Towards a Unifying Approach to City Sustainability on the Changing Expression of Urbanisation in Bengaluru

Juhi Priyanka Horo and Milap Punia

Abstract On the path of accelerated urbanisation, India contains four of the world's ten largest cities Mumbai, Delhi, Bengaluru, and Kolkata. Bengaluru is prominent among the world's fastest growing cities that have attracted abound of the population, capital, and investments with robust connectivity. As a result, the pressure of the metropolis has swept over its carrying capacity, thereby affecting the resources, infrastructure, ecological diversity and land therein. Various 'cities' related multifaceted categories such as 'sustainable cities', 'smart cities', 'digital cities', 'resilient cities', 'low carbon cities', 'eco cities', and 'liveable cities' are into discourse which are still framing the distinctive character of cities which would have impression on the theoretical understanding and on the policymaking. This raises an issue of sustainability and quality of life for its citizens now and for future as well, under which, Bengaluru has to make key decisions on land use, sprawling peripheries, infrastructure, transport, and energy. This demands for a careful and rational provision of planning keeping in mind the issue of imbalance without forsaking the pre-requisite of the regions. The following research makes an attempt to analyse the urban environment; an emphasis on the associations of distributed aspects of urban growth, their relation and the resultant influences taking the study area of Bengaluru of Karnataka state. The outgrowth of centre towards periphery is gaining importance wherein the spatial as well as temporal changes in urbanisation helps in witnessing the prevalent land use changes provide insight of rate, extent, and direction of sprawl.

Keywords Shannon's entropy · Bengaluru · Urbanisation · Sustainability · Urban expansion

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1 Introduction

Human beings in their process of interactions with the environment and endowments have been persistent in altering the process of recycling of services by deliberate actions as responsive recipients. In the process of interactions, human faces impediments on its way of obtaining desired outcomes, hence struggle its own way to combat the situations, that either be constructive or destructive. Considering urban component as one of the dynamic domains of human interference, the outgrowth from the centre towards periphery is gaining importance and is discovered in rapidly urbanising metropolitan cities. Urbanisation unfolds the challenges of increased mobility and heterogeneity that has implications over the dire need of urban social and territorial sustainability rather than operationalize concrete methods of achieving sustainability [1]. Under the consideration of the complexity of larger cities, they also have the capability to overcome the challenges of cities, but it depends completely on the cities where such capacities need to be developed.

Bengaluru presents a perfect example of rapidly increasing urban landscape at the cost of natural ecosystems. As per Nagendra, Bengaluru had 19,800 lakes in 1830 which provided 50% of water supply in Bengaluru. Bellandur Lake in Bengaluru has been in news flash for the upsurge of foam and froth along with smoke and flames as a result of unusually heavy rain in the city [2, 3]. An estimate of 400–600 million litres of untreated sewage is diverted to the lake every day, thus creating an unhealthy environment and life miserable for the citizens [4–8]. Despite series of intervention on the rejuvenation of the lake, the implementation is still in process [9]. The Respirable Suspended Particulate Matter (RSPM) has exceeded the national permissible limit in Bengaluru [10–13]. The increased concentration of the mentioned chemicals, loss of wetlands and vegetation has altered the natural heat budget of the area and is widely hampering the natural setting of the environment by converting it into urban heat island and causing reasons for future flooding within the urban limits [14]. The increased concentration of the mentioned chemicals, loss of wetlands and vegetation has altered the natural heat budget of the area and is widely hampering the natural setting of the environment by converting it into urban heat island and causing reasons for future flooding within the urban limits [14]. The vehicular stress imposed by the improved connectivity and distressed urbanisation cause problems for surrounding areas, especially the times of high traffic congestion and high speeds [15]. These provision of urban services and thereby the management of resources have gained popularity to study the nexus of the urban systems; what Broto and Sudhira call ‘Engineering modernity’ [16].

The objectives of the research explored the importance of city sustainability with respect to urban expansion of Bengaluru to become a smart city. The effect of urban transition is such that it is proportional to the scale of population shift [17]. It is also because the cities, especially Indian cities replicate the growth model of the international urbanized economies in order to battle in the pace of world competency. The growth model of Bengaluru needs to explore through the research; the changes in urban dynamics in the spatio-temporal context in association with the

spatially disseminated constituents of urban growth. Such development happens to be biased as it leads only the affordable class but it creates social and spatial fragmentation that subjugates the destitute class. As far as the directional change is concerned, the usual trend of sprawl is either radial around the city centre, on the urban fringe, the edge of an urban area or linear extension along highways [14]. The further research focuses on the zonal and directional changes of urban growth in Bengaluru to validate the trend. The urban expansion of Bengaluru is indicative of the fact that much of the urban development has been a concentration in and around. Vaddiraju [18] predicates this pattern of urbanisation of Bengaluru similar to the exclusionary urbanisation evoked by Kundu [19].

2 Study Area

Geographically, Bengaluru is located to the South-east in Karnataka extending from 12°49′5″N to 13°8′32″N and 77°27′29″E to 77°47′2″E. The erstwhile Bangalore Mahanagara Area (BMA) constituted a population of 5.8 million in 2001 to 8.4 million in 2011 now renamed as Bruhat Bengaluru Mahanagara Palike (BBMP) [20, 21]. The areal extent of Bengaluru Mahanagara Palike (BMP) of 226 km^2 has now increased to 741 km^2 of BBMP forming the largest municipal corporation in India (Fig. 1). The population density has increased from 7,880 persons per sq. km to 11,330 persons per sq. km during the mentioned decade. In 1961, with a population of 1.2 million, Bengaluru stood the sixth-largest city in India and the fastest city of Mysore State and its administrative capital. Coinciding with the uncontrolled rise in its population, the city underwent a change in the economic structure and, therefore, emerged an industrial centre. According to Census 1961, Bengaluru constituted of two Class II towns, four Class IV towns, five Class V towns and one Class VI town [22]. Bengaluru became one of the ‘Million-plus cities’ of India in 1961 and was notified as Greater Bangalore in December 2006.

3 Data Used and Methods

The research is based on the quantitative exploration of the urban growth in terms of the spatially disseminated constituents. In order to deal with the perspective, the base maps were used from the District Census Handbook (DCH), BBMP (2001 and 2011), Census of India. The boundaries of BBMP, wards, etc. were retained from the above-mentioned source. Furthermore, the spatial aspects need to quantify the research area to grasp the knowledge about the area. For this, Primary Census Abstract (PCA) of BBMP wards (2001 and 2011) was obtained from Census of India website. The large-scale changes in land use and land cover are efficiently monitored by the remote sensing datasets and are available in profusion. For the purpose of the research on spatial constituents, Landsat-4 and Landsat-8 images

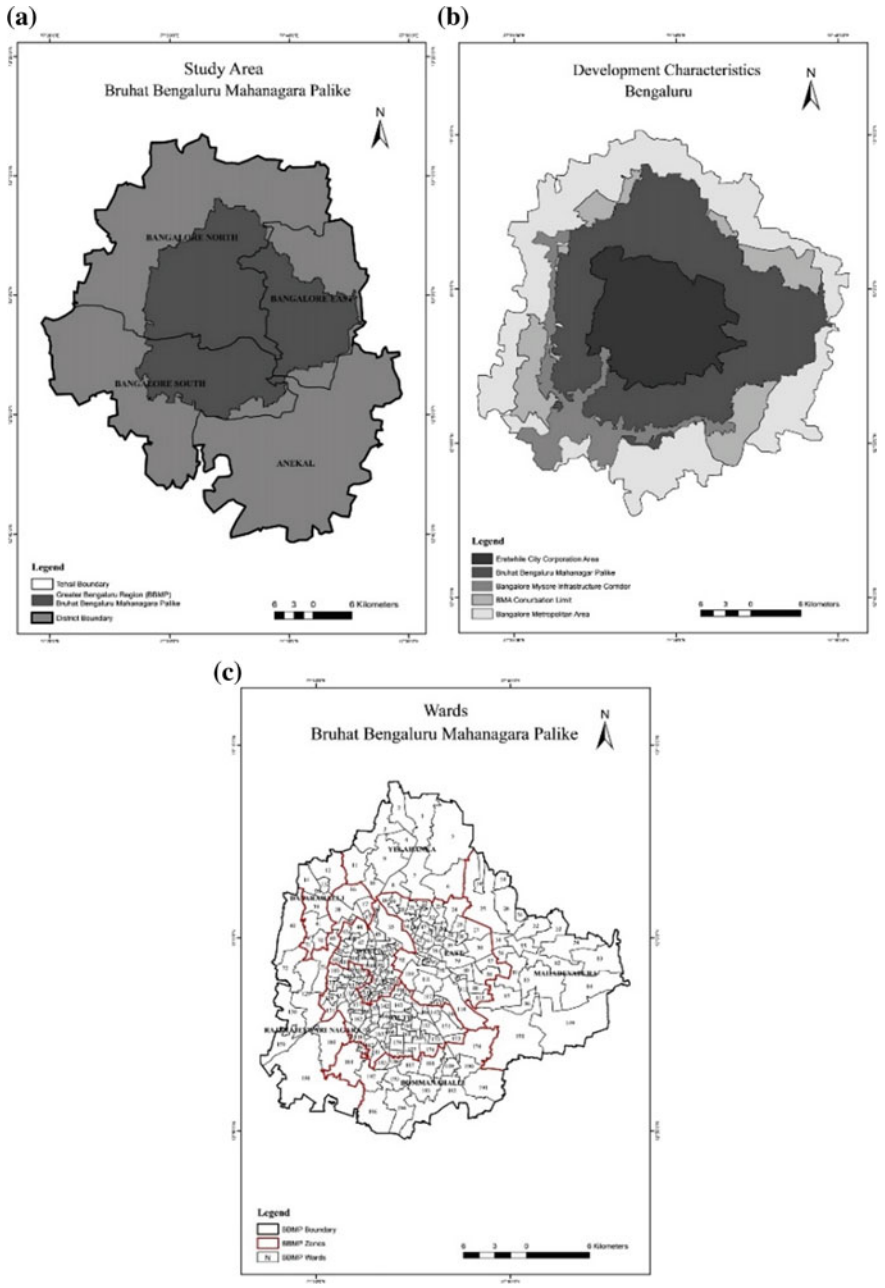

Fig. 1 **a** Study area (BBMP); **b** development characteristics of Bengaluru; **c** BBMP zones and wards. *Source* Administrative Atlas of Karnataka 2011 and BBMP

were taken from United States Geological Survey (USGS) Earth Explorer for the years of 2001 (March 27), 2005 (February 18), 2011 (March 7), and 2005 (January 13). 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.

As per the objectives mentioned framed, following methodology has been put forward for the research:

3.1 Shannon's Entropy Index (Form and Type of Urban Growth)

The force of energy; one of the fundamental driving forces of nature which is omnipresent is what is known as entropy which drives all creation and destruction. The concept of entropy is much related to the second law of thermodynamics which infers that entropy of an isolated system never decreases. The isolated system here means that neither the mass nor the energy is bound to follow in or out. If there are 'n' numbers of ways, a system can function then the entropy will increase with an increase in 'n'. According to Tiwary [23], 'Entropy is a way to quantify the overall disorder or chaos of a system'. Quantitatively, it can be better expressed in terms of the research on urban growth in the article.

Shannon's entropy [24] can be computed for different areas to investigate the form and type of urban growth and the sprawl pattern. The formula for Shannon's entropy (H_n) is:

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

where

P_i = Proportion of the variable in the ith zone (e.g. proportion of built-up area in each ward)
n = Total number of zones (e.g. total number of wards)

The range of entropy values extends between 0 and log n, wherein, homogeneity of the urban from will posses values towards 0 and values closer to log n reveal that the distribution is much dispersed and of varied types. Larger values of entropy correspond to the delineation of sprawl.

3.2 Shannon's Entropy Values Classification

As already mentioned, the value of Shannon's entropy ranges from zero (0) to infinity, and so there is no upbound limit. In this study, the values of the index for the regions of BBMP ranges between 0.400 and 1.800, so the number of a range is

Table 1 Range and palette for Shannon's entropy values

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

prepared accordingly [25]. Arc Map 10.2.2 provides several palettes that makes the visualisation easy and identifiable (Table 1).

3.3 Classification of Land Use and Land Cover Change

The conventional techniques of mapping the land use changes imply heavy expenses and time. However, with improvement in technological assistance, the quantification of impervious surfaces has authenticated the research proficiency along with the spatial data and analysis through the advanced methods of Remote Sensing and Geographical Information System (GIS). Comparisons of land use and

land cover over a span of years determine crisp transformations taking over time and space [26, 27]. Considering the above statement, similar applications have been made for study taking into account the satellite images of BBMP for the years of 2001, 2005, 2011, and 2015. The sub-categorical typologies enable a better understanding of urban diversity. These categories are: 'Built-up', 'Agriculture', 'Fallow land', 'Vegetation/Forest', 'Waterbodies', and 'Rocky Highlands'.

4 Spatial and Temporal Assessment of Urban Growth of Bengaluru in (2001–2015)

4.1 Analysis and Discussion

BBMP is subdivided into 8 administrative zones: West, South, Rajarajeshwari Nagar, Mahadevapura, East, Dasarahalli, Yelahanka, and Bommanahalli. East administrative zone comprises of an abound of wards, constituting BBMP with a total of 198 wards.

Since the focus area of the study is BBMP, an investigation from broader to narrow level gives a clear and precise picture of the scenario. The satellite images have been obtained from Landsat-4 and Landsat-8 of USGS Earth Explorer and the study area of BBMP has been extracted from each image. The land use and land cover changes are prominent when looked at the satellite images but classification gives a much clearer image of the scenario across time.

Figure 2 provides a classified image of land use and land cover. The built-up area of BBMP (Table 2; Fig. 3) has increased from 290.81 km^2 (42.11%) in 2001 to 327.89 km^2 (47.48%) in 2005 to 407.38 km^2 (58.97%) in 2011 to 500.13 km^2 (72.43%) in 2015. The agricultural fields initially experienced an increase by 2005 (6.62 km^2 in 2001 and 7.62 km^2 in 2005) but the years of 2011 and 2015 have shown a decrease in them (5.34 km^2 in 2011 and 5.21 km^2 in 2015). After the built-up, fallow land occupies a larger share of land use and land cover. The fallow land possessed 242.45 km^2 in 2001 but with the alternate use of land, it has suffered a reduction in its share as well as in area. It has now reduced to 9.95 km^2 in 2015. The major effect has also been on barren/waste land as it shot up to 2005 but it has also reduced to a considerable extent due to the alternative use of the land. The situation of vegetation/forest cover has been quite fluctuating, being 26.39 km^2 in 2001, peaked to 36.80 km^2 in 2005, reduced in 2011 with 30.01 km^2 and again picked up with 32.24 km^2 in 2015. The patches of waterbodies are decreasing from 9.09 km^2 (2001) to 7.39 km^2 (2015) in its area and share. The fluctuations in rocky highland are because of the forest areas over it. These regions with limited forest have shown a high percentage than when covered with more greenery. According to Indian Institute of Science (IISc), the resultant effects of urbanisation and expansion of Bengaluru between 1973 and 2016 have been such that it has led to 1005% increase in paved surfaces and a loss of its vegetation by 88%, whereas water bodies have declined by 85% between 2000 and 2014 [28].

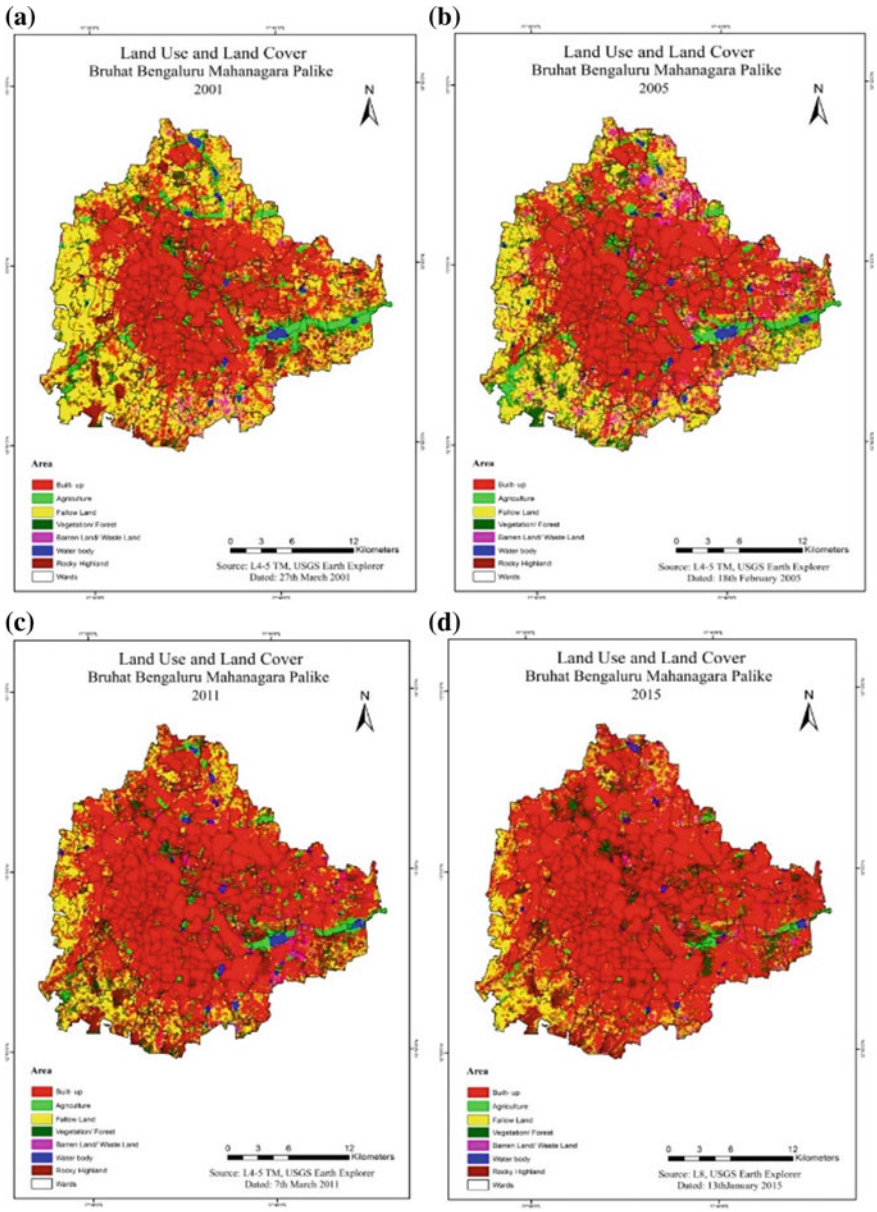

Fig. 2 Land use and land cover (BBMP); **a** 2001, **b** 2005 (BBMP, ward-wise), **c** 2011, and **d** 2015

Table 2 Change (absolute and percentage) in a built-up area, 2001–2015 (BBMP)

Year	Area (km^2)	Absolute change	Percentage of built-up	Percentage change in built-up area
2001	290.81	–	42.11	–
2005	327.89	37.08	47.48	5.37
2011	407.38	79.49	58.97	11.49
2015	500.13	92.75	72.43	13.46

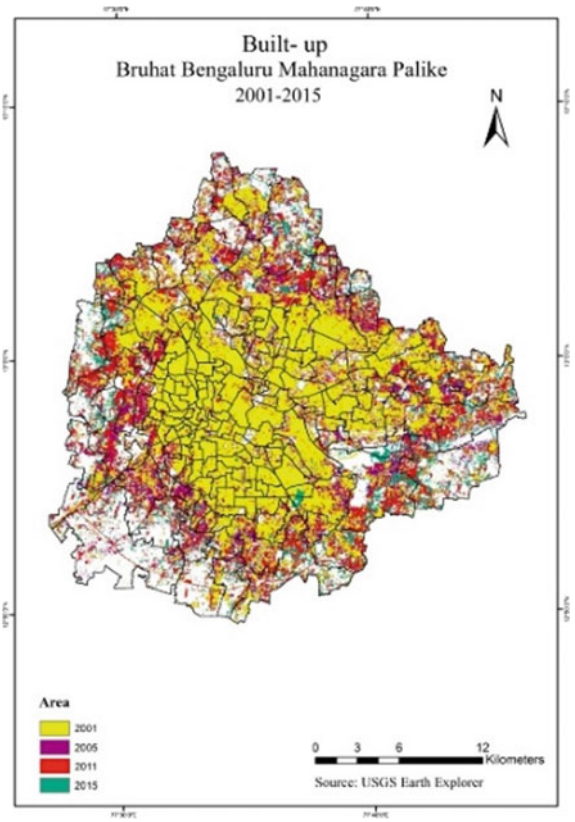

Fig. 3 Change in built-up area, 2001–2015 (BBMP, ward-wise)

4.2 Structural and Directional Transformations of Urban Growth of Bengaluru (2001–2015)

The study of patterns of urban growth of Bengaluru has been divided into zones and directions that will help us to know not only the sprawling pattern but also the direction and rate of change. In order to delineate the form and direction of urban growth, Shannon's entropy index has been applied to the study. The areal extent of

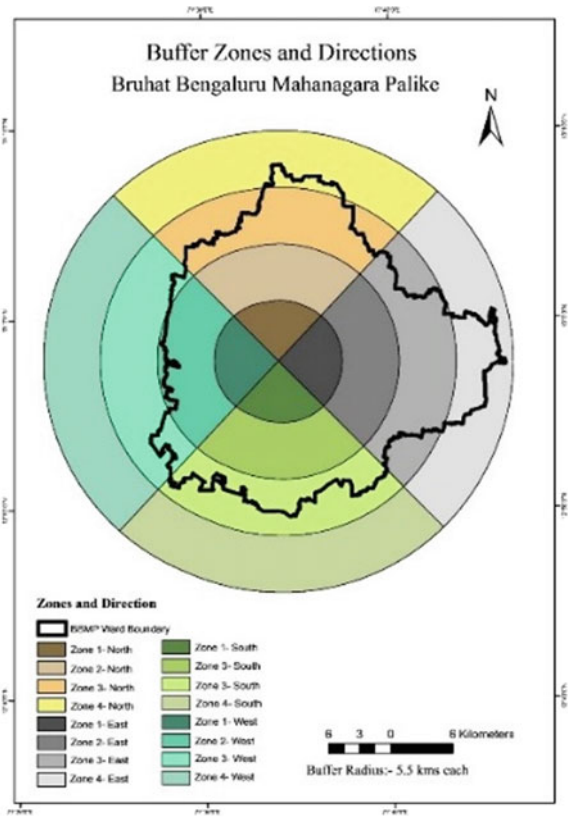

Fig. 4 Multiple buffer zones and directions of BBMP (North, East, South, and West)

BBMP is the boundary limit of the index and the analysis has been made in terms of zones. The formation of the zone has been prepared in Arc Map 10.2.2 with the method of multiple buffers, resultant 4 concentric zones (circles) of 5.5 km radius each. The zones have been named as Zone 1, Zone 2, Zone 3, and Zone 4 radiating from centre to the periphery and further they were subdivided into different direction: North, South, East, and West (Fig. 4).

Figures 5 and 6 show the form of urban growth along with the direction of influence from the year 2001–2015. Comparison of all the zones, Zone 1 of 2001 is compact, whereas as the movement is towards the periphery (Zone 4), the diversification is increasing. Considering the Western direction, this section shows remarkably highest diversification than the others direction. This implies that the West direction is diversified in its urban form. Next higher order is East. This region is less diversified than West but is more when compared with East and South. Highest diversification is seen in West of Zone 1, South of Zone 2, East of Zone 3, and Zone 4. East and South have higher diversification than North and West in all the Zones. In the year 2005 of the Zone 1, South (0.507) is less diversified than the other directions. However, all zones show increasing diversification. Zone 1 shows

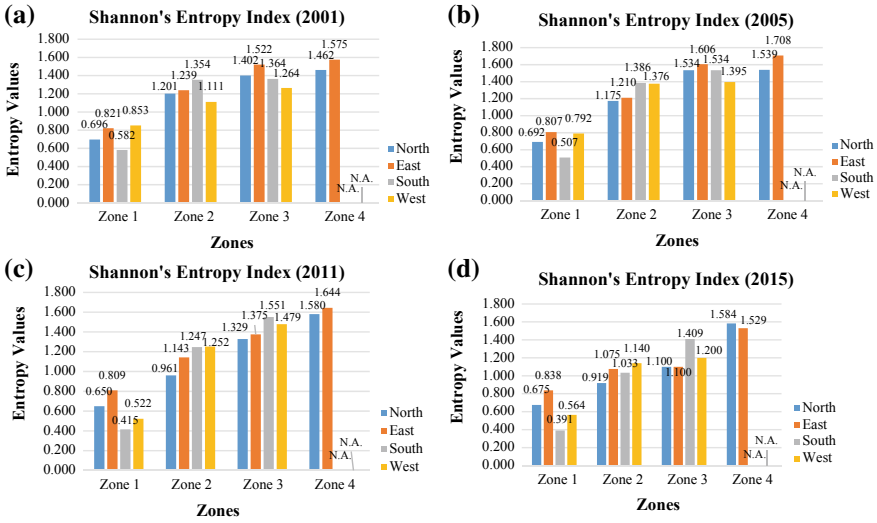

Fig. 5 Shannon's entropy index of BBMP; zone- and direction-wise: **a** 2001, **b** 2005, **c** 2011, and **d** 2015

fluctuating trend among direction, whereas the other zones show a gradual trend. Zones 2, 3, and 4 show equal level of urban growth which projects a higher diversification and lowing in South and West direction. The figure of 2011 represents the values of only three directions of Zone 4 because South and West direction does not fall under the limits of the study area. The North of Zone 1 shows a higher level of compactness but slight change has been observed from 0.650 to 0.809 in East causing slight diversity in land use. South and West are compact in nature. Zone 4 has higher diversification of urban growth than Zone 1, Zone 2, and Zone 3, but the rate of change is highest among South and West directions of all the Zones. In 2015, in Zone 1, there are differences in values causing fluctuations in directions. However, the rate at which these differ is nearly similar in Zone 2 and remains significantly fluctuating in Zone 3. South in all zones is attaining a disproportionate positive change. Another noticeable fact here is found in Zone 2. Zone 2 in previous years shown increasing diversification but the year of 2015 have recorded increasing compactness in all the direction. The North of all zones has experienced increasing diversification. However, the rate of diversification is decreasing. Same is the case with East, but this region is more diversified than North. The South of all zones presents a different picture. Though this region is more compact in nature in comparison to North and East but South was more diversified in Zone 2, exceeding North and East. The West direction is still increasing its diversity showing no signs of reduction.

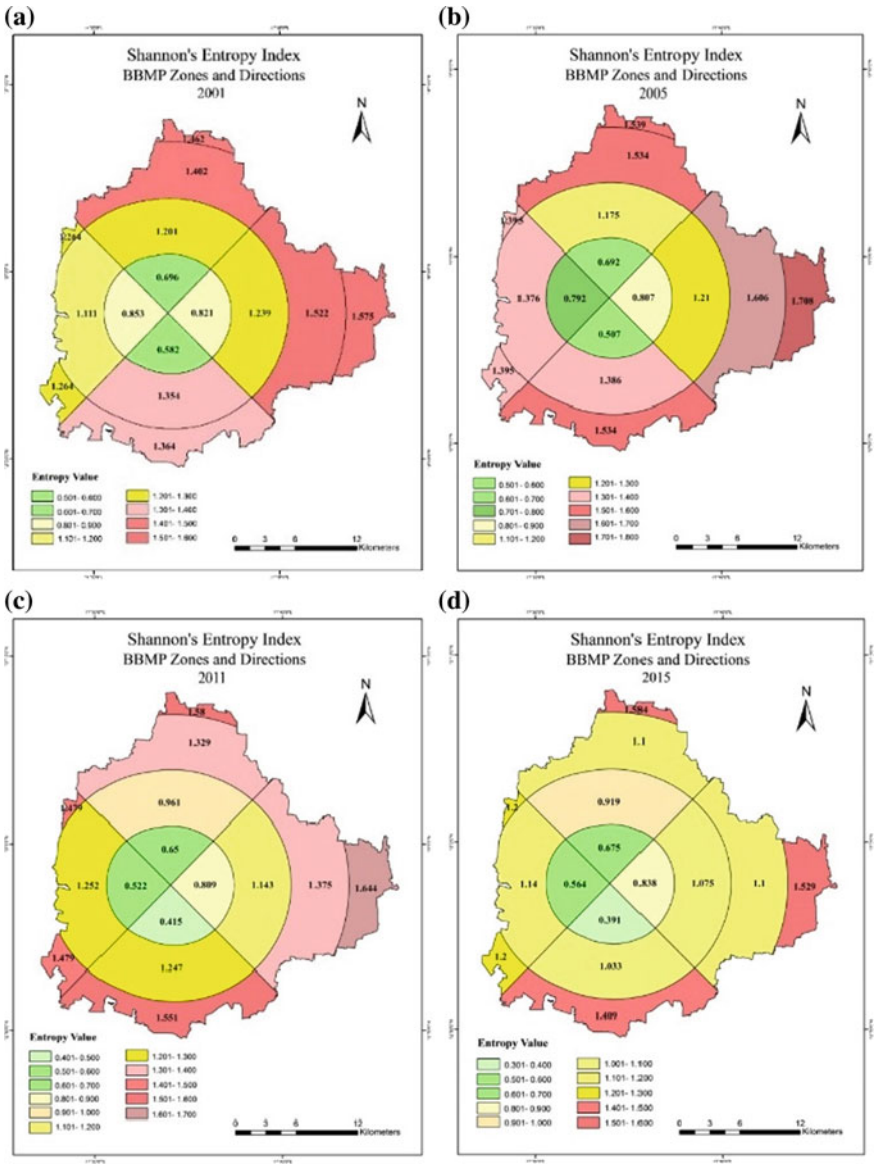

Fig. 6 Shannon's entropy index (BBMP zones): Direction-wise: **a** 2001, **b** 2006, **c** 2011, and **d** 2015

5 Inference around Bengaluru's Sustainability and Smart Cities

After the third attempt made, Bengaluru was shortlisted for Smart Cities Mission in 2017 and with the consequent pace of smart city project, the objective remains to make life of its citizens more remarkable [29–31]. This research dealt with Shannon's entropy index which detects the degree of compactness and the degree of diversification in any region. Due to restricted limits of a territorial region, the urban growth happens within its limits and cause densification in terms of its form (Fig. 7). Similar results have been procured through this study. Bengaluru Shannon's entropy values reveal that the development of settlements is taking place from centre to the periphery. In the initial years of study, there happens to be an increasing entropy value mostly in all the direction that suggests that there is a high diversity among the land use and land cover, all experiencing a change from centre to the periphery. But with the passing years, the values are decreasing that suggest that with due course of time the land use and land cover pattern have been changed to the more unified character. This suggests that Bengaluru has been expanding from the centre to periphery by engulfing the peripheral rural areas into its urban fold. This builds an expectation of growth of areas neighbouring Bengaluru [32]. Although the city-level planning and management for the restoration of the ecosystem services are dynamically active, yet it becomes essential to have data on the distribution of different components of a city and their geographical setting that can imply over better planning and management [14]. Bengaluru is seen as the

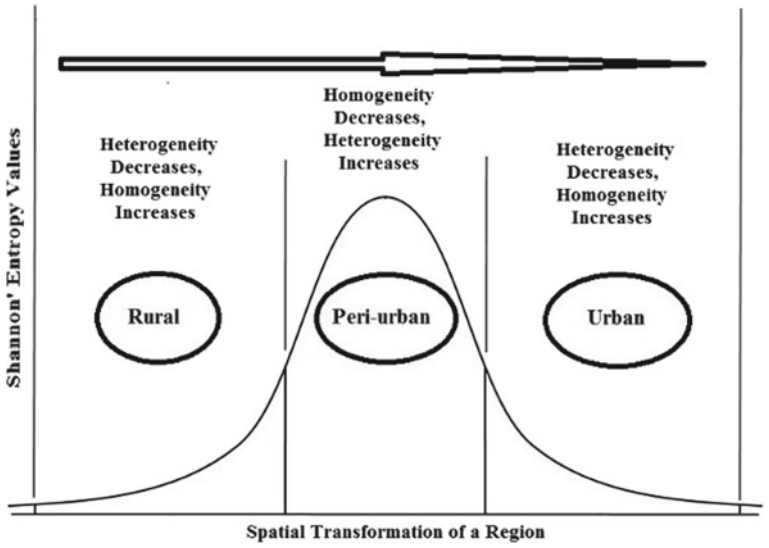

Fig. 7 Schematic representation of Shannon's entropy index. *Source* [25]

important artery of the global city, the integral sustainability of itself is into mystery thereby leading to a mismatch between the city in the frame and the city in its sustainability. In order to accommodate and direct the population fairly to adjacent perpheries, the city needs to explore spatially and we temporally so as to project itself as an inspiration city of Smart Cities Mission. Not only this, but this research will also help to exploit the resources efficiently, unstimulating clustering and avoiding adherence to irrational and irrepressible mode of consuming them.

The reflection of Shannon's entropy value proceeds with lower values at the beginning that suggest that the region has high homogeneity. Due to restricted limits of a territorial region, the urban growth happens within its limits and cause densification in terms of its form. The pre-existed rural region has low entropy values due to its homogenous agricultural nature with less of mixed uses. When the city reached a point where further sprawl within the boundary gets discontinued, the territorial extent is increased by the inclusion of peripheral areas which possess of less developed character. The entropy value increases, and this is caused by mixed urban and rural use. This is the transitional phase (Peri-urban) from rural to being urban. Once the rural region takes the shape of an urban region, the value again decreases due to the region attains a homogenous character.

Further research from this work lies on the demarcation of the large-scale changes that have caused much of the undesirable changes and to explore the possible solution for the same within the specified geographical setting. Individually, assessment can be performed depending on the urban component in consideration. However, this research incorporates large tracts of territorial limits; minute differences cannot be inferred from the above research. The form and pattern of growth as analysed through Shannon's entropy index provides the directional change of urban land uses over the years that will help to figure out the dominant direction of a rural–urban interface and underlies the causes of such growth at the location level where interventions can be made through proper planning. Furthermore, the locational change has an advantage over the transport sector because stronger the connectivity, the propensity of urban expansion will be more. This will also help in focusing on the other channels of connectivity that can decongest the city considerably and proper exploration can channelize the implementation process better.

6 Conclusion

Cities present an example of a socio-ecological system where there always to have an opportunity if interactions with the environment and ecologies but at present, the way, these interactions are modified; the interactions have produced negative impacts and environmental damage. Therefore, it becomes essential to draw the attention of the authorities to make them realise the substandard levels of living at the cost of inadequate modes of sustenance and non-resistance towards the unethical spurt in modernisation and urbanisation. We are living in a system where

every individual is craving just for sustenance; compromising with the sustainability whether in a city or in a village; ignoring the others' aspects of living that shapes the internal composition of the human body. The villagers apparently lead to the nourishment of the environment as their sustenance itself depends on the environment so it becomes one-to-one relationship with the same. But as far as city dwellers are in question, the inhabitants draw their needs from the environment but are discourteous towards repayment towards the same. Since the management authority is seated for the planning and implementation of the whole of the city, the driving force is to alert in order to make its citizens aware of the surroundings and environment. The matter of sustainability is not just limited to sustainable development wherein the resources are utilized in a way to keep it for future but the time has approached where the resources are not only to be saved but also to be rejuvenated at a rate higher than the pace of degradation; keeping in consideration the constant hike in population, the never-ending human needs from the environment and the rush of achieving high standards of living. The technologies can resort to faster rates of achieving a purpose but it can never repay the damages it makes to the environment. Of course, the pace at which technologies have advanced can never rejuvenate the environment at the same pace as nature has its own pace of nourishing itself but sooner the matter is brought into priority, faster will be the awareness among the human beings and also the implementation. The time has already reached where we need to build sustainability upon the built features of the city. It is not just about the city of Bengaluru but is a tale of every Indian city being remembered of the cool, mild, breeze climate throughout the year-the reality of which; at present speaks of the contrast experiences. The increased impervious surfaces along with the need for improved intercity links especially though roadways and railways have led to the widespread clearing of the natural-positioned constituents. All the more, in order to decongest the irreversible population of the city, the territorial limits are getting expanded and have incorporated the healthy peripheries into the overburdening limits of the city thereby adding to the degradation of the rural–urban interface. This becomes all the more brainstorming effort as the planning and implementation now require proportionately more solutions of sustainability over the already built spaces that can re-orient the material ecologies of cities for a better future; a better future not for human but a better future for nature.

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