

Appraising Spatio-Temporal Shifting of Urban Growth Center of Pimpri-Chinchwad Industrialized City, India Using Shannon Entropy Method

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How to cite this paper: Ranpise, R. S., Kadam, A. K., Gaikwad, S. W., & Meshram, D. C. (2016). Appraising Spatio-Temporal Shifting of Urban Growth Center of Pimpri-Chinchwad Industrialized City, India Using Shannon Entropy Method. *Current Urban Studies*, 4, 343-355.

<http://dx.doi.org/10.4236/cus.2016.43023>

Received: August 11, 2016

Accepted: September 27, 2016

Published: September 30, 2016

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Abstract

Uncontrolled urban development of Pimpri Chinchwad area was assessed to understand shifting of urban growth center and its controlling factors during last forty years. Out of forty, initial 20 years span (1973 to 1993) is compared to subsequent 20 years (1993 to 2013). The secondary data i.e. topographic maps (year 1970 and 2009) and satellite image MSS, LISS III (year 1973 and 1993) and LISS IV image (year 2013) were used for preparation of land use land cover maps. Furthermore, Shannon entropy computed by built-up land class, was showing the entropy 0.81, 0.92 and 0.97 for year 1973, 1993 and 2013 respectively, hence the steady growth during past forty years. However, growth centers of urban development shifts from automobile industries at Pimpri (central part) to information technology (IT) industries towards Hinjewadi (western part) area. This shift was determined from the demographic alteration in study area. To understand demographic alteration, the spatial results were verified through ground truth survey reveals population growth is in the form of vertical growth such as increase in multi storey buildings instead of single storey housing. This study highlights the shifting of urban growth centers in developing countries such as India from automobile to IT industries. The shifting of growth center was resulted into impact on existing public services (drinking water, sanitation, waste management, roads, hospitals etc.). In conclusion, present study warrants the attentions towards shifting of urban growth center from such rapidly growing industrial city of the developing countries while deciding future urban planning.

Keywords

Urban Growth Center, Shannon Entropy, Industrialized City, Pimpri-Chinchwad, Sub-Urbanization

1. Introduction

Urbanization is a continuous growth process (Spence et al., 2009; Shabu, 2010) in rapidly developing urban areas, when it further grows leads to suburbanization (Champion, 2001) and subsequently influence shifting of urban growth center (Zhou, 1997; Hermelin, 2007). This shift can be monitoring by change in population density, jobs, services and trade at the edge of urban land (Zhou, 1997). The urban land is characterized by population size/density, lifestyle and occupation with which people involved (Bryant, 2003; Tsai, 2005; Weeks, 2010). However, urban center is a business activity area (Cortright, 2015; Dobbs & Remes, 2012; Kotharkar et al., 2014) specifically area around post office or market area.

The spatial distribution of population is common around city center but random at sub-urban areas (Lie & Zhang, 2009; Champion, 2001). The random spatial growth of built up land (generally the housing units) refers to urban sprawl (Glaeser & Kahn, 2004; Sudhira et al., 2004; Glaeser et al., 2005). The sprawl and suburbanization are alternatively used terms in urban growth studies (Nechyba & Walsh, 2004; Frenkel & Ashkenazi, 2008). In suburbanization process population increases towards periphery region which further forms decentralization and later reversed called counter-urbanization (Zhou, 1997; Grigorescu et al., 2012). Suburbanization leading to shifting of urban growth centers is common in developing countries like Brazil, South Africa, South East Asia and in India (Brockhoff, 1999; Tran et al., 2008; Guest & Brown, 2005). There is hardly availability of any scientific data regarding assessment of shifting of urban growth centers, therefore a preliminary attempt has been made to assess the urban growth centers from Pimpri-Chinchwad industrialized city in India, a representative of developing countries.

This study had focused spatio-temporal shifting pattern of urban growth centers with respect to their possible reasons of initiation. The possible reasons hypothesized to be shifting of employment centers, infrastructures and increase in soft skill education in developing countries. To verify, quantify and confirm the reasons of urban growth shifting following objectives were assigned, 1) use of Shannon Entropy to assess the spreading behavior of urban area by spatio-temporal manner, 2) to know the spatio-temporal demographic alteration of study area, 3) to verify geospatial results with appropriate ground truth verification for accuracy assessment, 4) to identify the reasons behind shifting of urban growth centers in study area, and 5) to suggest BMP's (Best Management Practice's) for development of such urban growth shifted area at its early stages.

2. Study Area

Pimpri Chinchwad is a rapidly developing city of Maharashtra state, India, known for large number industries (more than 4086 large, medium and small scale industries (CDP, 2006; ESR, 2012-2013). The study area shown in **Figure 1** lies in Pune district with total area of 176 sq-km and 105 administrative wards (Annex-I). Geographically it is located at 18°37'07.04" in N and 73°48'13.43" E of western margin of the Deccan Plateau towards leeward side of the Sahyadri hill ranges (western ghat). The average height from the mean sea level is about 560 m. The major natural drainage are formed by river Pavana flowing through centre, river Indrayani in North and river Mula at south of study area.

Population wise study area ranked 18th in India (1.7 million) with an average growth rate of 104.39% for last five decades (CDP, 2006; Census, 2011; ESR, 2013-2014). The urbanization and sub-urbanization processes are parallel and high density of population towards sub-urban parts (specially in last two decade) highlight rapid development of study area.

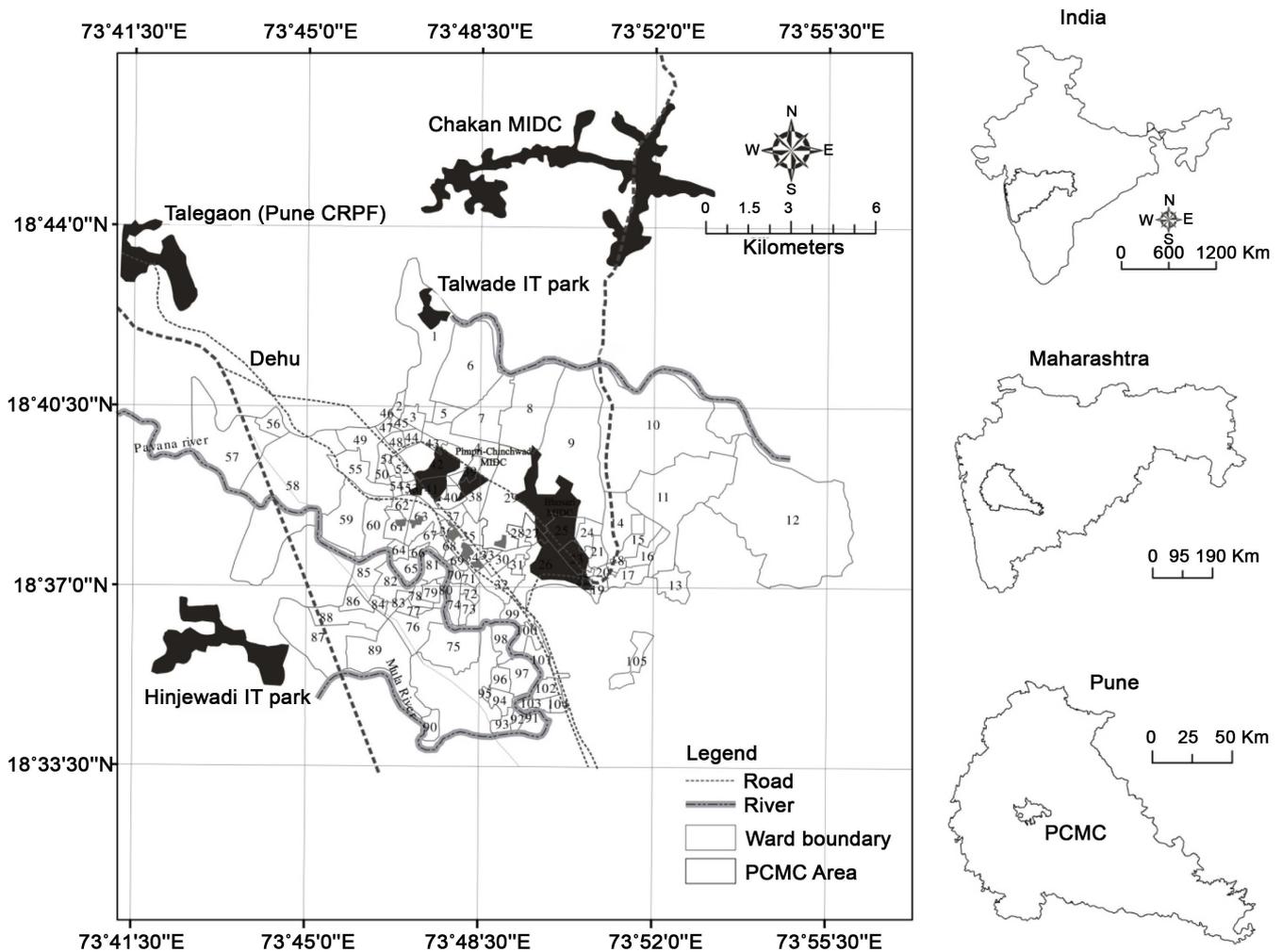


Figure 1. Detailed map of study area (PCMC).

3. Materials and Method

Topological data (year 1970 and updated 2009) of 1:50000 scale showing land-use pattern were procured from Survey of India (SOI), Pune. The scanned raster data was geo-referenced and digitized to convert it into usable form i.e. vector format (Ramchandran, 2000; Lee, 2014). Thematic (base) layers such as administrative boundaries, water bodies, residential and industrial areas were prepared using Arc-GIS 9.3.

Satellite images LISS III (1973 & 1993) and LISS IV (2013) used for land use land cover study had been acquired from USGS & NRSA Hyderabad. The geometric and radiometric corrections, image enhancement, rectification and re-sampling done prior to classification of satellite images. It helps to reduce the errors caused from different data acquiring periods, source of agencies, and spectral resolutions (Kumar, 2003). These images were processed further to supervised classification with maximum likelihood algorithm method in ERDAS imagine 9.2 (Anderson et al., 1976; Lubis & Nakagoshi, 2011). The information extracted was the built up land, agricultural land, waste land, vegetation and water bodies.

The urban expansion assessment done by clipping thematic layers of toposheets data on to the classified satellite image in Arc-GIS 9.3 (Aguda & Adegboyega, 2013; Dey & Greeshma, 2014). The statistical information obtained in the form of attribute data was further used in quantifying built-up land and urban sprawl (Sudhira et al., 2004; Shekhar, 2004; Bhatta, 2010).

The non-spatial, i.e., secondary data (ward wise population data) had been used to ascertain changing population density at the periphery region. The spatial changes in built-up land were estimated through field survey and secondary data.

The Shannon’s urban entropy measures the degree of spatial concentration and dispersal of built-up land between different time periods (Batty, 1974; Yeh & Li, 2001; Shekhar, 2004; Alabi, 2009; Mohammady & Delavar, 2015). The entropy was calculated first from the built-up land of individual ward and then sum total of 105 wards. For the measure of relative entropy (ΔE_t) a time scale (t) of two decade had been considered. The entropy values range between 0 and 1 where, the maximum value 1 represents distribution of built up land across the space and the minimum value 0 is concentration of built-up land in one area.

Entropy E_t and relative entropy ΔE_t (Bhatta et al., 2010; Pedro et al., 2013) were calculated using following equations where, E_t is the entropy of study area, D_j density of land growth, m is the total number of zones/wards of study area, and PD_j calculated from density of land of specific zone (ward) divided by total density of land growth. ΔE_t is the difference between two time periods it is a useful indicator to assess the magnitude of change of urban sprawl (Bhatta et al., 2010).

$$E_t = \frac{\sum_{j=1}^m PD_j \left(\log \left(\frac{1}{PD_j} \right) \right)}{\log(m)} \tag{1}$$

$$PD_j = \frac{D_j}{\sum_{j=1}^m D_j} \tag{2}$$

$$\Delta E_t = (t+1) - (t) \quad (3)$$

Ground truth analysis: Ground truth survey of approximately 10 percent of study area were made to understand population shift, increasing number of settlements and distribution of population density. Hence, horizontal growth i.e. spreading of built up land in parallel directions with single or two storey housing units and vertical growth i.e. multi-storey buildings (floors-three and above) were marked from center to boundary of study area. Also new commercial establishments along the roads and periphery region had marked as new growth points.

4. Results and Discussion

Measuring Entropy to assess spreading behavior of study area:

The entropy is estimated using the sum total of entropy of 105 administrative wards calculated from built up land of individual ward in respective decade, shown in **Table 1**.

Year 1973 was showing lowest entropy (0.81) indicates minimum dispersal of built-up land. The built up land of year 1973 was accounting only residential or industrial land, in contrast, high entropy values in year 1993 (0.92) and 2013 (0.97) signifies urban sprawl (Yeh & Li, 2001). The entropy result was showing a steady growth and continuous spreading of built up land in past forty years. Also, the change in population (98572 in 1971 to 1727692 in 2011), population density and increasing built-up land can be witnessed to urban growth of study area.

The temporal changes and degree of dispersal of land development i.e. urban sprawl is evaluated by change in entropy (ΔE_t) value. Results in **Table 2** showed change in entropy value i.e. dispersal of land of development signify urban sprawl. A ribbon strip and leap frog type behavior of sprawl (Barnes et al., 2002) was observed in study area.

4.1. Demographic Alteration and Spatio-Temporal Changes

In past forty years population had increased 20.6 times, whereas built-up land grows about 25.83 percent. The industries present along old highway and railway line were

Table 1. Shannon's entropy 1973, 1993 and 2013.

Year	Total area covered by satellite image in sq. Km	Total no. of wards in PCMC	Built-up area in sq. Km	Entropy calculated as E_t
1973	170.38	105	03.09	0.81
1993	170.38	105	20.42	0.92
2013	170.38	105	43.43	0.97

Table 2. Change in Entropy (ΔE_t).

Sr. No.	Year	Entropy E_t	Change in Entropy ΔE_t
1	1973-1993	0.81	0.11
2	1993-2013	0.92	0.04
3	2013	0.97	

causing parallel residential growth. Clusters of built up land at central part, southern part, i.e., towards Pune city, and at village centers (now the wards) were seen in 1973 and 1993.

A constitutional amendment act (1992) and Jawaharlan Nehru National Urban Rural Mission (JNNURM) programme (2005) of India had been influencing the economic development (CDP, 2006) of study area.

The spatial changes as LULC (land use land cover change) from 1973-2013 have shown in Table 3, it represents urban growth pattern both in direction and magnitude of built up land (Sankhala & Singh, 2014). A decreasing percentage of waste land, agriculture land, minute change in water bodies and increase of built-up land and vegetation were observed in LULC.

A simultaneous growth of population and built up land can be seen in Figure 2. It shows a linear forecast trend-line of percent growth of built-up land, non-built-up land and population growth. The percent built up land has been increasing at an alarming rate it shows 1.84% in 1973, 12.14% in 1993 and 25.83% in 2013.

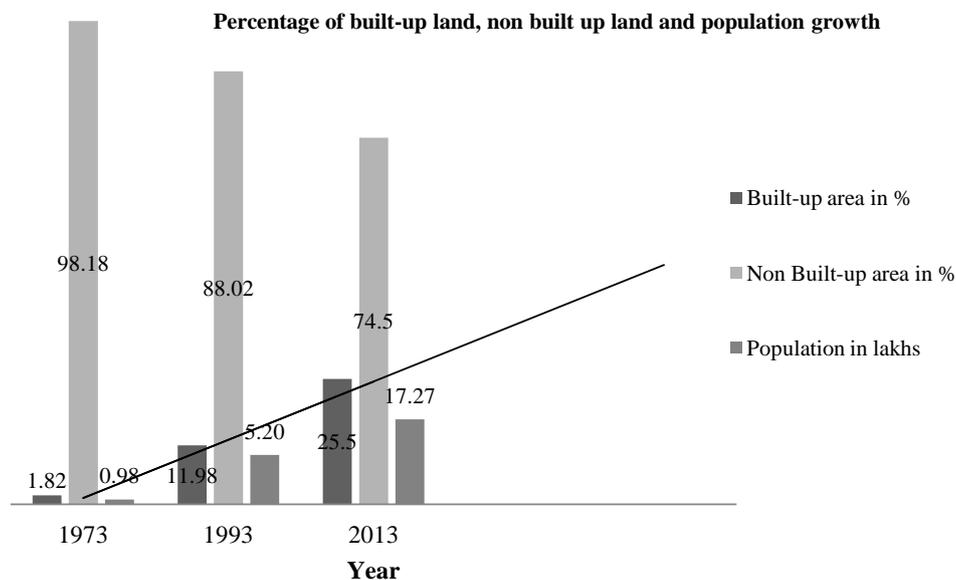


Figure 2. Percentage of built-up and non built up land in study area.

Table 3. Results of satellite image classified for year 1973, 1993 and 2013.

Sr. No.	Class name	1973		1993		2013	
		Area in Km ²	LULC %	Area in Km ²	LULC %	Area in Km ²	LULC %
1	Built-up land	3.095	1.84	20.42	12.14	43.44	25.83
2	Water bodies	1.89	1.12	2.09	1.24	2.12	1.26
3	Forest/Vegetation	8.36	4.97	14.08	8.37	22.91	13.62
4	Agriculture land	51.01	30.34	63.81	37.95	38.24	22.74
5	Waste land	106.025	63.06	69.98	41.62	63.67	37.87
	Total Area in Km ² /Percentage	170.38	100	170.38	100	170.38	100

4.2. Population Density Shift

As shown in **Figure 3**, Pimpri (ward No. 31&32) and Chinchwad (ward No. 64, 65 & 66) were the main villages (origin of city) in 1971 at the time of formation of municipal corporation and hence considered as urban center. It also shows the population spread around Pimpri, Chinchwad and other villages which are now become the wards of PCMC. The clusters of high population densities were observed at ward No. 46 - 61, 72, 73, 77, 79, 90, 91, 95, 96 and 103 due to occurrence of industrial zone and available public facilities (bus stand, railway station, municipal offices, police station, schools, hospital and post office) in that period.

Figure 4 is showing population density in year 1991, where the high population density observed towards Nigdi Pradhikaran (residential) area. These areas are mainly coming under planned residential zone of PCMC (ward No. 2,3,4,5, 46, 47, 48, 49, 50, 52, 55). Also the Bhosari and Moshi areas were showing high population density it can

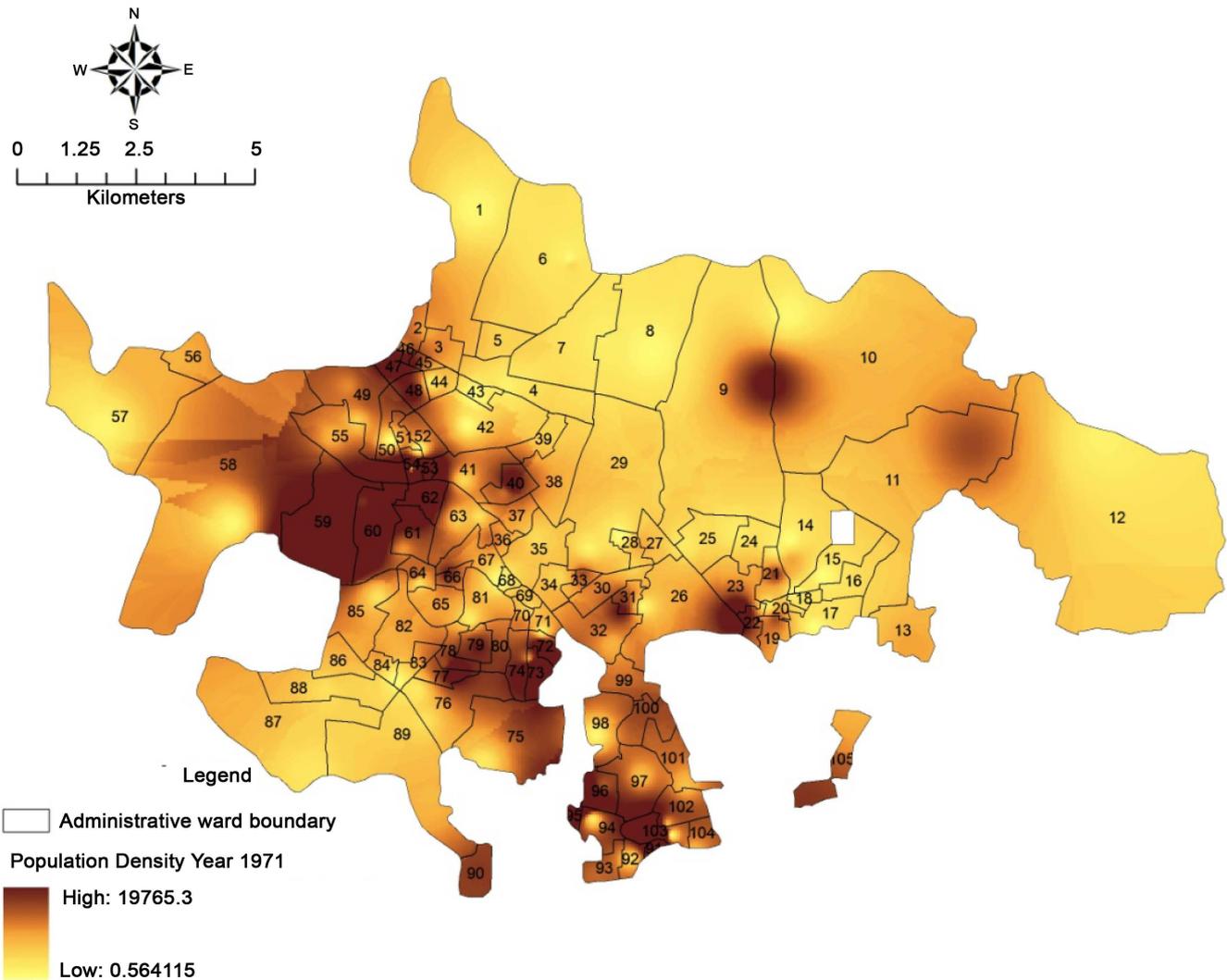


Figure 3. Population density of study area in year 1971.

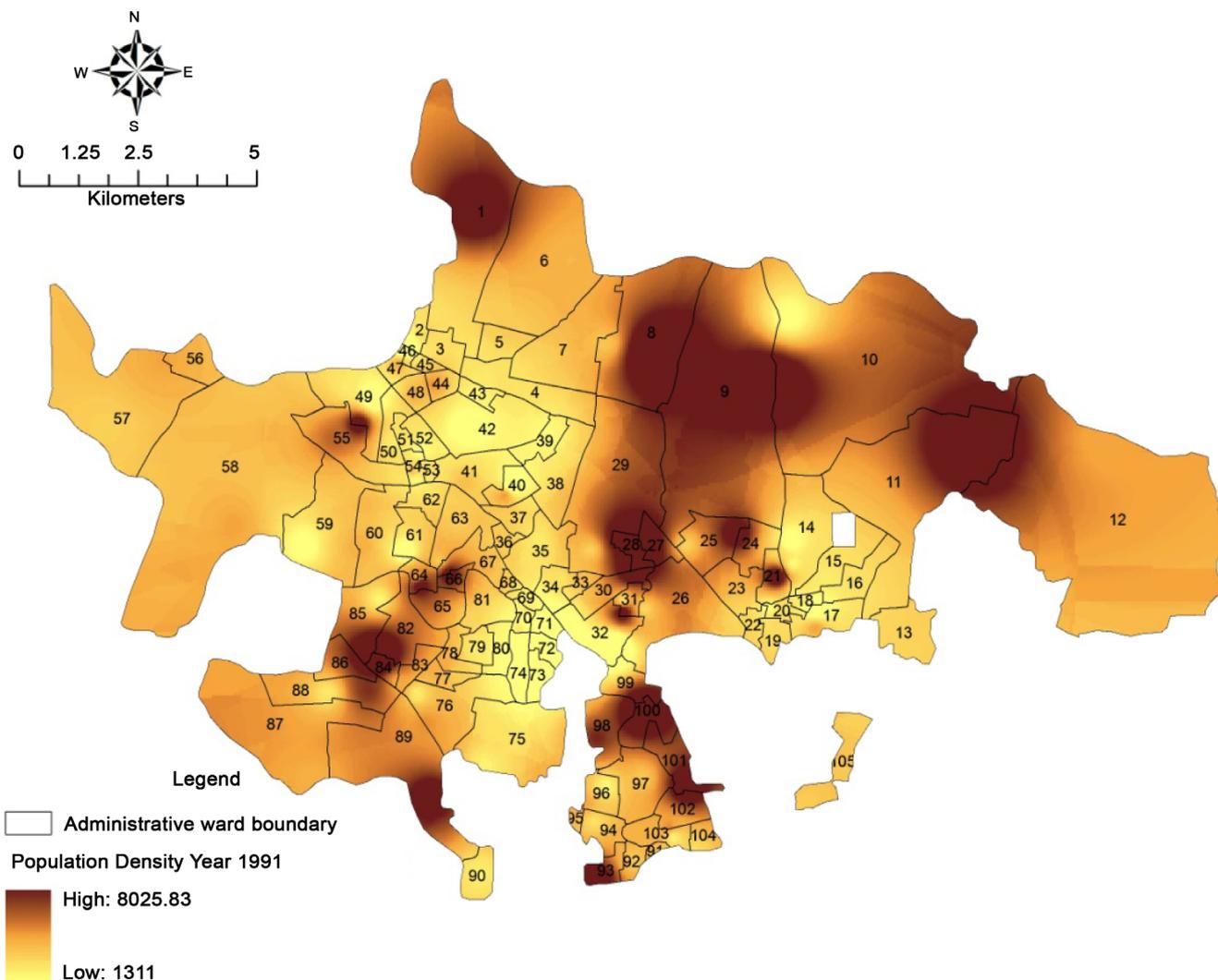


Figure 4. Population density of study area in year 1991.

be due to presence of a state highway (Pune-Nashik) and growing industries in Talavade and Chakan areas.

Figure 5 indicates high population density towards northern, south eastern and south part of study area. A clear shift of urban areas from Pimpri Chinchwad central to Wakad, Talavade, Chikhali was observed here. The economic pull (job opportunities) and infrastructural amenities (connectivity/accessibility) were attracting large population (internal and external) from urban to sub-urban localities (CDP, 2006-2012; ESR, 2013-2014) it becomes major cause of shift for migrating population.

4.3. Ground Truth Survey

Total 11.76% area was surveyed from Pimpri-Chinchwad (assumed center). The housing units and shops (ground (G), G + 1, G + 2 and/or G + 3 floor) around two major industries were going away from the assumed center. Where the patches of slum near

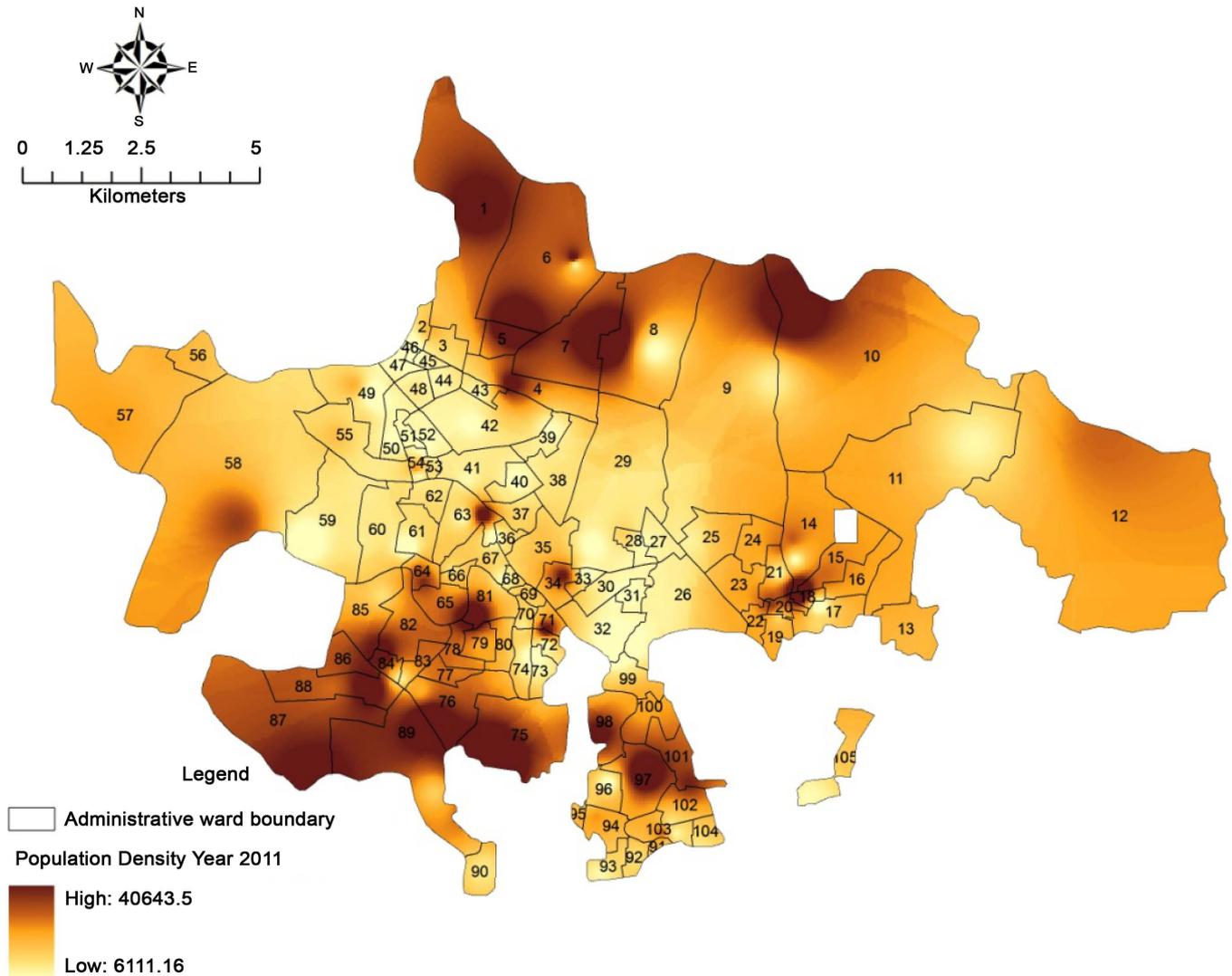


Figure 5. Population density of study area in year 2011.

railway line and bus stands showed high population densities. The housing pattern of G or G + 1 except few multi-storey buildings at central part was indicating leap frog type of sprawl.

A transition phase of urban center shifting noticed at south western part (Thergaon and Wakad villages) where the agriculture land was totally disappeared and transformed into built up land. The built up (residential) type of G + 5 to G + 9/10/11 in these areas is showing increases of population density and public service demands. This may ultimately causes formation of new urban center.

The urban areas marked by rivers and highway forming administrative boundary at wakad, nigdi and moshi as sub-urban part showed maximum population growth in past two decades. Increasing demand of housing in last few years is another reason for large settlements in these areas. In addition, market facility, shops and services have accelerates the rate of urban center shifting at PCMC.

Factors causing urban center shift: The population density from earliest center was observed to be shifting around periphery due to new industrial development (Zhao & Wang, 2015). These newly formed industrial zones towards the north of study area namely Talavade, Chakan and Talegaon (Figure 1) are of average 15 and 30 Km from periphery and center respectively. The transport facility and accessibility, low cost of living (i.e. housing) around periphery region, opportunities for agricultural workers to get jobs in non-technical field since unavailability of farming land and a scope for expansion of administrative boundaries in future are the possible reasons for urban shift in northern part of study area.

The south western part of study area was similarly showing increasing population density i.e. shifting of urban centers. The presence of Hinjewadi IT park is causing this shift in last few years. High wages, improved lifestyle, and improved transport system facilitates rapid urban development (Baum-Snow, 2013) of this region. Hinjewadi IT park is the largest IT industry in India (CDP, 2006) providing jobs to more than two lack population. Large proportion of technical and non-technical working population of study area have been connected to this region. The distance from periphery to Hinjewadi IT park is about 7 Km. This all have made migration of people towards south western part and ultimately urban shift.

The increasing population densities at northern and southwestern part of study area have reached to its peak and establish itself as the new urban form and therefore, the new urban centers.

BMP for new urban growth centers: Use of population projection studies in long term planning can help to manage the needs of growing urban areas. The growing urban areas should consider a land development and urban environmental planning well in advance. The major environmental issues can get priority which includes water supply, solid waste management, waste water treatment, storm water drainages, public transport and roads etc. (Johnson, 2001; Wilson & Chakraborty, 2013). The demands of new urban center shift presumed to be increases hence the geographical expansion and the limits of economical and political boundaries should be taken in consideration for such developing urban areas.

5. Conclusion

The rapid infrastructure growth can be viewed through residential growth, large road network and public services (water supply, sewage and waste disposal, slum, health and education), it boosts the population growth through migration from outside. Use of GIS, Remote sensing and Shannon entropy techniques are the suitable method of urban sprawl measurement. The leapfrog and ribbon strip type of urban sprawl can be ascertain from the residential growth at village centers, industrial areas, along roads, highways and railway line. Besides that increase of built up land and simultaneous decrease in agriculture land and waste land are witnessing urban growth.

The temporal changes observed from satellite image analysis can be useful in planning and decision making process of such rapidly growing city. The uncontrolled urban

growth should be restricted through proper planning and management or else it impacts on natural environment (air, water, soil, noise pollution). Temporal changes of built-up land and population density change at the periphery regions proves shifting of urban center at study area.

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