar zone
4. Vasundhara zone
5. Mohan Nagar zone

Each administrative zone comprises of wards, constituting 80 wards (Ghaziabad Nagar Nigam, n.d.). The study includes these 80 wards and the analysis has been for the same level (Fig. 3). This section evokes a closer examination of land use and land cover, limiting the study to only the Ghaziabad wards. The satellite images were obtained from Landsat-4, Landsat-8, and LISS-III for four-time periods 2001, 2006, 2011, and 2015. These images have been subset out of the original images and then Maximum Likelihood Classification has been executed.

The Fig. 4 and Table 4 represent maps of land use and land cover classification for different years. The built-up occupies an area of 53.77 km^2 in 2001. It covers 60.52 km^2 in 2006 accounting for 31.73% of the total area. After 10 years it increased to 64.05 km^2. By 2015 the area has become so dynamic that the figure becomes 89.92 km^2. Similarly the percentage share also increases from 30.42% (2001) to 31.73% (2006) to 36.24% (2011) to 50.80% (2015). Agriculture has experienced a major setback as it used to be 26.52 km^2 area (15.01%) in 2001, 31.80 km^2 (16.67%) in 2006 which increased in 2011 to 30.43 km^2 (17.22%) but reduced in 2015 to

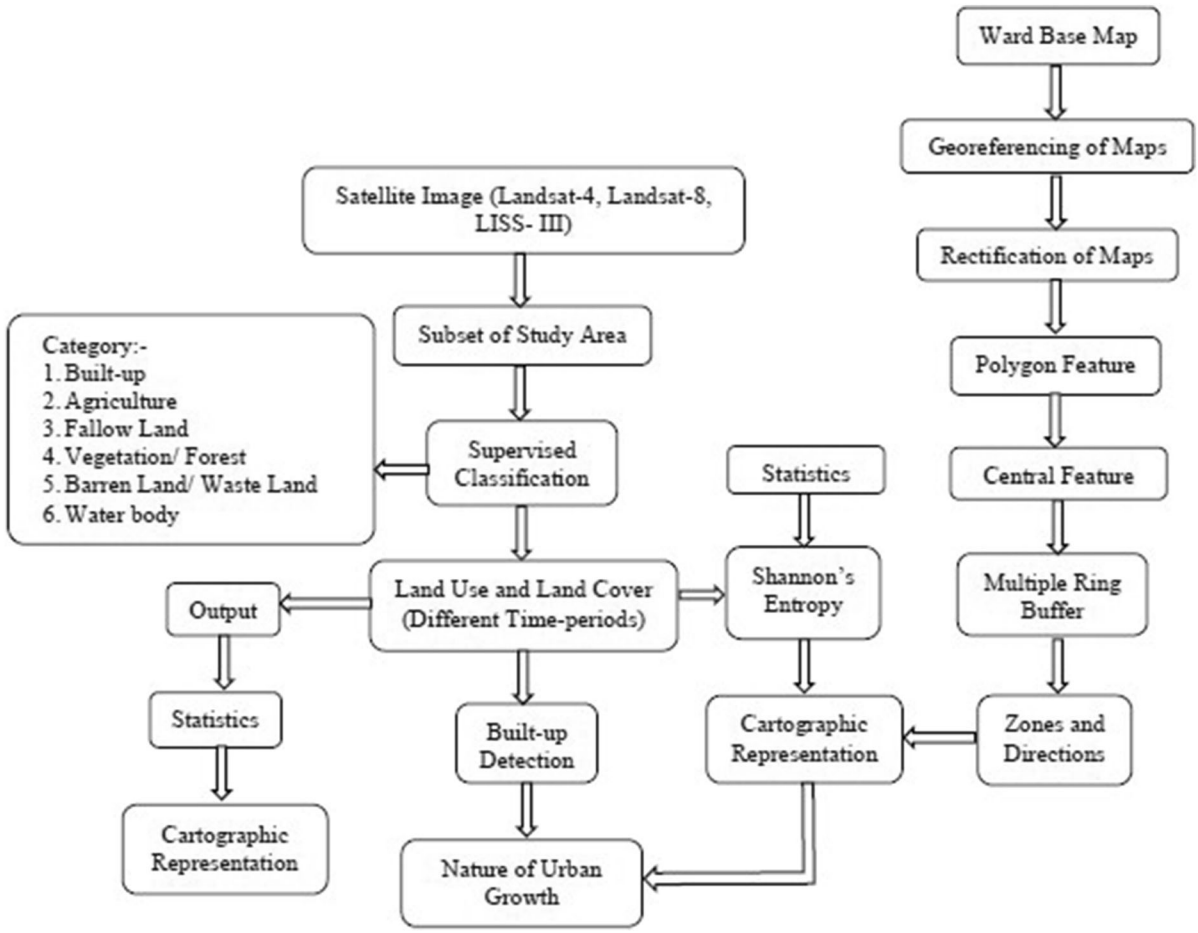

Fig. 2 Research design to compute Shannon's entropy index

7.94 km^2 (4.49%). Fallow land is still in increase which recorded 23.14 km^2 (13.09%) in 2001, 59.37 km^2 (31.12%) in 2006, it reduced in 2011 and covered 35.22 km^2 (19.93%), and in 2015 it increased to 51.46 km^2 (29.07%) The year of 2015 marked huge expanse of fallow lands due to the non-cropping season map. Barren/waste lands are on decrease from 30.47 km^2 (17.24%) in 2001 to 24.49 km^2 (12.84%) in 2006 to 26.64 km^2 (15.07%) in 2011 to 13.29 km^2 (7.51%) in 2015. Vegetation/forest has also suffered a setback and reduced by a major areal coverage and percentage. In 2001, it used to be 40.09 km^2 (22.68%) covering the wards and is constantly reducing in its extent which was 10.85 km^2 (5.69%) in 2006, in 2011 it was 16.77 km^2 (9.49%) and at present in 2015 it is covering 13.88 km^2 (7.84%). In the same way, water bodies have also suffered over their coverage. In 2001, water bodies covered 2.74 km^2 area (1.55%), 3.72 km^2 (1.95%) in 2006, increased by 2011 and recorded 3.62 km^2 (2.05%) further reduced to 0.51 km^2 (0.29%).

As the built-up is increasing, the absolute numbers are also increasing. The percentage change in built-up has also recorded a gradual increase in increasing percentages. The percentage change in the built-up area of Ghaziabad has increased nearly four-fold from 10.50 to 40.18% between 2011 and 2015 (Table 5). This means that the built-up is not only increasing but it is increasing at an increasing rate. This is also very well graphed in the Fig. 5 below.

The ward-wise built-up show differential growth rates during different time periods. However, they are irrespective of their location, they may or not belong to each side. The wards have been experiencing sudden transformations because of the need to accommodate the large population and hence the productive or the

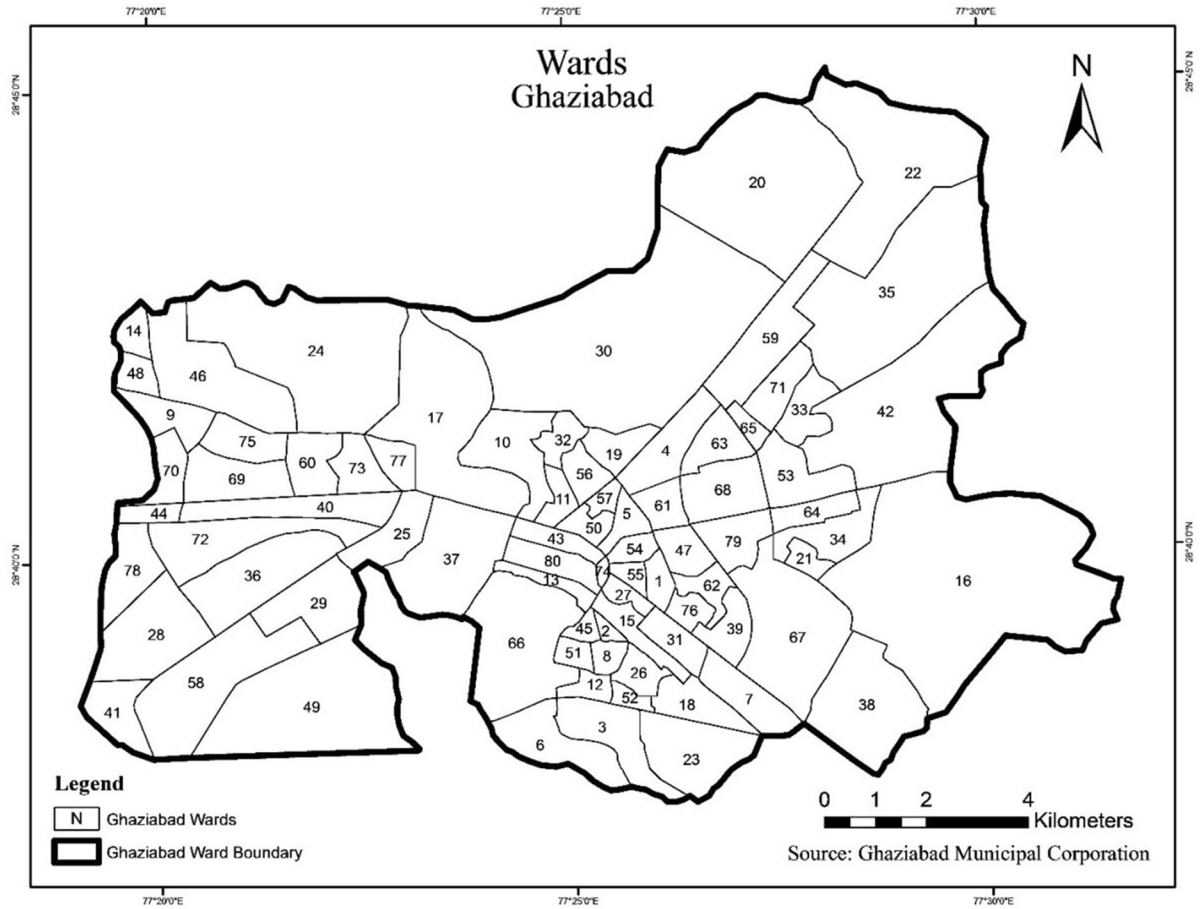

Fig. 3 Ghaziabad wards. *Source*: Ghaziabad Municipal Corporation

regions that are proclaimed to be productive in future are intensely being converted to commercial and residential locations (Fig. 6).

Form and direction of urban growth of Ghaziabad ward (2001–2015)

The global connections, widespread phenomena, occur in four different ways. They function at a greater speed, operates on a larger scale, creates a new level of complexity between policy and practice and it has multiple dimension, i.e., economical, technological, political, legal, social, and cultural (Vliet 2002). Such linkages have played a dynamic role in incorporating multiple and interdependent connections. Although the effects of globalisation have its effects on both rural and urban areas, the centrifugal and centripetal force tends to be centred in cities. Cities are the dynamics engines of growth hence they attract population at large scale.

Ghaziabad, the study area has also been the centre of growth and the driving force for attracting the population. Such processes have led to the increase in the built-up areas as also visible in the land use and land cover classification. Since the present cities are witnessing haphazard growth, it becomes necessary to understand the pattern of transformations taking place over the land use pattern. In order to determine the form and type of urban growth, Shannon's entropy model has been used. Ghaziabad ward has been subdivided into 4 buffer zones of 3 km each. Each zone forms a concentric circle radiating from the centre to periphery, i.e., Zone 1, Zone 2, Zone 3, and Zone 4 and has been analysed for 4 different years, i.e., 2001, 2006, 2011, and 2015 (Figs. 7, 8, 9).

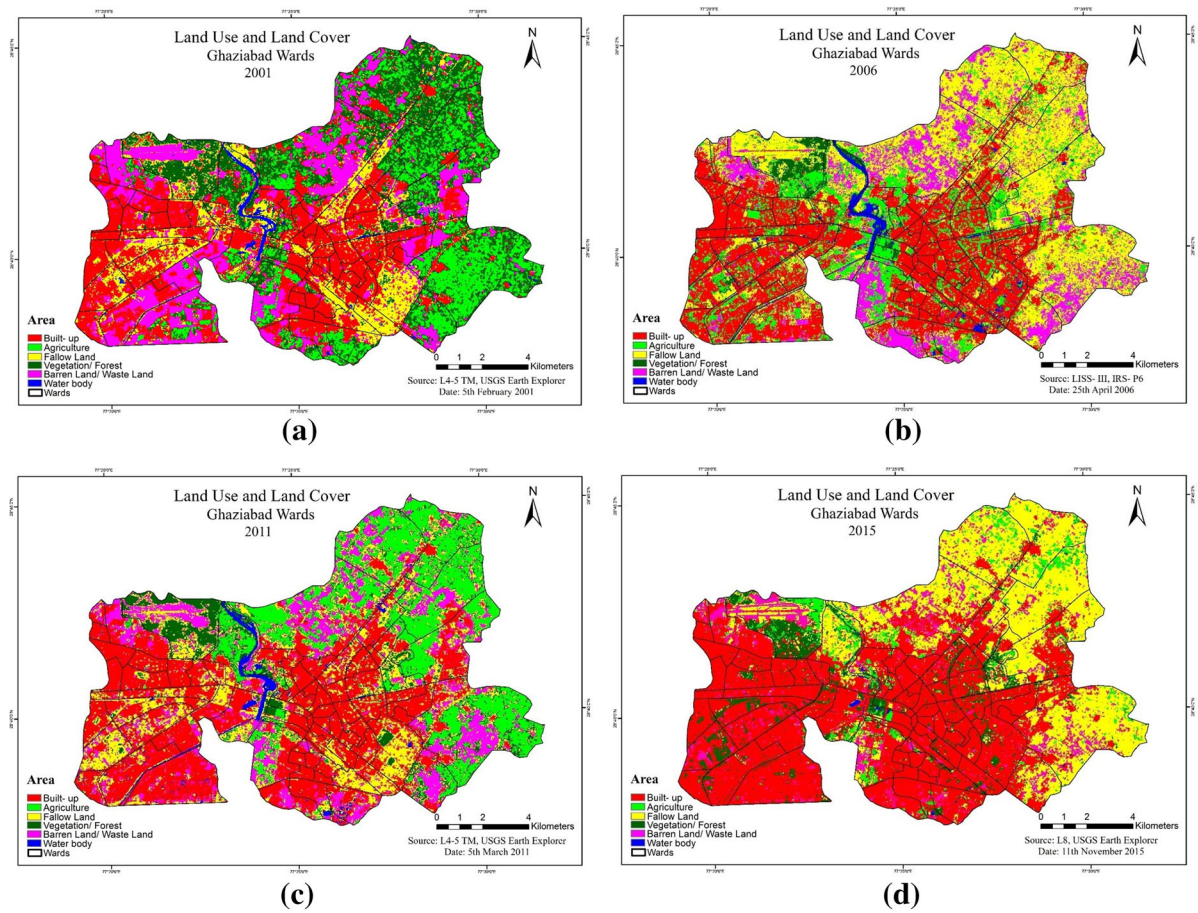

Fig. 4 Land use and land cover of Ghaziabad (ward-wise): (**a**) 2001, (**b**) 2006, (**c**) 2011 and (**d**) 2015

Table 4 Land use and land cover statistics, 2001–2015 (Ghaziabad ward)

Category	2001		2006		2011		2015	
	Area (km^2)	Percentage to total area	Area (km^2)	Percentage to total area	Area (km^2)	Percentage to total area	Area (km^2)	Percentage to total area
Built-up	53.77	30.42	60.52	31.73	64.05	36.24	89.92	50.80
Agriculture	26.52	15.01	31.80	16.67	30.43	17.22	7.94	4.49
Fallow land	23.14	13.09	59.37	31.12	35.22	19.93	51.46	29.07
Barren land/waste land	30.47	17.24	24.49	12.84	26.64	15.07	13.29	7.51
Vegetation/forest	40.09	22.68	10.85	5.69	16.77	9.49	13.88	7.84
Water body	2.74	1.55	3.72	1.95	3.62	2.05	0.51	0.29

The shades of colour represent the density of features in the region. Light palettes refer to low values meaning homogeneity and dark palettes refer to high values meaning heterogeneity. The map of 2001 shows that the Zone 1, Zone 3, and Zone 4 show a high degree of compactness and Zone 2 show a high degree

Table 5 Change (absolute and percentage) in the built-up area, 2001–2015 (Ghaziabad ward)

Year	Area (km^2)	Absolute change	Percentage of built-up	Percentage change in the built-up area
2001	53.77	–	30.42	–
2006	60.52	6.75	32.80	7.81
2011	64.05	3.53	36.24	10.50
2015	89.92	25.87	50.8	40.18

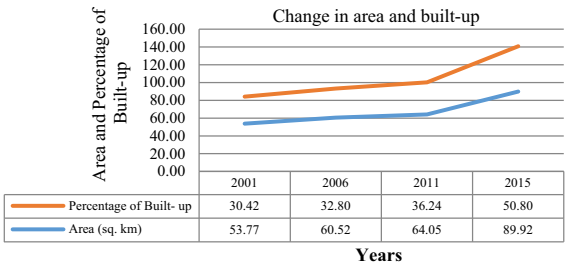

Fig. 5 Change in the area and built-up area, 2001–2015 (Ghaziabad ward)

of diversification. This means that Zone 2 still have divergence in its pattern however the Zones besides Zone 2 are of homogenous nature. However, Zone 1 is more homogenous than Zone 3 and Zone 4. Among the last two, Zone 4 is more homogenous than Zone 3. This explains that the Zone 2 and Zone 3 and the wards therein are in a situation of maximum transformation than the other zones.

In 2006, the core area has witnessed a decrease in their number witnessing increasing homogeneity in

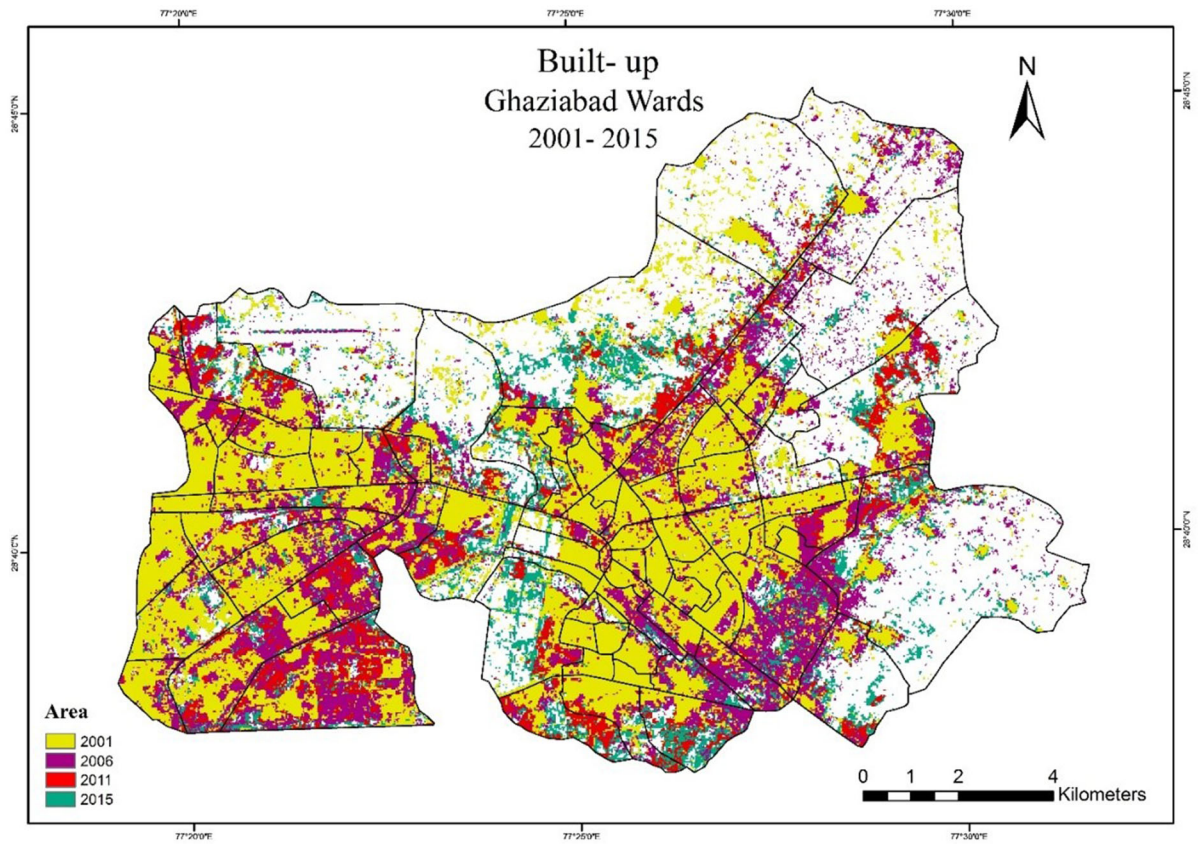

Fig. 6 Change in the built-up area, 2001–2015 (Ghaziabad, ward-wise)

their growth pattern. The core zone, i.e., Zone 1 possesses 1.290 which increases once the Zone changes and it becomes 1.631. In Zone 3, the value reduces to 1.428 and Zone 4 (1.025) again attains homogeneity. The core areas are under constant transformations culminating into a compact settlement. The peripheral areas have also low values suggesting a homogenous nature though its values are greater than the core. This means the core is under rapid transformation than the peripheral areas which more or less have a similar character of being rural.

In 2011, there occur transformations in values of Shannon's entropy index for all the zones. The values of Zone 1 further reduced to 1.237, Zone 2 also reduced to 1.600. However, Zone 3 and Zone 4 experienced an increase from 1.585 to 1.605 and 1.526 to 1.552 respectively. The values represent that Zone 1 and Zone 2 are attaining compact nature whereas Zone 3 and Zone 4 are still on the diverse side of the pattern. Similarly, the wards falling in their respective categories show similar characteristics as of their respective Zones.

The year of 2015 shows a different picture of the Index. This year has largely attained a homogenous

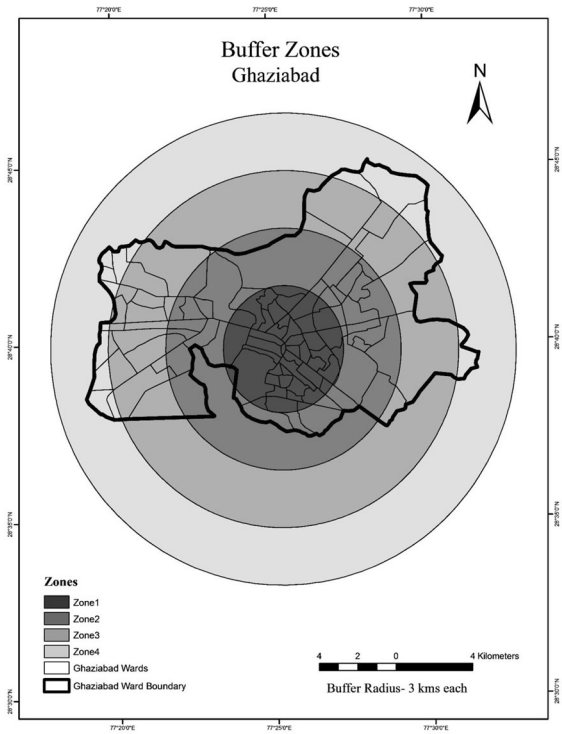

Fig. 7 Multiple buffer zones in and around Ghaziabad ward

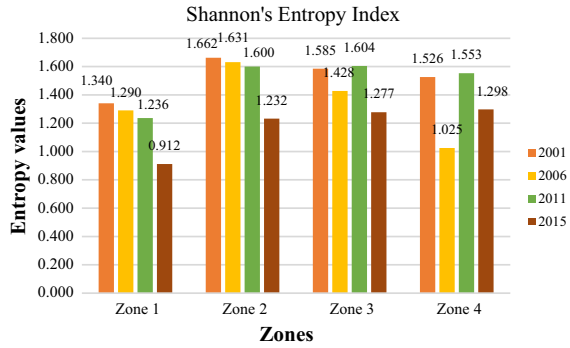

Fig. 8 Shannon's entropy index of Ghaziabad; zonal-wise (2001–2015)

character as also shown by the shades of color. In this year, the values represent light shades which itself means that the values have become lower and so homogeneity has increased. The previous years were more of dark color, especially towards the periphery. Though this year has shown a decrease in values of peripheral zones, the central zone itself has further reduced in its colour, shade, form, and pattern. Zone 1 possess 0.912 in 2015 which was 1.237 in 2011, Zone 2 has 1.232 in 2015 which was 1.6 in 2011, Zone 3 has 1.277 in 2015 which was 1.605 in 2011, and Zone 4 has 1.298 which was 1.552 in 2011. The rate at which the zones are transforming is seemingly high as the values suggest across time. Zone 2 and Zone 3 are at the dynamic side where transformation is taking at a high rate.

The above analysis shows a simplified pattern of urban growth according to zones. However, this does not provide the directional change, the direction which has more probability of transformation. In order to resolve this situation of research, each zone has been divided into directions, namely, North, East, South, and West. Next, the analysis has been preceded not only with the zones but also includes directional change.

The Shannon's entropy index of 2001, 2006, 2011, and 2015 for Ghaziabad ward has been shown in terms of map (Fig. 10) and representation through graphs (Fig. 11). The trend of temporal changes shows the differential pattern of urban growth across zones and direction. Different directions show different values hence different patterns. In Zone 1 among the four directions, East is less diversified (0.760) followed by South (1.204), North (1.263), and West (1.729). In Zone 2, the sequential changes occur from East

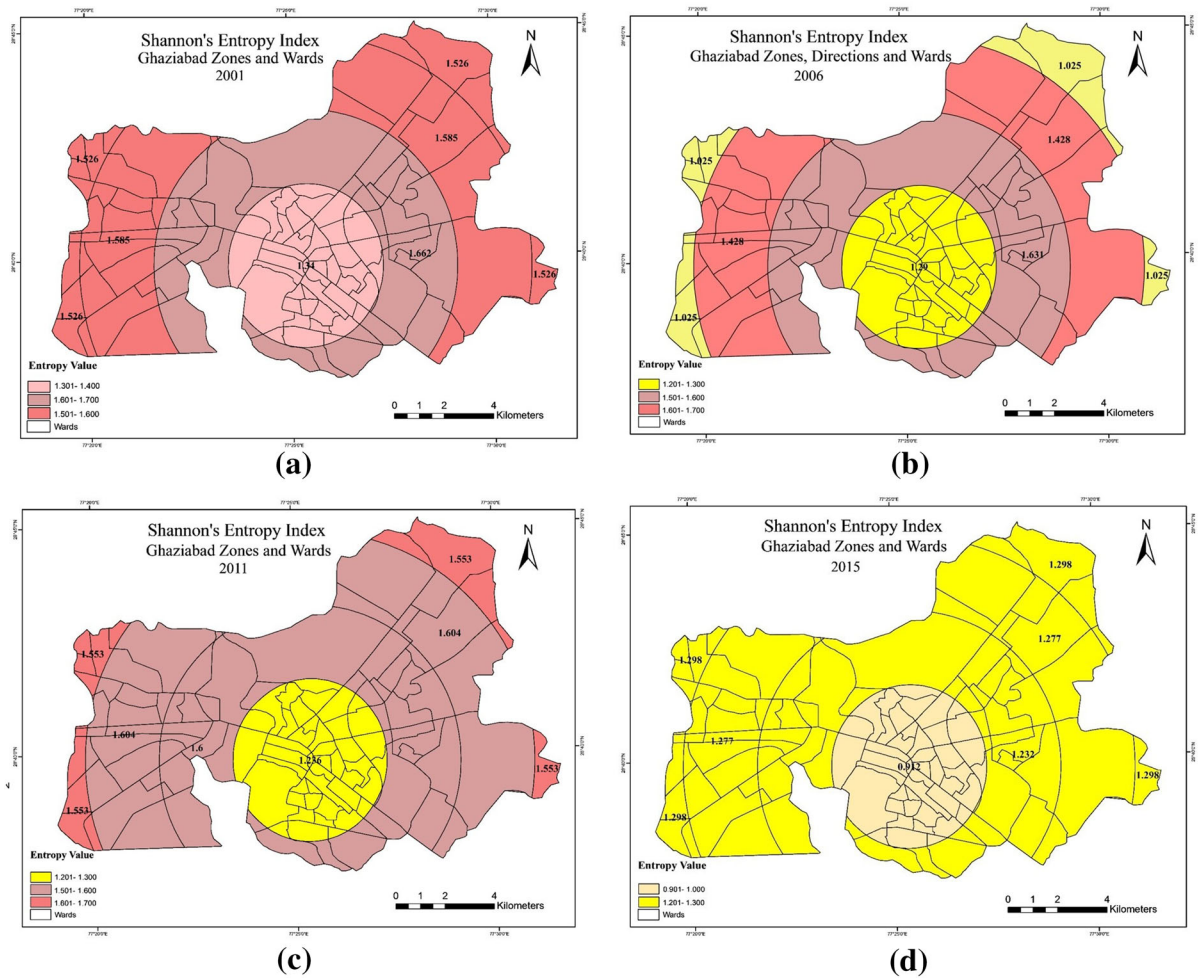

Fig. 9 Shannon's entropy index, Ghaziabad (zone and ward-wise): (**a**) 2001, (**b**) 2006, (**c**) 2011, and (**d**) 2015

(1.635) to North (1.630) to South (1.612) to West (1.586) thus changing from diverse to compact. Zone 3 and Zone 4 represent a similar type of pattern, high to the North, followed by West and East. The boundaries of Ghaziabad ward do not extend to South for these zones so the bars are invisible. However, the patterns of Zone 4 are much compact than Zone 3. Zone 2 still shows a high level of diversification and all the directions are located at near around values of Shannon's entropy index. The North, East and South direction show a higher diversification in Zone 2. The rest Zone of the same direction has lower values. Similarly, the wards of the respective peripheries have been experiencing change the way zones and their directional locations are. To the West, the zones are experiencing diversification from Zone 4 to Zone 1. This is indicative of that the west region is experiencing spiral from Delhi to Ghaziabad, and Delhi is located to the South-west of Ghaziabad. Similarly, the wards are also getting transformed from the periphery to the centre.

Similar to 2001, the year of 2006 has been analysed for four zones (Zone 1, Zone 2, Zone 3, and Zone 4) and four directions each (North, East, South, and West). In the North, the pattern of growth and densification shows an increasing pattern from the centre and decreasing towards the periphery. The values report 1.218 (Zone 1), 1.459 (Zone 2), 1.116 (Zone 3) and 1.006 (Zone 4). A similar trend is noticeable for the East direction; increasing from the centre and decreasing towards the periphery. The values increase from Zone 1 (0.788) to Zone 2 (1.345),

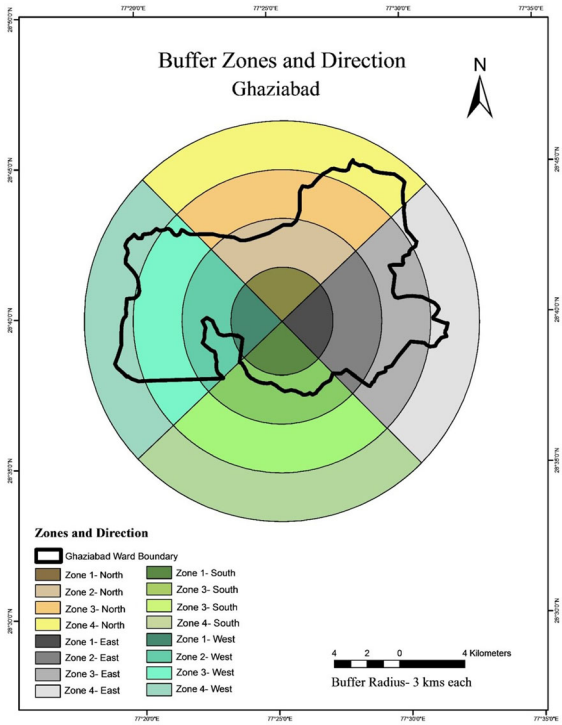

Fig. 10 Multiple buffer zones and directions of Ghaziabad ward (North, East, South, and West)

then starts reducing to Zone 3 (1.345) to Zone 4 (0.756). The Southern extent of Ghaziabad extends only to two zones. Here, the value is not increasing but showing a decreasing trend from Zone 1 (1.118) to Zone 2 (0.769). The West direction has shown a fluctuating trend of densification. The values fluctuate with the change in zones. It peaks in Zone 1 with a value of 1.506, then decreases to 1.166 in Zone 2. It again increases to 1.368 in Zone 3 and finally reduces to 1.1.70 in Zone 4. Zone 1 and Zone 2 are evident of maximum transformations from being compact than the earlier pattern of diversification. Zone 3 has seen a decrease suggesting intermediate zone between rural and urban, whereas Zone 4 is in the primary phase of transformations.

The Shannon's entropy index of 2011 shows a different scenario than what was concluded from 2001. In Zone 1, the West has the lowest value which is 0.144, increases to South (0.998) to West (1.504) to North (1.572). Similar is the increase in diversification trends. In Zone 2, the fall of values is observed from North (1.763) to East (1.545) to West (1.370) to South (1.364). In Zone 3 and Zone 4, trends are differently located. The East direction of Zone 3 has the highest value of 1.543 which reduced to North (1.504) to West (1.245). In Zone 4, the lowest values are observed in East (0.920) and it increases to West (1.193) to North (1.217). Similar are the trends of diversification. As the value increases the diversification increases and as the value decreases homogeneity increases. In terms of directional change, West direction with its lowest value (0.144) increased significantly when movement took place to Zone 2 (1.545) and again its starts decreasing which is recorded at 1.543 in Zone 3 and 0.920 in Zone 4. However, Zone 1 and Zone 4 are homogeneous in nature; Zone 2 and Zone 3 are more diversified. In terms of directional change, West direction with its lowest value (0.144) increased significantly when movement took place to Zone 2 (1.545) and again its starts decreasing which is recorded at 1.543 in Zone 3 and 0.920 in Zone 4. However, Zone 1 and Zone 4 are homogeneous in nature; Zone 2, and Zone 3 are more diversified.

The year of 2015 shows most of the values below 1, a few with peaks above 1. The Zone 1 shows a divergent nature to the West with peaking value of 1.461. The rest of the directions remains at low values indicating much more homogeneity in their nature. The North has a value of 0.763 which changes to 0.50 for East, to 0.613 to the South and 1.461 to the West. Zone 2 experienced low value in the South (0.940) which increase in the West (0.973), then to the East with 1.166 and finally to the North 1.329. Zone 3 experiences fewer differences in the direction, recorded 1.005 (North), peaking towards East (1.044) and again lowering much below North with a value of 0.990. In Zone 4, wide differences between North (0.890) and East (0.582) and fewer differences between North (0.890) and West (0.887). In terms of directions, values for North are increasing from Zone 1 (0.763) to Zone 2 (1.329) and then it is decreasing from Zone 3 (1.005) to Zone 4 (0.890). Similar patterns are visible for East where the values are increasing from Zone 1 (0.505) to Zone 2 (1.166) and again decreasing from Zone 3 (1.044) to Zone 4 (0.582). For South direction, the values are increasing from Zone 1 (0.613) to Zone 2 (0.940). However, the values for West are fluctuating because this direction has attained urban growth mostly from the periphery to the core. Hence the value of Zone 4 is 0.887, Zone 3 is 0.990, Zone 2 is 0.973, and Zone 1 is 1.461 (Fig. 12).

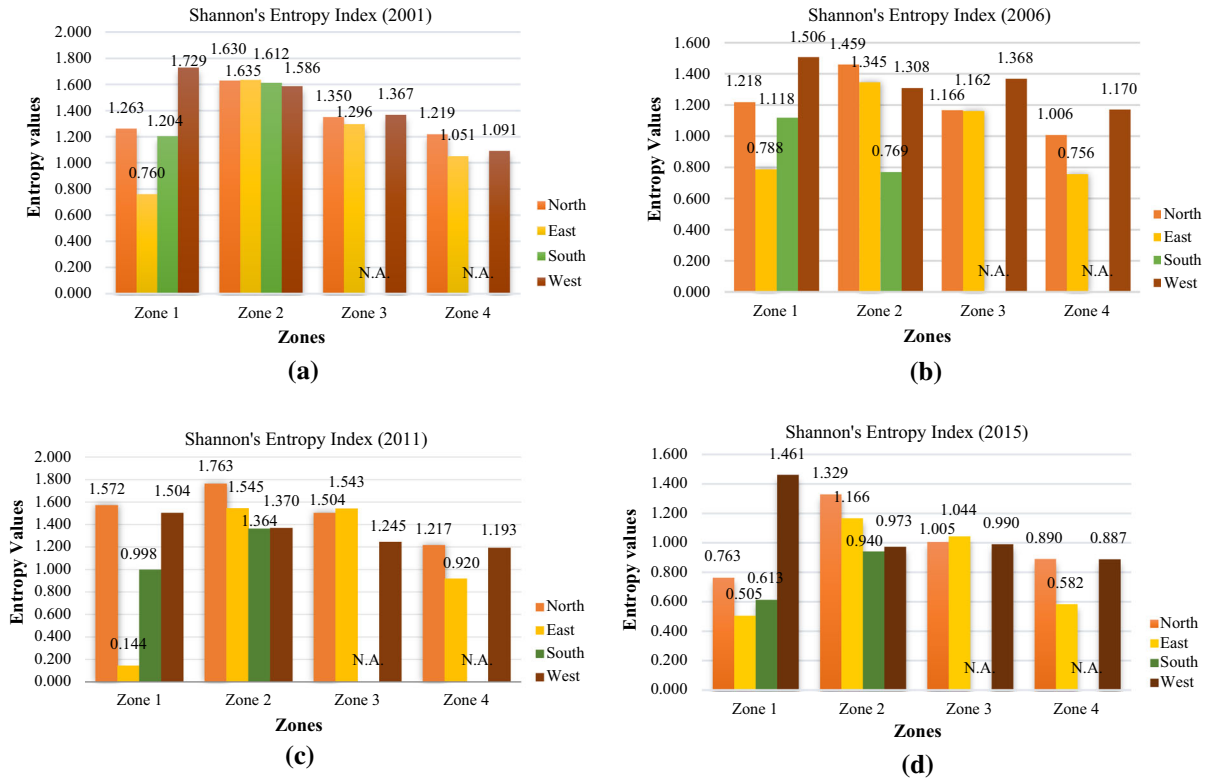

Fig. 11 Shannon's entropy index of Ghaziabad ward; zone and direction-wise: (**a**) 2001, (**b**) 2006, (**c**) 2011, and (**d**) 2015

Observation and interpretation of results

This study dealt with Shannon's entropy index which detects the degree of compactness and the degree of diversification in any region. For the purpose, Ghaziabad city level perspective has been taken into consideration. For this purpose, a land use and land cover classification were performed for the study area for 2001, 2006, 2011, and 2015. With the provided data, the study area was divided into 4 buffer zones and 4 directions each. The resultant values determine Shannon's entropy values. The value ranges from 0 to $\log_n$. The values closer to 0 indicate a high compact character of the urban growth whereas values towards $\log_n$ denote more diversification.

The concept of Shannon's entropy raises the transformation of regions that take place from rural to being urban. Urban growth starts from a low developed region, i.e., rural. Since the rural areas sustain the natural resources and have less diversification in terms of its land use, the entropy value is recorded low. However, since the population is on increase and the advances in information technology, the rural region starts to convert to different uses in order to sustain its economy. The region now increases in its entropy value as mixed uses of land is prompted. Since the territorial limits are under limitations, the regions grow within its territory and this leads to densification. As densification increases, the region which used to be an agricultural one now gets converted to built-up areas, a homogenous pattern. This phase again leads to a decrease in entropy values due to it homogenous character. This pattern of growth continues to grow and the surrounding areas are subsequently brought into the urban fold (Fig. 13).

Ghaziabad is also experiencing changes in its land use and land cover pattern. However, the sprawling pattern of settlement is different in this case. Although Ghaziabad itself is increasing from the centre to the periphery, more changes are evident from southwest direction, i.e., from Delhi. This is because Delhi is extending its territorial limits and has been implementing the Delhi NCR plan which also includes the Ghaziabad region. The entropy values of Ghaziabad

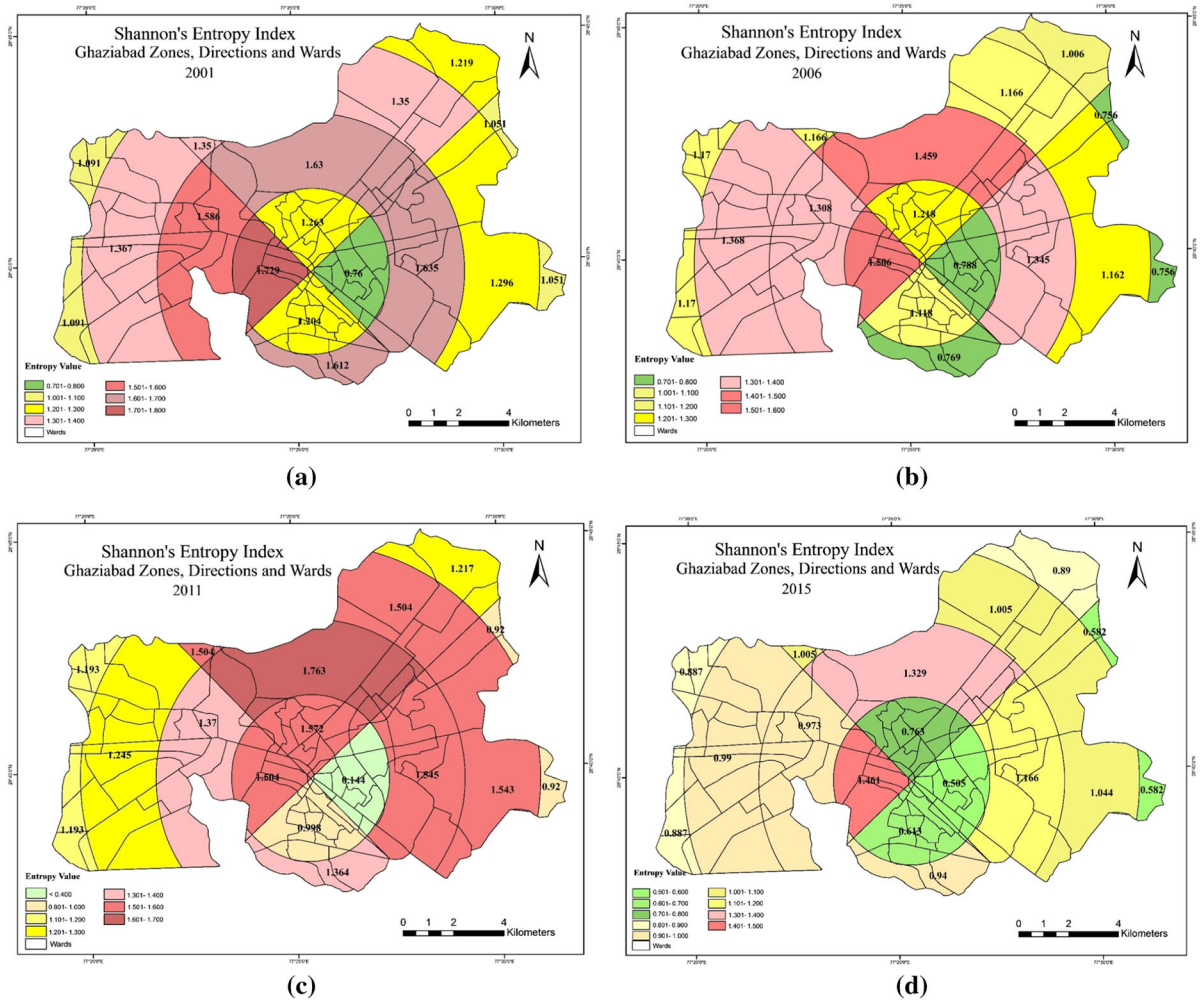

Fig. 12 Shannon's entropy index (Ghaziabad zones): direction, and ward-wise: (**a**) 2001, (**b**) 2006, (**c**) 2011, and (**d**) 2015

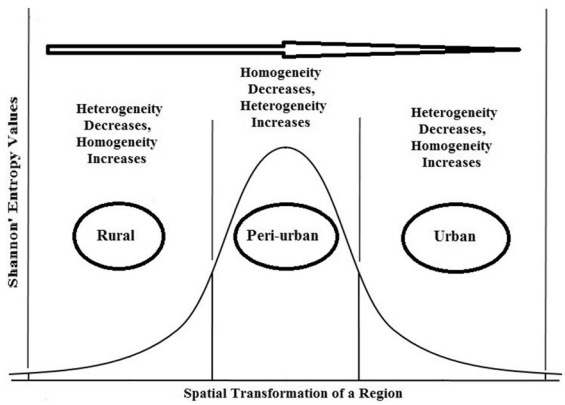

Fig. 13 Schematic representation of Shannon's entropy index and the study

increased from the centre to the periphery in the North, East, and South direction. But in the South-east, the value is decreasing from centre to the periphery. This means that more changes are experienced in the periphery than in its centre. The varied type of land use pattern at the intersection of Ghaziabad and Delhi is tremendously changing because of the strengthened transport corridors and with the ease of commutation. So, in the case of Ghaziabad, the expansion is more from the South-west than the other directions.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Human and animal rights This chapter does not contain any studies with human participants performed by any of the authors. This chapter does not contain any studies with animals performed by any of the authors. This chapter does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants included in the study.

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