



Relative Shannon's Entropy Approach for Quantifying Urban Growth Using Remote Sensing and GIS: A Case Study of Cuttack City, Odisha, India

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Abstract

Urbanization is a developing process at the cost of the environment. Many fertile agricultural and forest land are concealed under the belt of urban growth. In this study, we integrate the statistical method (Relative Shannon's entropy) with remote sensing and GIS to quantify the urban growth pattern of Cuttack City of Odisha. Satellite images of Landsat-5 Thematic Mapper and Resourcesat-1 (IRS-P6) LISS-III were downloaded from USGS and Bhuvan sites of ISRO. The study area is clipped from images with AOI (area of interest) using masking tool and is classified using maximum likelihood classification tool of ArcGIS 10.3 software to prepare LULC (Land use/Land cover) map of the investigated area for the years 1990, 2000, 2010, 2018. The Cuttack City spreads over about 45.205 sq. Km. It has been observed that 46.75% growth of built-up has been made from 1990 to 2018. Similarly, vegetation cover and water bodies have been reduced by 35.71% and 68.60%, respectively, from 1990 to 2018. Relative Shannon's entropy method was used to quantify the pattern of urban growth of Cuttack City. The entire study area is classified into 37 zones to depict the growth pattern of every nook and corner of the city from 1990 to 2018.

Keywords Remote sensing · GIS · Maximum likelihood · Classification · Central business district · Entropy

Introduction

Rapid urban growth is a major concern for developing countries, as it brings serious environmental consequences like alteration of land use/land cover of a region, loss of agriculture and forest land, depletion of groundwater level and rise of land surface temperature (Alsharif et al., 2015; Belal & Moghanm, 2011; Bhatta, 2009; Pathan et al., 1989; Patra et al., 2021; Rawat et al., 2013). As per the 2011 census, 31.16% (377 million) of the total population in India are living in urban areas and is projected to be 40.76% in 2030 (United Nations, 2011). The driving force that let people move from rural to urban areas is for availing better education, job opportunity, health care, entertainment and livelihood (Bekele, 2005; Cohen, 2006;

Godfrey & Julien, 2005; Iqbal & Khan, 2014; McGranahan & Satterthwaite, 2014; Peng et al., 2011; Zhang, 2001). As a result, there is a sharp rise in urban population and simultaneous growth of the planned urban area and unplanned urban slum. Due to the unplanned spread of growing slums, the government faces challenges to maintain sanitation, hygiene, supply of pure drinking water and electricity to these slum dwellers. Population and urban growth are directly related to each other (Bhatta, 2009). In India, population growth and unplanned development resulted in urbanization (Bhatta, 2009; Sudhira et al., 2004).

Therefore, it is highly essential to monitor the growth of the city to maintain sustainable planning and development (Punia & Singh, 2012; Inostroza et al., 2013; Alsharif & Pradhan, 2014; Dadras et al., 2015; Fertner et al., 2016; Mosammam et al., 2017; Ozturk, 2017; Sahana et al., 2018; Shukla & Jain, 2019). Conventional chain surveying and mapping techniques to measure urban growth was a very tedious and time-consuming process. In the recent year with growing technology of remote sensing and GIS

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integrating with statistical methods urban planners and environmental researchers assess urban growth in less time and with high accuracy (Borana et al., 2020; Jat et al., 2008; Punia & Singh, 2012; Roy & Kasemi, 2021; Sudhira et al., 2004). The pattern of sprawl can be detected, mapped and analysed using remote sensing and GIS (Barnes et al., 2001). In this study, Cuttack City is chosen as an area of interest because of recent trends of increase in population density of city from 3170 per sq km in 2011 to 3855 per sq km in 2018. The city once upon a time was a major business hub during British rule. Subsequently, the city became an urban heat land and there has been gradual environmental degradation, vegetation loss and rise of city temperature (Swain & Goswami, 2014a, 2014b). So, it was essential to assess the urban growth of the Cuttack City and monitor population trends. With the availability of high-resolution temporal satellite images over city settings, it is easy to depict spatial change in city landscape over a period of time (Punia & Singh, 2012). Researchers used various statistical methods integrating with remote sensing and GIS to assess urban growth patterns. Two important methodologies that researchers frequently use are Shannon's entropy and the cellular automata (CA) model (Punia & Singh, 2012). One of the applications of entropy is to indicate the degree of urban sprawl by verifying whether urban growth is compact or dispersed (Lata et al., 2001; Punia & Singh, 2012). In the current study, we use relative Shannon's entropy method to quantify the urban form of the Cuttack City. Relative Shannon's entropy value lies between 0 to 1 and 0.5 is taken as the threshold value (Ozturk, 2017). Resulted value of more than 0.5 indicates urban sprawl and less than 0.5 indicates compact urban area.

Study Area

Odisha is located in the eastern part of our country surrounded by West Bengal, Chhattisgarh, Andhra Pradesh and Jharkhand. The study area is Cuttack City and one of the ancient towns of Odisha. It is also headquarter of the Cuttack District of Odisha, India (Fig. 1). Geographically, it is a delta (situated at 20° 27' 54" N latitude and 85° 52' 45" E longitude) and located in between Kathajodi and Mahanadi River. The city carries a lot of historical importance and value in Odisha history. Cuttack is also called a millennium city and silver city due to its 1000 years of remarkable history and fabulous silver filigree work.

Data and Methodology

Landsat satellite images of different years (1990, 2000 and 2010) were downloaded from the USGS website. Resourcesat-1 satellite image for the year 2018 was collected from the Bhuvan site of ISRO (Table 1). For better analysis and minimum error, all the Landsat satellite images having less than 20% cloud cover were collected for our studied years. Landsat imageries were downloaded in GeoTIFF format having UTM projection and WGS 84 reference datum.

Population data were collected from census records of India and Google sources. For accurate assessment of the classified image of satellites, 150 sample ground-truthing points were collected (Fig. 2). Corporation boundary is brought from Cuttack Municipal Corporation (CMC) website. Finally, it was digitized and georeferenced using GIS software.

Pre-processing of Data

The images area is collected as the standard product. These are radiometrically and geometrically corrected. But due to different standards and references used by image supplying agencies, images are not perfectly overlaid. To resolve this issue, images are co-registered to attain subpixel accuracy. In this study, we used satellite imagery of different spatial resolutions. The images are resampled from higher spatial resolution to lower spatial resolution images. A decrease in spatial detail has resulted from resampling. Therefore, pixel sizes of the images were unchanged to avoid probable changes in the precision of the classification process of various radiometric spectral and spatial resolutions. Then, images were clipped with AOI (area of interest) using the masking tool in ArcGIS 10.3 software.

Measuring Urban Growth

The Land use–land cover classification has been performed using ArcGIS 10.3 by means of maximum likelihood supervised classification (MLC) to measure built-up growth (Saleem et al., 2018; Zeng et al., 2015). The supervised classification depends upon Bayes theorem [Eq. (1)] to predict the probability of pixels to designate a particular land cover class (Alkaradaghi et al. 2019).

$$P(A|B) = \frac{P(B|A)P(A)}{P(B)} \quad (1)$$

where A, B are events and $P(B)$ is not zero. $P(A|B)$ is the likelihood of event A occurring given time B is true. $P(B|A)$ is the likelihood of event B occurring giving time

Fig.1 Location map of the study area

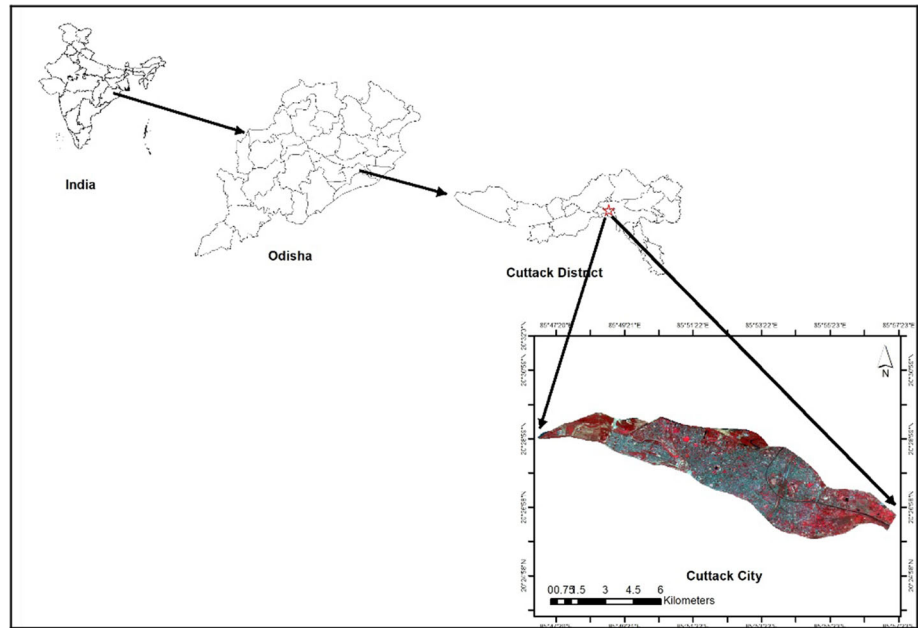


Table 1 Specifications of satellite imagery

Satellites	Year	Scene_ID	Sensor	Bands	D.O.A	Reso (m)
Landsat -5	1990	LT51390461990293BKT00	Thematic Mapper	7	20–10–1990	30
Landsat -5	2000	LT51390462000337SGI00	Thematic Mapper	7	02–12–2000	30
Landsat -5	2010	LT51400462010115KHC00	Thematic Mapper	7	25–04–2010	30
Resourcesat-1(IRS-P6)	2018	L3_SAT_10B_V1_85.75E20.25N_F45T15	LISS-iii	4	06–01–2018	24

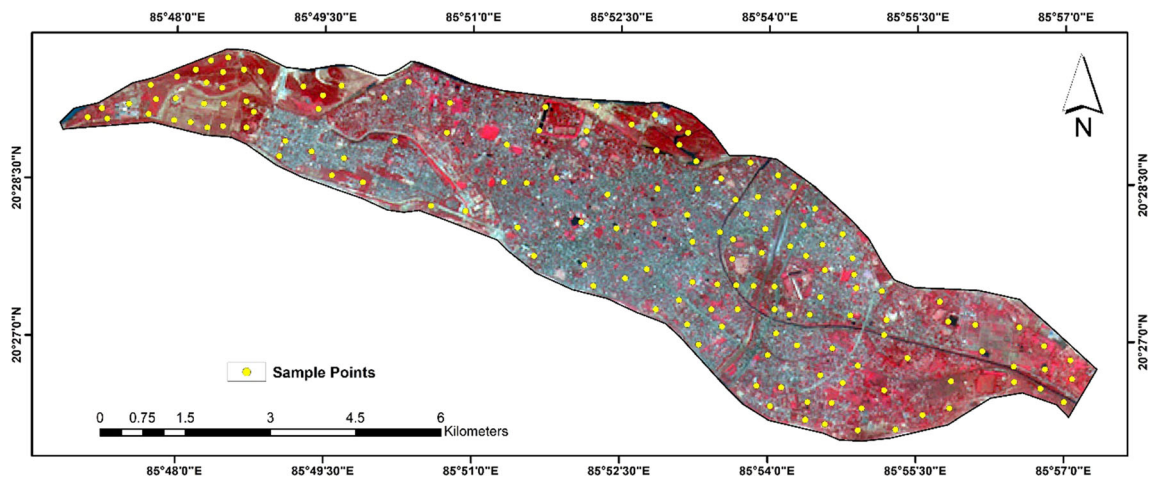


Fig. 2 Overlaid GPS points on satellite imagery of the study area

A is true. P (A) and P (B) are the probability of observing A and B independently of each other.

All the satellite images of different years were stacked to make composite images and then are classified by the MLC (maximum likelihood classification) tool of ArcGIS

10.3 software. Then, the image is classified into four classes, namely Built-up (urban area, habitation), vegetation (agriculture land, forest, etc.), water body (ponds, canal, etc.) and barren land (fallow land, river bank wet area, unutilized land, etc.) to demonstrate the built-up area

change detection from the year 1990 to 2018. For post-classification accuracy assessment, we used 150 sample ground-truthing points to find out user's accuracy, producer's accuracy, and overall accuracy. As we primarily focus on urban growth assessment, we categorized all the imageries of different years as built-up areas and non-built-up areas.

Shannon's Entropy Model

Shannon's entropy is a widely accepted method for the assessment of urban growth patterns (Bhatta et al., 2010; Kumar et al., 2007; Li & Yeh, 2004; Sudhira et al., 2004). Shannon's entropy can be used to measure the extent of spatial compactness or dispersion of geographical variable (x_i) among n zones (Theli, 1967; Thomas, 1981).

Shannon's entropy is given by H_n

$$H_n = - \sum_{i=1}^n P_i \log e(P_i) \quad (2)$$

$$H_n = \sum_{i=1}^n P_i \log e(1/P_i)$$

$$P_i = \frac{X_i}{\sum_{i=1}^n X_i}$$

where P_i is the proportion of variable (here built-up area) in the i th zone. X_i is the observed value of the variable in the i th zone. n is the total number of zones.

The Shannon's entropy value lies between 0 and $\log(n)$. If entropy value lies closer to zero that implicates compact distribution of urban area and if the value lies closer to $\log(n)$ then it shows the dispersed distribution of urban area. Halfway mark of $\log(n)$ is kept as threshold if measured

entropy goes beyond that, then that will be called the sprawling city (Das & Angadi, 2020; Mithun et al., 2016). Relative Shannon's entropy is used to scale up entropy values ranging from 0 to 1 (Das & Angadi, 2020). The relative entropy for n zones is calculated as follows (Thomas, 1981):

$$H'_n = \frac{H_n}{\sum_{i=1}^n \ln(n)} \quad (3)$$

If relative Shannon's entropy value goes beyond 0.5 (threshold), it can be said that urban area is sprawling. Similarly, if the result goes below 0.5, it is inferred that there is compact built-up area. The investigated area is classified into different zones to explore the growth of urban sprawling. Bhatta et al. (2010) divided the study area into 8 pie sections to assess urban sprawl. Sudhira et al. (2004) emphasized the important factor of urban growth like roads and city centres and created a buffer zone around it for measurement of the urban growth. Sarvestani et al. (2011) created a concentric circular zone about the centre of the study area to assess growth. Punia and Singh (2012) calculated entropy with the ward boundary of the study area. In the present study, although we have proper administrative and ward boundaries of our investigated area, we haven't used it. It is because these wards are not fixed in area and number, as over the years it is changed for better and easy administration purposes (Das & Angadi, 2020).

Here, we divide the study area from CBD (Central Business District) of Cuttack City, that is supposed to be Badambadi, which is of historical importance and is a major business hub. Here, we used relative Shannon's entropy which is not restricted by the number of divisions and is not affected by how we divide the study area (Abubakar et al., 2015; Bhatta et al., 2010). So, we divide

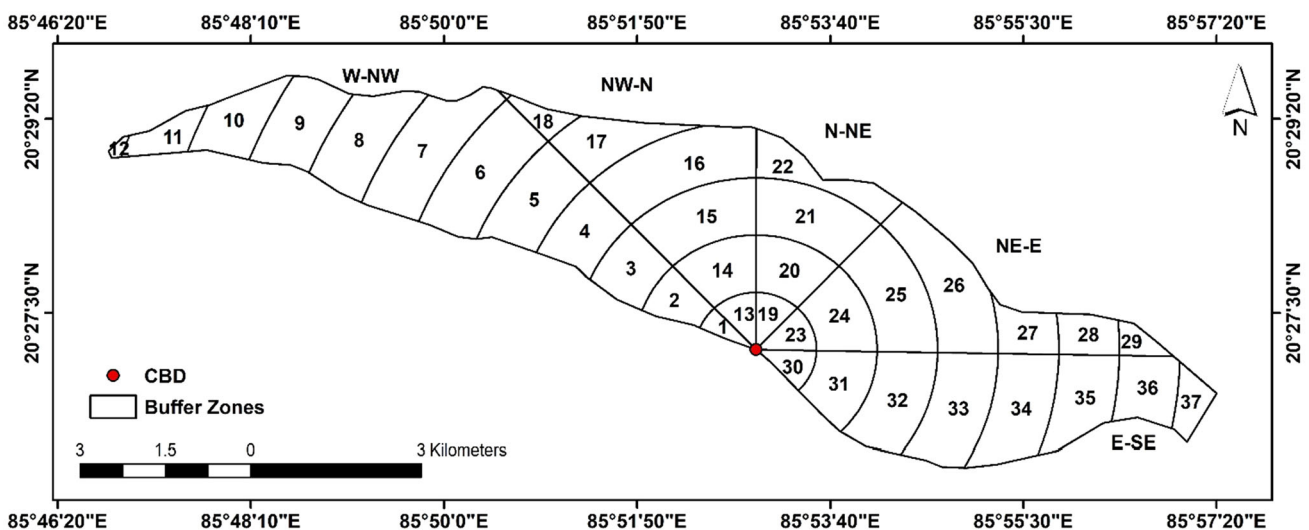


Fig. 3 Zone Division of Study Area

the study area into 5 pie sections from CBD. These 5 cardinal directions are namely W–NW, NW–N, N–NE, NE–E, E–SE. Each zone is subdivided into a concentric circle pattern of a 1 km radius to find out urban sprawl in every nook and cranny of the Cuttack City. In total, 37 vector maps of the study area are produced and used to clip the raster image into 37 zones (Fig. 3).

Results and Discussion

Land Use Land Cover Change Dynamics in Cuttack City

Using the maximum likelihood classification tool in ArcGIS 10.3 software, all imageries from 1990 to 2018 are

classified into 4 major classes (Figs. 4, 5, 6, 7). Area statistics of our classified images for 1990, 2000, 2010 and 2018 are shown in Table 2. The results demonstrate that built-up area sharply increases from 1990 to 2010 but from 2010 a sudden peak in the built-up area was observed. The overall accuracy of classified image was 90.26% (1990), 91.60% (2000), 90.56% (2010), 93.25% (2018) as depicted in Table 3. Kappa coefficient comes around 0.88 (1990), 0.91 (2000), 0.89 (2010) and 0.92 (2018). Accuracy percentage and Kappa coefficient show the strong agreement of classified image with ground sample truthing points (Congalton, 1991; Das & Angadi, 2020).

Over the years from 1990 to 2018, the change in a built-up area is around 9 km². This increase in the built-up area comes from the major cutting of trees, because around 6.88 km² of vegetative lands were lost in 28 years. Table 2

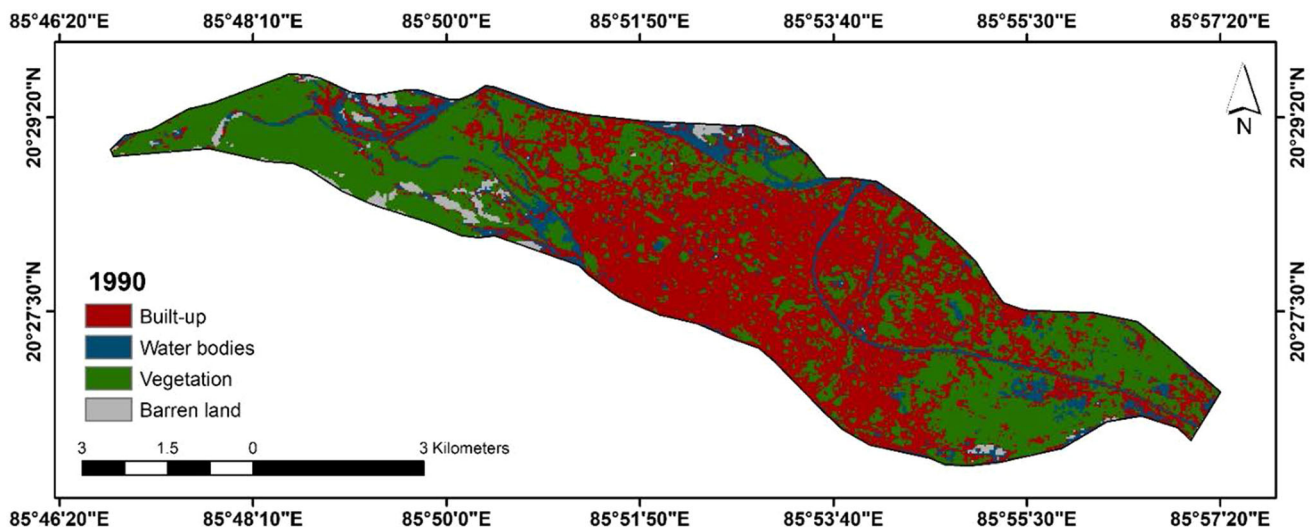


Fig. 4 Land use land cover change dynamics during 1990

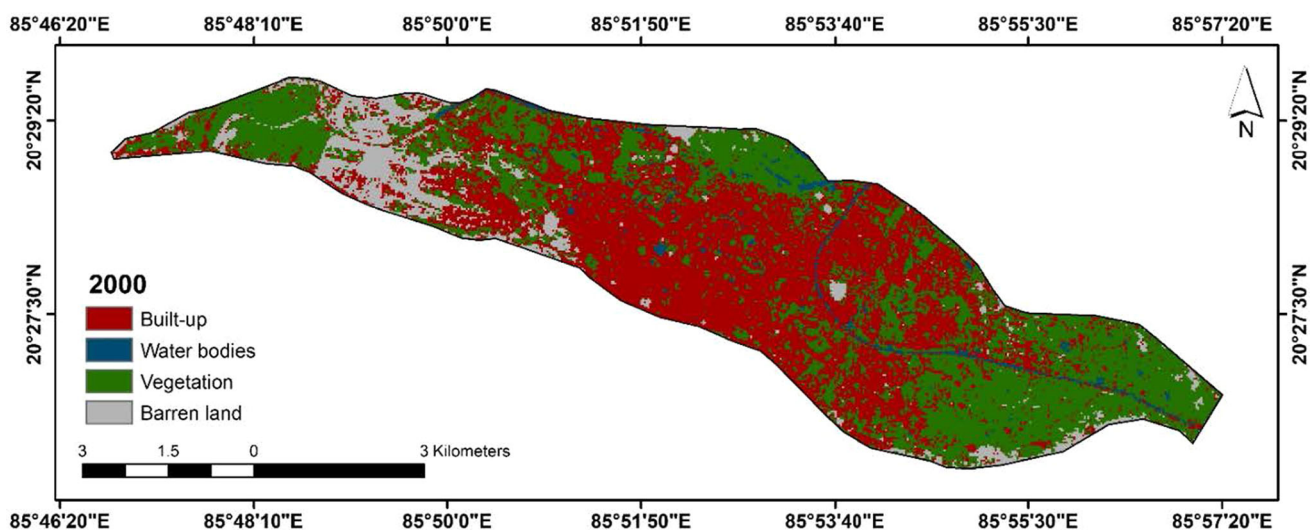


Fig. 5 Land use land cover change dynamics during 2000

depicts that vegetation lost its feet under the belt of urban development. From 1990 to 2000, there is no expansion of built-up land but during 2010–2018, there are a sudden jump of a built-up area of about 6.26 sq. km (2010) to 28.37 sq. km (2018) out of 45.205 sq. km total landmass of Cuttack City. This huge jump in urban expansion is primarily due to some of the developmental work by Municipal Corporation like the development of the number of huge supermarkets in the city, the building of national law university, maritime museum and most importantly developing Cuttack as one of the largest business hubs of Odisha. This developmental work during 2010–2018 leads to the flow of people from underdeveloped districts of

Odisha to Cuttack City. Cuttack attracts people around the state for a better health care facility. From 1990 to 2018, the built-up area has increased by 46.47%, while vegetation has decreased by -35.71% , which is a major concern. Areas that were once covered with green vegetation have now been developed with new housing schemes of CDA (Cuttack Development Authority). Again, one of the major concerns for city dwellers is the decrease in water bodies by 68.60% as some ponds have been dried up and converted into slum areas by landfilling. For a better and sustainable development plan for Cuttack City, these issues should be addressed by urban planners and policymakers.

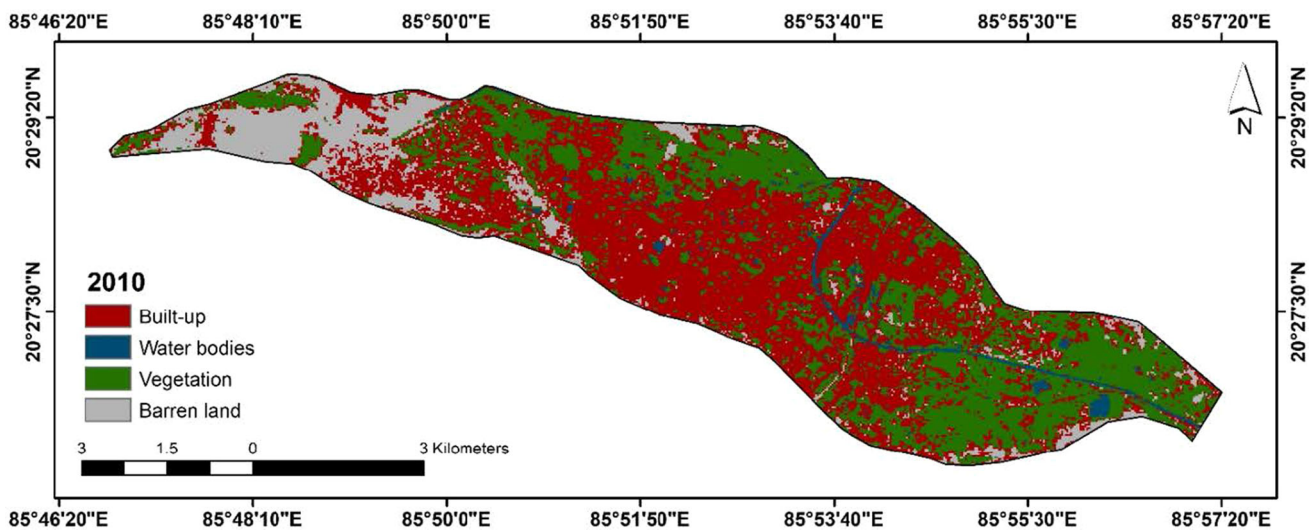


Fig. 6 Land use land cover change dynamics during 2010

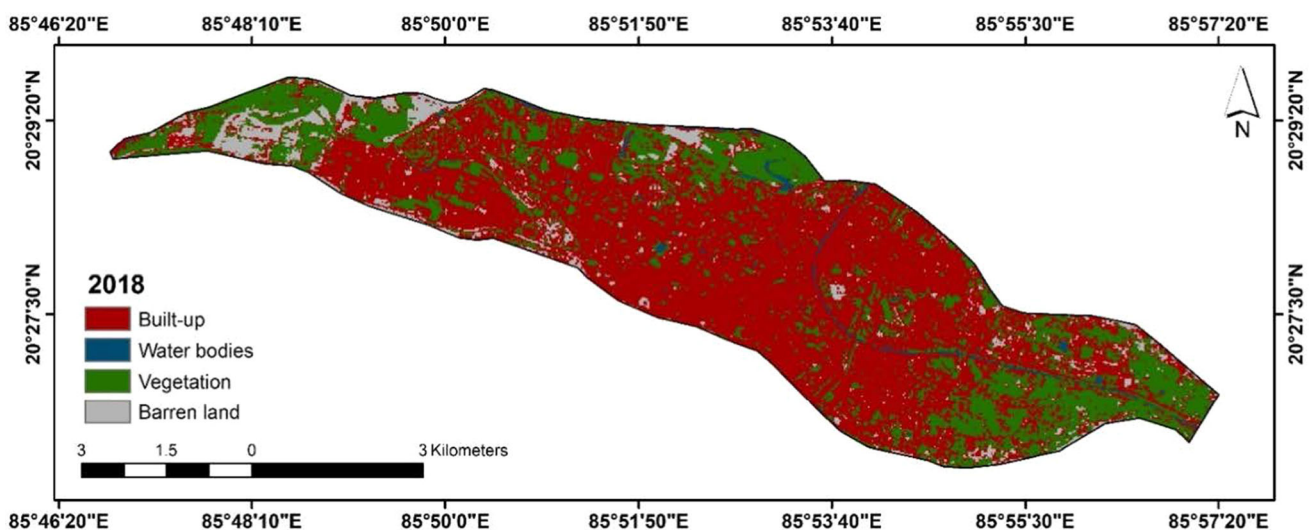


Fig. 7 Land use land cover change dynamics during 2018

Table 2 Land use/land cover changes of classes

Land use Classes	Year					Change in area					Percentage change in the area				
	1990	2000	2010	2018	2018	1990–2000	2000–2010	2010–2018	1990–2018	1990–2018	1990–2000	2000–2010	2010–2018	1990–2018	
Built-up Area	19.371	20.507	22.112	28.374	28.374	1.136	1.605	6.262	9.003	9.003	5.867	7.825	28.318	46.475	
Vegetation	19.284	19.037	16.342	12.396	12.396	-0.247	-2.694	-3.946	-6.888	-6.888	-1.282	-14.154	-24.149	-35.719	
Water	4.142	1.031	1.250	1.300	1.300	-3.110	0.219	0.050	-2.842	-2.842	-75.098	21.204	4.014	-68.606	
Barren	2.408	4.630	5.501	3.135	3.135	2.221	0.871	-2.365	0.727	0.727	92.227	18.814	-43.003	30.176	

N.B.—Areas in Square Kilometre

Population Growth and Built-Up Area

The growing population and standard of living of people lead to an increase in demand for better facilities and per capita consumptions. So, it is essential to develop a statistical model to find the trend of population growth and predict future population projection. For finding population growth of Cuttack City out of different distributions like linear, logarithmic, exponential, power distribution, we found quadratic distribution as the most suitable one for finding population growth (Fig. 8). The quadratic relationship for finding population growth of Cuttack City is calculated as follows:

$$P = 35.254x^2 - 129946x + 1E + 08 \tag{4}$$

where P is population and x is years (decades).

It has the highest correlation coefficient of 0.985. Other distributions have lower correlation coefficients than quadratic distribution. As the above quadratic equation has the highest correlation coefficient, it has been used for future projection of population for Cuttack City.

The urban growth for the period from 1990 to 2018 is presented in Figs. 9, 10, 11, 12. Table 4 reveals that the built-up area increases from 19.37 to 28.37 sq. km with a net 9 sq. km expansion of the built-up area. It also depicts that population growth percentage over the years from 1990 to 2018 surpasses the percentage of urban expansion. Percentage growth in population from 1990 to 2018 is around 79.78%, while over the same period, percentage growth in a built-up area is 46.47%, which indicates that per capita consumption of land is decreasing.

The average annual growth rate of population and compound annual growth rate for the built-up area has been calculated (Table 5) as population growth is always exponential but not for the built-up area (Punia & Singh, 2012). Table 5 shows that during 1990–2000, the population growth rate was at an all-time high. During this period per capita, land consumption was very high. During the second phase (2000–2010) there is a considerable decrease in population growth rate (1.32%) and simultaneously increase in built-up growth rate (0.75%). But in the third phase, there is a sudden jump of built-up area growth rate (2.49%) with population growth rate (1.72%) (Fig. 13). During the period 2010–2018, the built-up area growth rate increases considerably due to the major growth of the city in terms of education, health care, business development.

Urban Growth in Different Cardinal Directions

Built-up area in five directions is found out by clipping classified temporal raster into five parts in five cardinal directions (Figs. 14, 15, 16, 17, 18). Then, in every

Table 3 Results of accuracy assessment

Sl.no	Accuracy assessment	Land cover	Cuttack City			
			1990 (%)	2000 (%)	2010 (%)	2018 (%)
1	Producer accuracy	Built-up area	91	93	92	94
		Vegetation	85	84	88	82
		Water	93	92	91	94
		Barren land	89	90	91	93
2	User accuracy	Built-up area	93	89	88	92
		Vegetation	91	93	92	94
		Water	88	87	90	92
		Barren land	93	90	89	91
3	Overall accuracy		90.26	91.60	90.56	93.25

Fig. 8 Population growth of Cuttack City and Trend line

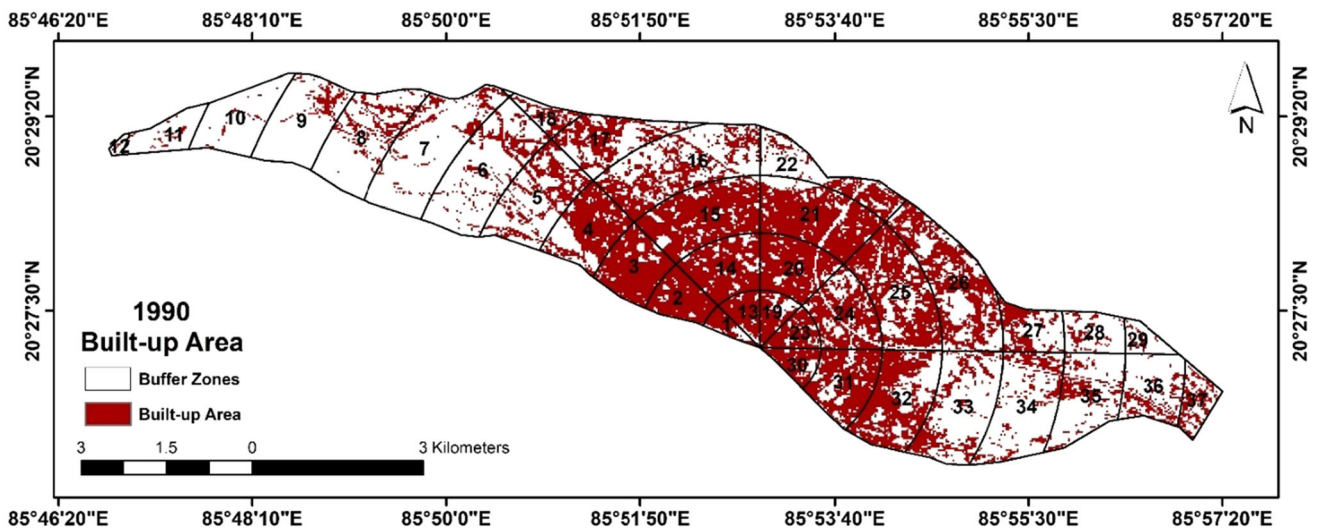
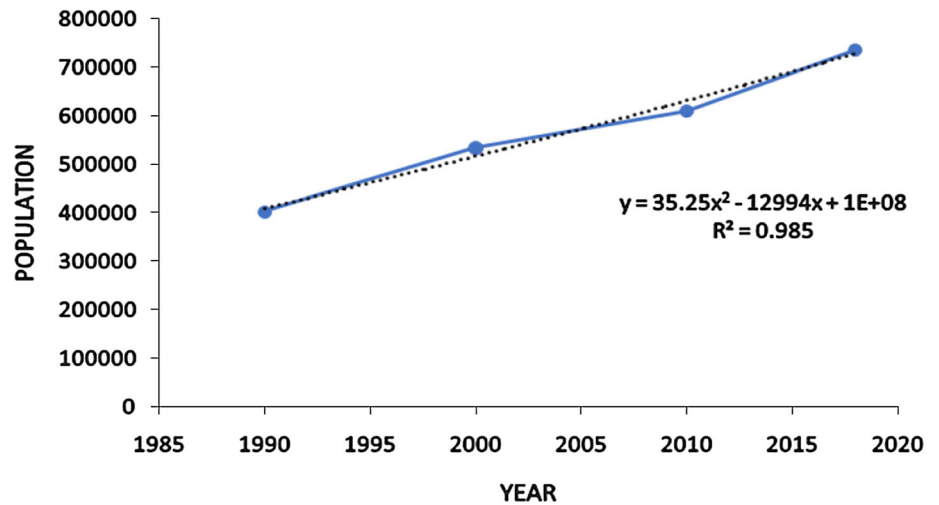


Fig. 9 Urban growth during the year 1990

direction built-up area is calculated by multiplying the number of built-up pixels by the area of a single pixel.

Table 6 depicts the change in the built-up area within the different sectors over a different year span. To understand the discrepancy, we need to find the difference between

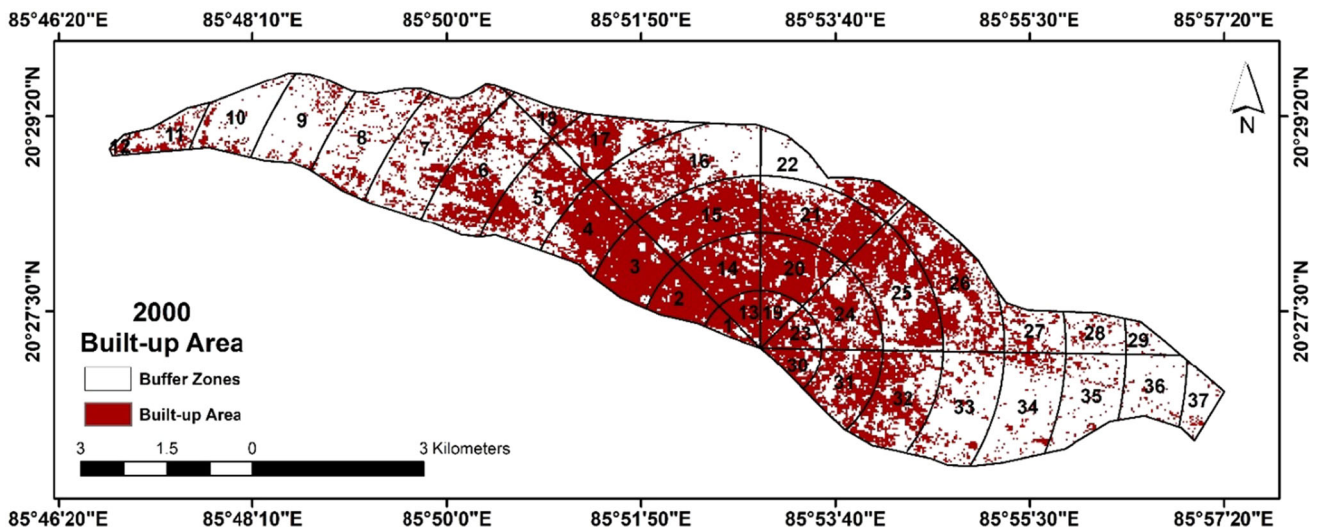


Fig. 10 Urban growth during the year 2000

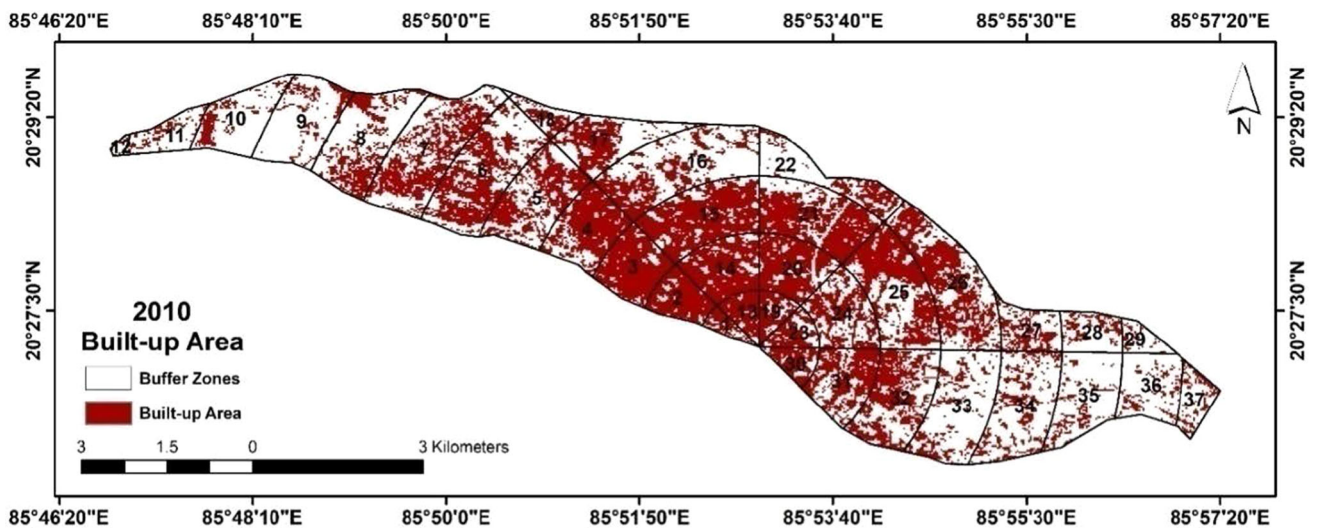


Fig. 11 Urban growth during the year 2010

observed growth and expected growth (Bhatta et al., 2010). The expected urban growth can be calculated by considering Table 6 as matrix M , with elements M_{ij} .

Where $i = 1, 2, 3 \dots n$ (time period of analysis, rows), $j = 1, 2, 3 \dots m$ (zone, column of table)

$$M_{ij}^E = \frac{M_i^s * M_j^s}{M_g} \tag{5}$$

$$M_i^s = \text{row total}, \quad M_j^s = \text{column total}, \quad M_g = \text{grand total} = \sum_{i=1}^n \sum_{j=1}^m M_{ij}$$

Expected urban growth for each zone of each span is calculated by the product of marginal totals divided by grand total (Almeida et al., 2005; Bhatta et al., 2010).

By using Eq. (5) expected urban growth has been calculated that is shown in Table 7. The difference between observed growth and expected growth is presented in Table 8. Table 8 depicts the discrepancy in urban expansion for each section and each period (Bhatta et al., 2010). A negative value indicates less urban growth and a positive value indicates growth higher than expected. From our analysis, the N–NE sector showed a higher discrepancy during 2000–2010. In our analysis discrepancy of expected growth from observed growth is not on the higher side which indicates that our classified growth is nearly equal to expected growth. If the deviation is high, it can be said that the variable is independent of another same category of variables (Bhatta et al., 2010).

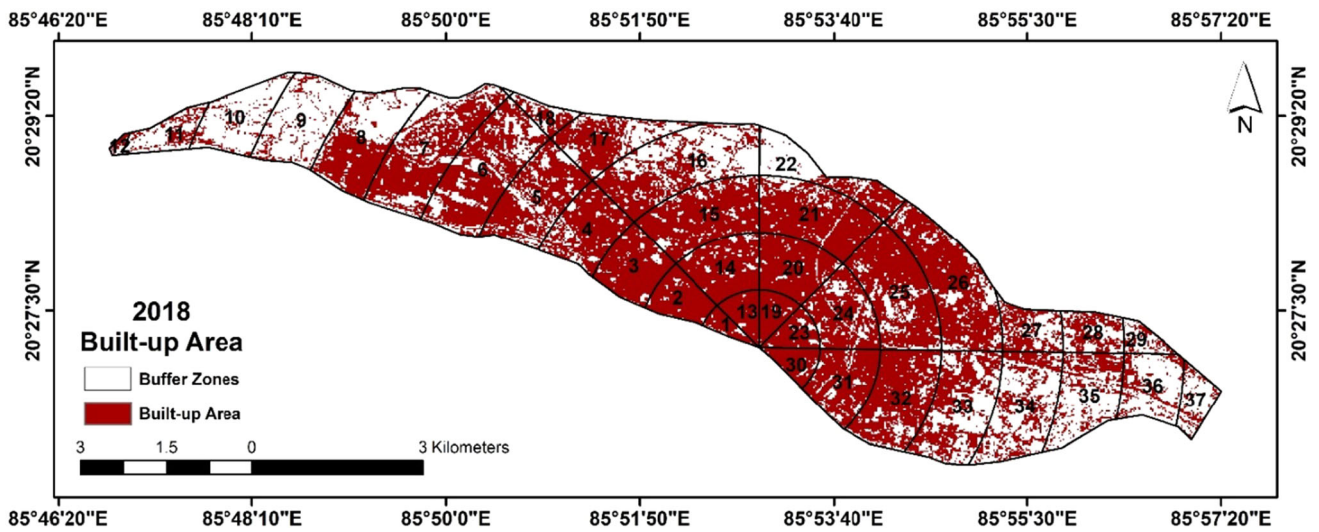


Fig. 12 Urban growth during the year 2018

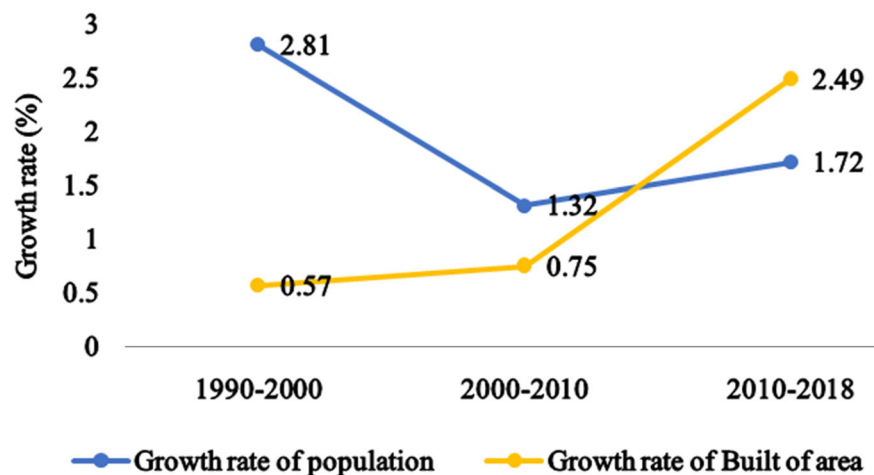
Table 4 Urban growth statistics of Cuttack City 1990–2018

Year	Built-up area (sq. km)	Increase in Built-up area (sq. km)	Percentage increase in Built-up area (%)	Projected population	The absolute increase in population	Percentage growth in population (%)
1990	19.37	–	–	403,418	–	–
2000	20.51	1.14	5.87	534,654	131,236	32.53
2010	22.11	1.60	7.82	610,189	75,535	14.13
2018	28.37	6.26	28.31	735,259	115,070	18.86
	–	9.00	46.47	–	321,841	79.78

Table 5 Growth rate of population and built-up area (1990–2018)

Year	Growth rate of population (%)	Growth rate of Built of area (%)
1990–2000	2.81	0.57
2000–2010	1.32	0.75
2010–2018	1.72	2.49

Fig. 13 Growth rate comparison of population and built-up area (1990–2018)



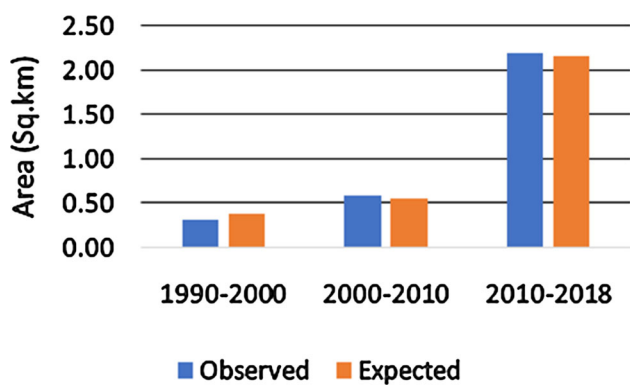


Fig. 14 Observed versus expected growth in W–NW direction

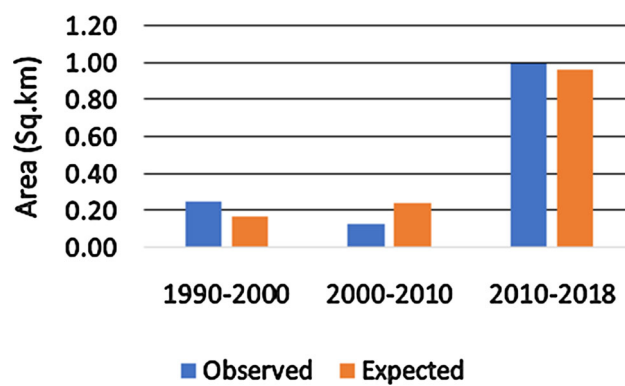


Fig. 17 Observed versus expected growth in NE–E direction

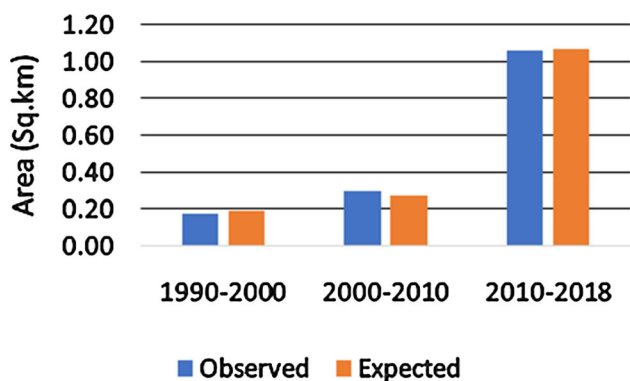


Fig. 15 Observed versus expected growth in NW–N direction

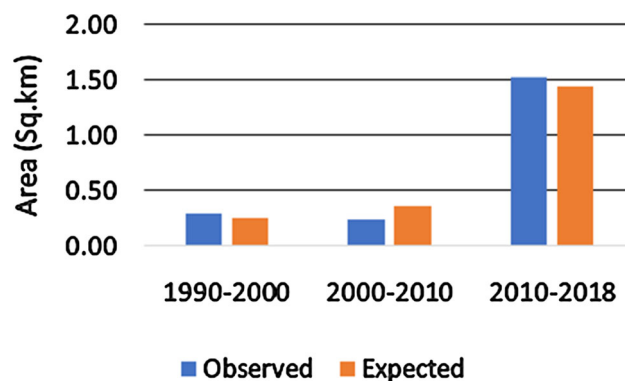


Fig. 18 Observed versus expected growth in E–SE direction

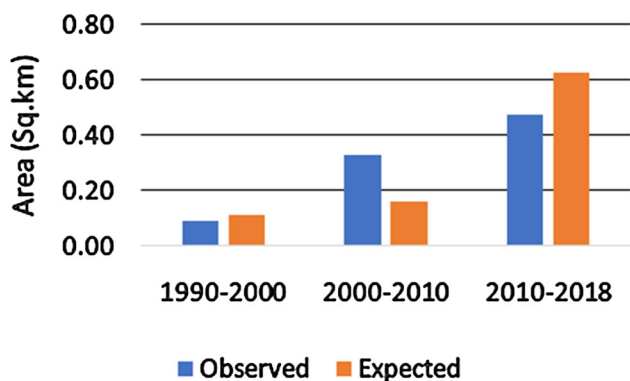


Fig. 16 Observed versus expected growth in N–NE direction

Relative Shannon’s Entropy for Urban Sprawl Analysis

Shannon’s entropy is used to measure the extent of spatial compactness or dispersion of a geophysical variable among n zones (Jat et al., 2008; Punia & Singh, 2012). Here, in this study, zone-wise built-up area is considered as a geophysical variable and is used to find urban growth on all the 37 zones of the study area over the entire temporal span. Entropy and relative entropy are calculated. The entropy, relative entropy and change in relative entropy over the

years in 37 different zones of the study area are presented in Table 10.

Relative Shannon’s entropy ranges from 0 to 1. A value closer to zero indicates the compact or concentrated distribution of urban area, whereas a value near to 1 shows urban sprawl in a dispersed manner. Thus, higher entropy means higher sprawl (Alsharif et al., 2015). The threshold value of relative Shannon’s entropy is 0.5. A value less than 0.5 considers the compact distribution of the urban area, while more than 0.5 considers urban sprawl. Table 9 demonstrates that during 1990 there is a compact distribution of urban area, but after 2000 onward relative Shannon’s entropy value crossed threshold (0.5) value which depicts sprawling of Cuttack City.

To calculate urban growth in each zone and direction we have calculated change in relative entropy over three spans (1990–2000, 2000–2010, 2010–2018) of the study area. A higher positive relative entropy value indicates higher sprawl and more dispersed expansion, while a higher negative value indicates a compact or concentrated urban area or crowded area. Figure 19a–e reveals the change in relative entropy and spatiotemporal change of built-up area over the three-time span on each zone of Cuttack City. Figure 19a shows the W-NW direction where a relatively compact urban area is detected in zones of 1, 2, 5, 9, 12 in

Table 6 Observed Built-up area of urban in a different direction over the year from 1990 to 2018

Year	W–NW	NW–N	N–NE	NE–E	E–SE	Row total
1990–2000	0.32	0.18	0.09	0.25	0.30	1.14
2000–2010	0.59	0.30	0.33	0.13	0.25	1.60
2010–2018	2.20	1.06	0.48	1.00	1.53	6.26
column total	3.11	1.54	0.90	1.38	2.07	9.00

N.B—Areas in Square Kilometre

Table 7 Expected Growth of built-up area (Sq. km)

Year	W–NW	NW–N	N–NE	NE–E	E–SE
1990–2000	0.39	0.19	0.11	0.17	0.26
2000–2010	0.55	0.27	0.16	0.25	0.37
2010–2018	2.16	1.07	0.63	0.96	1.44

Table 8 Difference between observed growth and expected growth (Sq. km)

Year	W–NW	NW–N	N–NE	NE–E	E–SE
1990–2000	– 0.08	– 0.02	– 0.02	0.08	0.04
2000–2010	0.04	0.03	0.17	– 0.11	– 0.12
2010–2018	0.04	– 0.01	– 0.15	0.03	0.09

Table 9 Overall relative Shannon's entropy of Cuttack city (1990–2018)

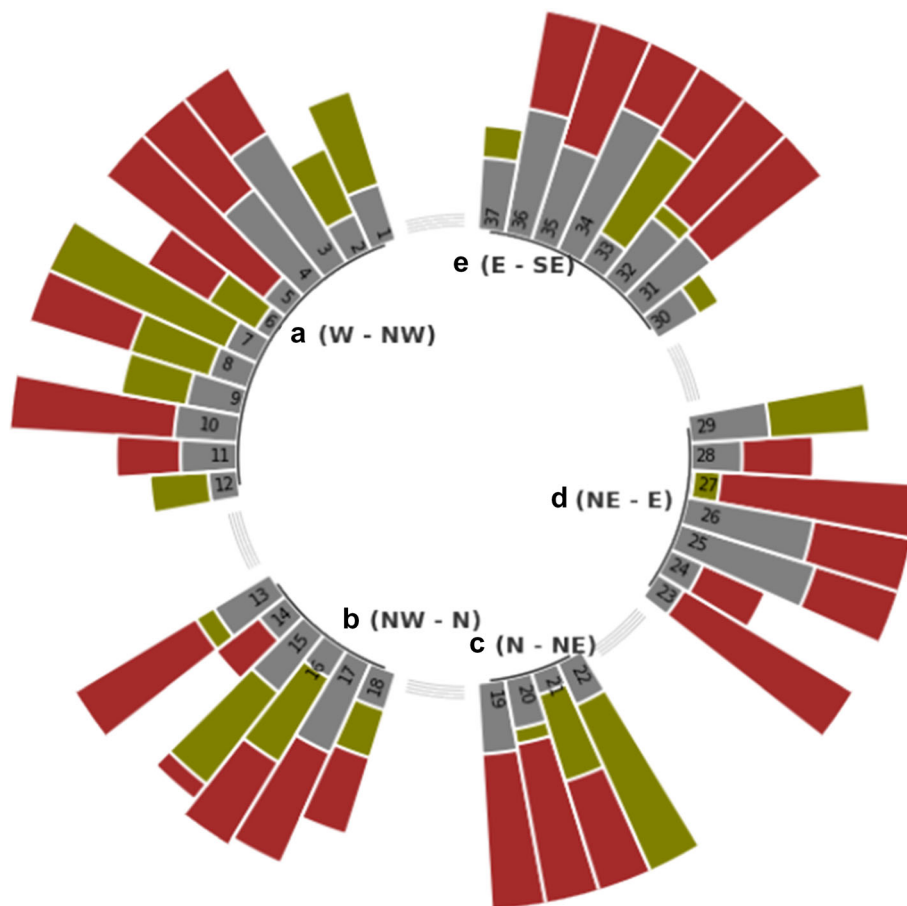
Year	Relative Shannon's Entropy
1990	0.486
2000	0.511
2010	0.545
2018	0.664

all three temporal spans but extensive sprawl is shown in 3, 4, 7, 8, 10, 11 zones in the 2010–2018 period. In these zones, relatively more growth has been recorded during 2010–2018 compared to the 1990–2000 and 2000–2010 periods. Because during this period lot of infrastructure development work done in this zone like the establishment of prominent engineering and architectural college and most importantly housing plan of Cuttack development authority (CDA) attract people all around the state resulted in the establishment of malls, cinema halls, multi-brand retail stores that trigger sudden built-up growth in this zone. In the NW–N direction zone (Fig. 19b), 15 shows growth in the built-up area during 2000–2010, but maximum urban expansion is achieved in zone 16 during

2010–2018. Maximum growth shown in zone 16 primarily due to many malls and single-brand stores of clothes and jewellery were established on the fringes of the ring road (main city road), like Pantaloon store, Lalchand jewellery, etc., that attract people from different zones for shopping. As ring road is the main city road for communication and transport from city, small marginal establishments were developed in due course of time leading to build up growth. In the N–NE direction (Fig. 19c), growth is more in zone 22 during 2000–2010. On the other hand, there was no growth in the same zone during 2010–2018. There is a sudden sprawl in zone 22, From the field verification of zone 22 of the study area we found that there is a comprehensive decrease in vegetation area to establish a maritime museum and other important institutes like BOSE engineering college, Biju Pattnaik film and television institute and other health care institutions that set off built-up area development, that is evident from the result of relative Shannon's entropy of zone 22 as shown in Table 10. In the NE–E direction (Fig. 19d), 25, 26, 27 number zones show a heavy spike in urban sprawl during 2010–2018. From field verification, we found that these zones are part of the core city of Cuttack having some of the oldest establishments are there like Mal Godown Market, National Rice Research Institute, etc., but the spike in built-up during 2010–2018 is due to the growth of few private software companies and start-ups that give employments to youth all around the state of Odisha leading to the development of new roads shops and housing colonies. Finally, in the E–SE direction (Fig. 19e), we see zones 31, 33, 34, have dispersed urban built-up in 2010–2018 than that of previous two time periods (1990–2000 and 2000–2010). There is less change of relative entropy in zones near CBD which demonstrates that these zones are highly concentrated. Urban growth increases with increasing distance from CBD, but some zones are highly compact and some show a high degree of sprawl.

All this infrastructure development work gets its peak during the phase of 2010–2018, massively due to new infrastructure development projects taken by Cuttack Municipal Corporation, which results in the hike of 46.7% in the built-up area from 1990 to 2018. This infrastructure development was done after the reckless cutting of trees

Fig. 19 Temporal variation of change in relative entropy in **a** W–NW, **b** NW–N, **c** N–NE, **d** NE–E, **e** E–SE directions



where the vegetation areas suffered degrowth of -35.71% during 1990–2018. One of the major concerns is a decrease in the percentage of a water body area (-68.60%) in the study period, some of them dried up and some were landfilled. This undesirable change in the LULC pattern is a serious concern for Cuttack Municipal Corporation to achieve sustainable development where vegetation and water spaces are considerably decreasing under the belt of infrastructure development.

Conclusion

For achieving sustainable development and cumulative growth policy for urban development, unplanned urban expansion is a potential threat. This present study is an attempt to reveal the pattern and growth of expansion of urban areas in Cuttack City to help the planner to develop better and sustainable urban planning.

In Urban growth modelling, temporal satellite images were classified to find the growth and decrease in land use and land cover parameters over the years. Moreover, urban growth was correlated with projected population data to find the growth rate of an urban area with an increase in

population growth rate. The results depict that the built-up area growth rate (2.49%) is higher than the population growth rate (1.72%) during the 2010–2018 period. The statistical method (Bhatta et al., 2010) is applied to find out the discrepancy of observed urban sprawl with expected urban growth.

The urban expansion pattern was also explored by calculating relative Shannon's entropy for quantifying urban growth patterns. The study area is divided into 5 pie sections and circular buffer zones of a 1 km radius from CBD. Researchers use road networks, commercial points, etc., to find out urban expansion. This method is suitable for metro cities or some cities of developed countries. Otherwise, Shannon's relative entropy method is a very easy and reliable method for urban growth pattern assessment. As urban growth is unplanned in Cuttack City, zone-wise evaluation of underdeveloped land and the land unsuitable for urban expansion by remote sensing is a herculean task. Therefore, it is suggested that in an attempt to demonstrate urban sprawl, Shannon's entropy values must be used to calculate the extent of urban sprawl and the fractal value should be used to understand the change in the fractal dimension of the sprawl.

Table 10 Entropy, relative entropy, change in relative entropy

Dir	Zones	Entropy				Relative entropy				Change in relative entropy		
		1990	2000	2010	2018	1990	2000	2010	2018	1990–2000	2000–2010	2010–2018
W–NW	1	0.0131	0.0153	0.0213	0.0216	0.0036	0.0042	0.0059	0.0060	0.0006	0.0017	0.0001
	2	0.0534	0.0549	0.0592	0.0593	0.0148	0.0152	0.0164	0.0164	0.0004	0.0012	0.0000
	3	0.0465	0.0523	0.0571	0.0812	0.0129	0.0145	0.0158	0.0225	0.0016	0.0013	0.0067
	4	0.0597	0.0640	0.0660	0.0822	0.0165	0.0177	0.0183	0.0228	0.0012	0.0006	0.0045
	5	0.0795	0.0806	0.0809	0.0906	0.0220	0.0223	0.0224	0.0251	0.0003	0.0001	0.0027
	6	0.1018	0.1024	0.1052	0.1107	0.0282	0.0284	0.0291	0.0307	0.0002	0.0008	0.0015
	7	0.1074	0.1087	0.1180	0.1358	0.0297	0.0301	0.0327	0.0376	0.0004	0.0026	0.0049
	8	0.0550	0.0565	0.0612	0.0982	0.0152	0.0157	0.0170	0.0272	0.0004	0.0013	0.0102
	9	0.0167	0.0188	0.0235	0.0249	0.0046	0.0052	0.0065	0.0069	0.0006	0.0013	0.0004
	10	0.0086	0.0110	0.0119	0.0437	0.0024	0.0031	0.0033	0.0121	0.0007	0.0002	0.0088
	11	0.0153	0.0175	0.0189	0.0236	0.0042	0.0048	0.0052	0.0065	0.0006	0.0004	0.0013
	12	0.0015	0.0027	0.0060	0.0062	0.0004	0.0007	0.0017	0.0017	0.0003	0.0009	0.0000
NW–N	13	0.0199	0.0224	0.0257	0.0371	0.0055	0.0062	0.0071	0.0103	0.0007	0.0009	0.0031
	14	0.0756	0.0769	0.0774	0.0808	0.0209	0.0213	0.0214	0.0224	0.0004	0.0001	0.0009
	15	0.0937	0.0965	0.1037	0.1117	0.0259	0.0267	0.0287	0.0309	0.0008	0.0020	0.0022
	16	0.0821	0.0834	0.0884	0.1195	0.0227	0.0231	0.0245	0.0331	0.0003	0.0014	0.0086
	17	0.0529	0.0567	0.0583	0.0667	0.0146	0.0157	0.0161	0.0185	0.0010	0.0005	0.0023
	18	0.0112	0.0127	0.0161	0.0225	0.0031	0.0035	0.0045	0.0062	0.0004	0.0009	0.0018
N–NE	19	0.0228	0.0255	0.0280	0.0372	0.0063	0.0071	0.0078	0.0103	0.0008	0.0007	0.0025
	20	0.0705	0.0725	0.0750	0.0845	0.0195	0.0201	0.0208	0.0234	0.0005	0.0007	0.0026
	21	0.0966	0.0975	0.1018	0.1127	0.0268	0.0270	0.0282	0.0312	0.0002	0.0012	0.0030
	22	0.0339	0.0357	0.0512	0.0532	0.0094	0.0099	0.0142	0.0147	0.0005	0.0043	0.0006
NE–E	23	0.0240	0.0252	0.0255	0.0360	0.0067	0.0070	0.0071	0.0100	0.0003	0.0001	0.0029
	24	0.0684	0.0698	0.0698	0.0738	0.0189	0.0193	0.0193	0.0204	0.0004	0.0000	0.0011
	25	0.0952	0.1006	0.1027	0.1156	0.0264	0.0279	0.0284	0.0320	0.0015	0.0006	0.0036
	26	0.0967	0.1017	0.1026	0.1239	0.0268	0.0282	0.0284	0.0343	0.0014	0.0003	0.0059
	27	0.0253	0.0255	0.0266	0.0379	0.0070	0.0070	0.0074	0.0105	0.0000	0.0003	0.0031
	28	0.0229	0.0249	0.0258	0.0305	0.0063	0.0069	0.0071	0.0084	0.0005	0.0003	0.0013
	29	0.0016	0.0046	0.0115	0.0122	0.0004	0.0013	0.0032	0.0034	0.0008	0.0019	0.0002
E–SE	30	0.0291	0.0310	0.0337	0.0363	0.0081	0.0086	0.0093	0.0100	0.0005	0.0008	0.0007
	31	0.0562	0.0595	0.0607	0.0783	0.0156	0.0165	0.0168	0.0217	0.0009	0.0003	0.0049
	32	0.0846	0.0876	0.0912	0.1028	0.0234	0.0243	0.0252	0.0285	0.0008	0.0010	0.0032
	33	0.0696	0.0709	0.0766	0.0951	0.0193	0.0196	0.0212	0.0263	0.0004	0.0016	0.0051
	34	0.0169	0.0229	0.0243	0.0642	0.0047	0.0063	0.0067	0.0178	0.0017	0.0004	0.0110
	35	0.0299	0.0337	0.0340	0.0448	0.0083	0.0093	0.0094	0.0124	0.0011	0.0001	0.0030
	36	0.0145	0.0193	0.0200	0.0286	0.0040	0.0054	0.0055	0.0079	0.0013	0.0002	0.0024
	37	0.0037	0.0065	0.0105	0.0137	0.0010	0.0018	0.0029	0.0038	0.0008	0.0011	0.0009

As a whole the study depicts that the town exhibits substantial urban growth in different temporal periods, edge expansion is dominant and the trend of urban sprawls has been increased in Cuttack. The local body should take necessary steps to evaluate the urban sprawl of the Cuttack in depth. The dynamics of built-up land use models studied by remote sensing in regular intervals is handy to predict the future urban growth of a small city like Cuttack. It will

guide future planning to reduce urbanization's detrimental effects. Moreover, such an urban growth process around this city necessitates a clear urban planning policy.

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Conflict of interest The authors do not have any conflict of interest.

References

- Abubakr, A. A., Pradhan, B., Mansor, S., & Shafri, H. Z. M. (2015). Urban expansion assessment by using remotely sensed data and the relative Shannon entropy model in GIS: A case study of Tripoli, Libya. *Theoretical and Empirical Researches in Urban Management*, 10(1), 55–71.
- Alkaradaghi, K., Ali, S. S., Al-Ansari, N., & Laue, J. (2018). Land use classification and change detection using multi-temporal Landsat imagery in Sulaimaniyah Governorate, Iraq. *Conference of the Arabian Journal of Geosciences* (pp. 117–120). Cham: Springer.
- Almeida, C. M. D., Monteiro, A. M. V., Câmara, G., Soares-Filho, B. S., Cerqueira, G. C., Pennachin, C. L., & Batty, M. (2005). GIS and remote sensing as tools for the simulation of urban land-use change. *International Journal of Remote Sensing*, 26(4), 759–774.
- Alsharif, A. A., Pradhan, B., Mansor, S., & Shafri, H. Z. M. (2015). Urban expansion assessment by using remotely sensed data and the relative Shannon entropy model in GIS: A case study of Tripoli, Libya. *Theoretical and Empirical Researches in Urban Management*, 10(1), 55–71.
- Alsharif, A., & Pradhan, B. (2014). Urban sprawl analysis of Tripoli metropolitan city (Libya) using remote sensing data and multivariate logistic regression model. *Journal of the Indian Society of Remote Sensing*, 42(1), 149–163.
- Barnes, K. B., Morgan, J. M., III., Roberge, M. C., & Lowe, S. (2001). *Sprawl development: Its patterns, consequences, and measurement* (pp. 1–24). Towson University.
- Bekele, H. (2005). Urbanization and urban sprawl. *Royal Institute of Technology: Stockholm, Sweden*.
- Belal, A. A., & Moghanm, F. S. (2011). Detecting urban growth using remote sensing and GIS techniques in Al Gharbiya governorate, Egypt. *The Egyptian Journal of Remote Sensing and Space Science*, 14(2), 73–79.
- Bhatta, B. (2009). Analysis of urban growth pattern using remote sensing and GIS: A case study of Kolkata, India. *International Journal of Remote Sensing*, 30(18), 4733–4746.
- Bhatta, B., Saraswati, S., & Bandyopadhyay, D. (2010). Urban sprawl measurement from remote sensing data. *Applied Geography*, 30(4), 731–740.
- Borana, S. L., Vaishnav, A., Yadav, S. K., & Parihar, S. K. (2020). Urban growth assessment using remote sensing, GIS and Shannon's entropy model: a case study of Bhilwara city, Rajasthan. In *2020 3rd international conference on emerging technologies in computer engineering: Machine learning and internet of things (ICETCE)* (pp. 1–6). IEEE.
- Cohen, B. (2006). Urbanization in developing countries: Current trends, future projections, and key challenges for sustainability. *Technology in Society*, 28(1–2), 63–80.
- Congalton, R. G. (1991). A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment*, 37(1), 35–46.
- Dadras, M., Shafri, H., Ahmad, N., Pradhan, P., & Safarpour, S. (2015). Spatio-temporal analysis of urban growth from remote sensing data in Bandar Abbas city Iran. *The Egyptian Journal of Remote Sensing and Space Sciences*, 18(1), 35–52.
- Das, S., & Angadi, D. P. (2020). Assessment of urban sprawl using landscape metrics and Shannon's entropy model approach in town level of Barrackpore sub-divisional region, India. *Modeling Earth Systems and Environment*, pp. 1–25.
- Fertner, C., Jørgensen, G., Nielsen, T. A. S., & Nilsson, K. S. B. (2016). Urban sprawl and growth management—drivers, impacts and responses in selected European and US cities. *Future Cities and Environment*, 2(1), 1–13.
- Godfrey, R., & Julien, M. (2005). Urbanisation and health. *Clinical Medicine*, 5(2), 137.
- Inostroza, L., Baur, R., & Csaplovics, E. (2013). Urban sprawl and fragmentation in Latin America: A dynamic quantification and characterization of spatial patterns. *Journal of Environmental Management*, 115, 87–97.
- Iqbal, M. F., & Khan, I. A. (2014). Spatiotemporal land use land cover change analysis and erosion risk mapping of Azad Jammu and Kashmir, Pakistan. *The Egyptian Journal of Remote Sensing and Space Science*, 17(2), 209–229.
- Jat, M. K., Garg, P. K., & Khare, D. (2008). Modelling of urban growth using spatial analysis techniques: A case study of Ajmer city (India). *International Journal of Remote Sensing*, 29(2), 543–567.
- Kumar, J. A. V., Pathan, S. K., & Bhandari, R. J. (2007). Spatio-temporal analysis for monitoring urban growth—a case study of Indore city. *Journal of the Indian Society of Remote Sensing*, 35(1), 11–20.
- Lata, K. M., Rao, C. S., Prasad, V. K., Badarianth, K. V. S., & Rahgavasamy, V. (2001). Measuring urban sprawl: A case study of Hyderabad. *GIS Development*, 5(12), 26–29.
- Li, X., & Yeh, A. G. O. (2004). Analyzing spatial restructuring of land use patterns in a fast-growing region using remote sensing and GIS. *Landscape and Urban Planning*, 69(4), 335–354.
- McGranahan, G., & Satterthwaite, D. (2014). *Urbanisation concepts and trends* (Vol. 220). Iied.
- Mithun, S., Chattopadhyay, S., & Bhatta, B. (2016). Analyzing urban dynamics of metropolitan Kolkata, India by using landscape metrics. *Papers in Applied Geography*, 2(3), 284–297.
- Mosammam, H., Nia, J., Khani, H., Teymouri, A., & Kazemi, M. (2017). Monitoring land use change and measuring urban sprawl based on its spatial forms the case of Qom City. *The Egyptian Journal of Remote Sensing and Space Sciences*, 20(1), 103–116.
- Ozturk, D. (2017). Assessment of urban sprawl using shannon's entropy and fractal analysis: A case study of Atakum, Ilkadam and Canik (Samsun, Turkey). *Journal of Environmental Engineering and Landscape Management*, 25(03), 264–276.
- Pathan, S. K., Jothimahi, P., Kumar, D. S., & Pendharkar, S. P. (1989). Urban land use mapping and zoning of Bombay metropolitan region using remote sensing data. *Journal of the Indian Society of Remote Sensing*, 17(3), 11–22.
- Patra, P. K., Behera, D., Naik, S. P., & Goswami, S. (2021). Spatio-temporal variation of vegetation and urban sprawl using remote sensing and GIS: A case study of Cuttack City, Odisha, India. *Journal of Geosciences Research*, 6(2), 213–219.
- Peng, X., Chen, X., & Cheng, Y. (2011). *Urbanization and its consequences*. Eolss Publishers.
- Punia, M., & Singh, L. (2012). Entropy approach for assessment of urban growth: A case study of Jaipur, India. *Journal of the Indian Society of Remote Sensing*, 40(2), 231–244.
- Rawat, J. S., Biswas, V., & Kumar, M. (2013). Changes in land use/cover using geospatial techniques: A case study of Ramnagar town area, district Nainital, Uttarakhand, India. *The Egyptian Journal of Remote Sensing and Space Science*, 16(1), 111–117.
- Roy, B., & Kasemi, N. (2021). Monitoring urban growth dynamics using remote sensing and GIS techniques of Raiganj Urban Agglomeration, India. *The Egyptian Journal of Remote Sensing and Space Science*, 24(2), 221–230.

- Sahana, M., Hong, H., & Sajjad, H. (2018). Analyzing urban spatial patterns and trend of urban growth using urban sprawl matrix: A study on Kolkata urban agglomeration, India. *Science of the Total Environment*, 628, 1557–1566.
- Saleem, A., Corner, R., & Awange, J. (2018). On the possibility of using CORONA and Landsat data for evaluating and mapping long-term LULC: Case study of Iraqi Kurdistan. *Applied Geography*, 90, 145–154.
- Sarvestani, M. S., Ibrahim, A. L., & Kanaroglou, P. (2011). Three decades of urban growth in the city of Shiraz, Iran: A remote sensing and geographic information systems application. *Cities*, 28(4), 320–329.
- Shukla, A., & Jain, K. (2019). Modelling urban growth trajectories and spatiotemporal pattern: A case study of Lucknow city, India. *Journal of the Indian Society of Remote Sensing*, 47(1), 139–152.
- Sudhira, H. S., Ramachandra, T. V., & Jagadish, K. S. (2004). Urban sprawl: Metrics, dynamics and modelling using GIS. *International Journal of Applied Earth Observation and Geoinformation*, 5(1), 29–39.
- Swain, B. K., & Goswami, S. (2014a). A study on noise in Indian banks: An impugnation in the developing countries. *Pakistan Journal of Scientific and Industrial Research Series a: Physical Sciences*, 57(2), 103–108.
- Swain, B. K., & Goswami, S. (2014b). Analysis and appraisal of urban road traffic noise of the City of Cuttack, India. *Pakistan Journal of Scientific and Industrial Research Series a: Physical Sciences*, 57(1), 10–19.
- Theil, H. (1967). *Economics and information theory* (No. 04; HB74. M3, T4.).
- Thomas, R. W. (1981). *Information statistics in geography*. Geo Abstracts.
- United Nations (2011). World Population Prospects: The 2010 Revision, Comprehensive Tables, Vol. 1, United Nations, New York; and https://en.wikipedia.org/wiki/Urbanisation_in_India
- Zeng, C., Zhang, M., Cui, J., & He, S. (2015). Monitoring and modelling urban expansion-A spatially explicit and multi-scale perspective. *Cities*, 43, 92–103.
- Zhang, T. (2001). Community features and urban sprawl: The case of the Chicago metropolitan region. *Land Use Policy*, 18(3), 221–232.

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