Monitoring and Characterizing Urban Sprawl in Raipur Urban Agglomeration, India from 2005 to 2015 using Geospatial Techniques

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Abstract. Urban sprawl is a significant challenge to sustainable urban development, particularly in developing nations. Based on remote sensing and geographic information system, this paper attempts to investigate land cover changes and urban sprawl characteristics of Raipur Urban Agglomeration (UA), India from 2005 and 2015. Landsat satellite images were extracted to conduct land cover change detection. Maximum Likelihood Classification tool in ArcGIS 10.3 was used to prepare land cover maps of Raipur UA. The accuracy of the land cover maps was assessed by determining overall accuracy and kappa coefficient. Transition matrix was prepared to identify the pattern of land cover conversion to built-up in Raipur UA. Major built-up growth direction was identified through the cardinal direction approach. Shannon’s entropy index and landscape metrics detect and characterize urban sprawl, respectively. The results indicated the prevalence of rapid urban sprawl with characteristics such as a reduction in agriculture and fallow land, outward expansion, monocentric development, and haphazard urban growth. The effect of urban development policies which has aggravated urban sprawl in Raipur UA has been discussed. The obtained results will be helpful to promote urban sustenance in the Raipur urban agglomeration.

Keywords. Remote Sensing, Land-cover, Urban sprawl, Landscape metrics, Raipur

1. Introduction
Currently, more than half (54% in 2014) of world’s population resides in urban areas as compared to 1950, when only 30% of the world’s population was urban [1]. Urbanization is occurring worldwide either through the transformation of rural to urban or through migration to an existing urban area [2]. Such transformation in last few decades has drastically affected natural environment and poses a threat to sustainable urban development [3].

In India, the spatial location of the urban population reveals, an estimated 180 million rural people live next to 70 largest urban centers, a number that will increase to about 210 million by 2030 [4]. Such rapid population growth occurring beyond the municipal boundary in the form of peri-urban growth induces urban sprawl [5]. The direct implication of such sprawl is a change in land-use and land-cover of the region as it induces the increase in the built-up and impervious areas [6]. Therefore,
it is essential to investigate the spatiotemporal urban sprawl to avoid unsustainable urbanization and mitigate its adverse impacts.

Due to the variation in the characteristics of urban sprawl in developed and developing nations, there is no universally accepted definition of urban sprawl [7]. Overall the major characteristics of urban sprawl are low-density development [8]; disperse growth [9], auto-dependent [10], growth along major roads [11], poor environment [12] and poor quality of life [13].

In India, researchers have conducted studies related to sprawl considering various aspects like land cover change detection [14], increase in built-up area [15], loss of water body and open spaces [16], increase in urban heat island [17]. RS (Remote Sensing) and GIS (Geographic Information System) has been extensively used to analyse urban growth and detect urban sprawl in many studies [18-19]. The integration of entropy indexes such as Shannon’s entropy, structure entropy, relative entropy, Renyi’s entropy and spatial entropy with RS and GIS has been conducted in many studies [20-21]. The metrics used in the urban sprawl studies can be classified into three categories such as expansion metrics, landscape metrics and geo-spatial metrics [22]. To analyse the urban growth dynamics in detail, researchers have divided the city as per cardinal directions [23], concentric circles of specific widths [24] and in few studies, both methods are applied.

Land cover changes along with urban expansion metrics were used to highlight the urban sprawl characteristics of Pune metropolis, India [25]. Similarly, urban sprawl matrix was used to explore different patterns of sprawl within Kolkata, India [26]. Researchers have investigated urban sprawl at multiple spatial levels in context to the administrative boundaries such as at regional [27], metropolitan [28], municipal [29] and ward level [30]. However, there has been minimal studies at an urban agglomeration level. An urban agglomeration is the most appropriate unit as it encompasses the nearby outgrowths, where urban sprawl is likely to occur.

Due to surpass in the carrying capacities of large or Tier-I cities (population >5 million), in India, future urban growth is likely to occur in mid-sized or Tier-II cities (population 0.5-5 million) [31]. Such projected urban growth in future might induce unplanned growth and eco-environmental problems due to capacity constraints [32]. Moreover, mid-sized cities are central to promote sustainable urban development [33]. In 2015, the United Nations adopted the 2030 Agenda for Sustainable Development, wherein the goal number 11, aims for sustainable cities and communities, which is possible through sustainable urban planning practices [34]. Therefore, this paper attempts to monitor urban growth and assess the urban sprawl pattern of Raipur, a fast-developing mid-sized city of central India during 2005 and 2015. The rest of the paper is divided into five sections as follows, section 2 describes the study area and data sources, section 3 explains the methods used in the research, section 4 exhibits the results and discussions, and section 5 presents the conclusions.

2. Study Area and Data sources

2.1 Study Area
Raipur is the capital of Chhattisgarh state of India and located in the Peninsular plateau region of India. The geographic location of Raipur UA is between 21°20’ to 21°13’ N latitudes and 81°32’ to 81°43’ longitudes covering an area of 192.55 km² (Figure 1). As per census 2011, Raipur UA comprises of Raipur Municipal Corporation (MC); Deopuri and Boriakhurd out-growths (OG) and Birgaon Municipality (M). It experiences a tropical wet and dry climate where the mean annual maximum temperature of Raipur is 33.2 °C and minimum temperature is 20.8 °C with precipitation of 1258.1 mm. As per the Census 2011, Raipur UA had a population of 1.123 million with a growth rate of 51.12% from the preceding census.

2.2 Data Sources
The spatial expanse of Raipur UA has been collected from the Census of India 2011 website. Since UA boundary was not readily available, it has been digitized in Arc GIS 10.3 and georeferenced with
the help of Google Earth features like national and state highways. To investigate urban sprawl, Landsat images for the year 2005 and 2015 were extracted from Landsatlook United State of Geological Survey (USGS) website. The detailed information of each image is exhibited in Table 1. Microsoft Excel 2017, Arc GIS 10.3, and FRAGSTATS 4.2.1 has been used for analysis and data representation purpose.

### Table 1. Descriptions of Landsat satellite images used in the study

| Landsat Sensor | Scene_ID         | Path/Row | No. of bands | Acquisition Date | Grid cell size (m) |
|----------------|------------------|----------|--------------|------------------|-------------------|
| 5 TM           | LT51420452005019BKT00 | 142 / 45 | 7            | 2005-01-19       | 30                |
| 8 OLI_TIRS     | LC81420452015015LGN01 | 142 / 45 | 11           | 2015-01-15       |                   |

### 3. Methods

The methodology followed in this paper is presented in Figure 2. It exhibits the process adopted for data analysis which includes data collection and methods adopted to monitor urban growth and assessment of urban sprawl characteristics in a mid-sized city.

#### 3.1. Land cover change detection

The bands of the Landsat satellite imagery were merged in ArcGIS 10.3 using the spectral tool before its use for change detection. The pre-processing of Landsat satellite images included radiometric normalization (noise removal, smoothing and sharpening of images) and spectral enhancement. The processed satellite images were clipped to extract the area of interest, i.e., Raipur UA. The Maximum Likelihood supervised Classification (MLC) method was adopted to classify the Landsat images into five major classes, i.e., vegetation, built-up area, agriculture, water body and fallow land in ArcGIS 10.3. For easy identification of land cover categories, the texture of the images was increased, Gaussian distribution was checked, and false-color composite (FCC) was prepared. During this process, the likelihood and statistics acquired from the spectral signatures were referred to classify the pixels of images into respective land cover classes. The MLC method depends on the Bayes’ theorem (Equation 1) to predict the probability of pixels for highest likelihood [35].
3.2 Accuracy Assessment and Transition Matrix

The accuracy assessment of each obtained land cover map was assessed with the help of ground truth data. The multiple random points for each land cover map were overlaid on the ground and matched to its characteristics using Google Earth [36]. The overall accuracy (OA) and kappa coefficient (k_i) were computed to examine the level of accuracy [22] (Equations 2 and 3).

\[
OA = \frac{\sum_{i=1}^{k} n_{ij}}{n} \quad \text{(Eq. 2)}
\]

\[
k_i = \frac{P_o - P_e}{1 - P_e} \quad \text{(Eq. 3)}
\]

where \( n_{ij} \) = diagonal elements in the error matrix, \( k = \) total number of classes, \( n = \) total number of samples in the error matrix, \( P_o = \) observed proportion of agreement, \( P_e = \) proportion expected by chance.

The spatio-temporal land cover change assessment was performed using land cover transition matrix. It the most widely used method to analyze the land cover changes through the image to image comparison between two time periods [37]. In this paper, the conversion of other land covers to built-up was computed using the transition matrix [38] (Equation 4).

\[
P_{ij} = \begin{bmatrix}
P_{11} & \cdots & P_{1n} \\
\vdots & \ddots & \vdots \\
P_{n1} & \cdots & P_{nn}
\end{bmatrix} \quad \text{(Eq. 4)}
\]

where \( P_{ij} \) indicates proportion of the landscape that experienced a transition from class \( i \) to class \( j \) between \( t_1 \) and \( t_2 \) and \( n \) is the total number of land cover types.
3.3. Cardinal Direction approach
The entire study area was divided into 8 cardinal directions, i.e., North-Northeast (N-NE), Northeast-East (NE-E), East-Southeast (E-SE), Southeast-South (SE-S), South-Southwest (S-SW), Southwest-West (SW-W), West-Northwest (W-NW) and Northwest-North (NW-N) to identify the major growth direction. This method quantifies the urban growth pattern occurring in different direction [39]. The CBD (Gol Bazar) was selected as a centroid for creating divisions. The spatiotemporal built-up area and the built-up growth rate was quantified for each direction to highlight the major growth direction.

3.4. Shannon’s entropy
Shannon’s entropy was employed to detect the degree of urban sprawl [40]. The entropy value if approaches zero, indicates compact development while values closer to \( \log(n) \) indicates urban sprawl. The study area was divided into eight zones (\( n \)) based on the cardinal directions, and a variable \( X \) takes on a value \( X_i \) for any zone, i.e., (i=1,2,3……n). The equation of Shannon’s entropy (\( H_n \)) used in this study is presented in Equations 5 and 6.

\[
H_n = - \sum_{i=1}^{n} P_i \log_2(P_i) \quad \text{(Eq. 5)}
\]

\[
P_i = \frac{X_i}{\sum_{i=1}^{n} X_i} \quad \text{(Eq. 6)}
\]

where \( P_i \) is the probability or the proportion of the variable occurring in the zone \( i \).

3.5. Characteristics of Urban Sprawl
Landscape metrics are based on information theory and fractal geometry concepts [41]. The use of multiple landscape metrics facilitates to determine the characteristics of urban sprawl. The open-source FRAGSTATS 4.2.1 software was used to compute the landscape metrics [42]. The metrics used in this study are listed in Table 2.

### Table 2. List of Landscape metrics used in this study

| S. No. | Landscape metrics            | Formula                                                                 | Description                                                                 | Significance                                      | Range                              |
|--------|------------------------------|-------------------------------------------------------------------------|----------------------------------------------------------------------------|---------------------------------------------------|------------------------------------|
| 1      | Mean patch Size (MPS)        | \( MPS = \frac{\sum_{i=1}^{n} a_{ij}}{n_i} \left( \frac{1}{10,000} \right) \) | Average patch size among the patches                                       | Higher values indicate outward expansion          | MPS > 0                              |
| 2      | Largest patch index (LPI)    | \( LPI = \frac{\max(a_{ij})}{\frac{1}{A}} \left( \frac{1}{100} \right) \) | Percentage of total built-up area occupied by largest built-up patch       | Higher values indicate monocentric development    | \( 0 < LPI \leq 100 \)                         |
| 3      | Area-weighted mean patch fractal dimension (FRAC_AM) | \( FRAC_{AM} = \sum_{i=1}^{m} \sum_{j=1}^{n} \left[ \frac{2 \ln(0.25p_{ij})}{\ln a_{ij}} \frac{a_{ij}}{A} \right] \) | Computes the shape complexity                                                | Higher values suggest increase in the shape irregularity i.e., haphazard growth | \( 0 < FRAC_{AM} \leq 2 \)               |

where \( j = 1 \ldots n \) patches, \( n = \) number of patches of (class) \( i \), \( i = 1 \ldots m \) patch types (classes), \( A = \) total landscape area \( (m^2) \), \( a_{ij} = \) area \( (m^2) \) of patch \( ij \), \( e_{ij} = \) total length of edge, \( p_{ij} = \) perimeter \( (m) \) of patch \( ij \)

4. Results and Discussions

4.1 Spatio-temporal land cover change assessment
The land cover change detection in Raipur UA was conducted for the year 2005, and 2015 and exhibited in Figure 3 and 4, respectively. Maximum supervised likelihood classification was adopted to classify different land cover within Raipur UA, i.e., vegetation, built-up area, agricultural land, fallow land, and waterbody.
Before proceeding further to analyze the land cover changes, an accuracy assessment was performed with the help of ground-truth data. Table 3 exhibits the results of accuracy assessment, i.e., overall accuracy (OA), kappa coefficient (κ). The OA of Raipur UA land cover maps was 91% for 2005 and 91.85% for 2015. Similarly, κ was 88.68% in 2005 and 89.72% in 2015. The obtained values are in accordance with the minimum 85% accuracy standards [43;44].

The land cover change assessment exhibits the dynamics of land cover changes within Raipur UA (Figure 5). During 2005 and 2015, vegetation land cover increased from 16.09 km² to 18.25 km², built-up increased from 65.07 km² to 99.76 km². However, agriculture land cover declined from 44.31 km² in 2005 to 33.27 km² in 2015, fallow land cover from 62.71 km² in 2005 to 38.65 km² in 2015, and waterbody land cover from 4.37 km² in 2005 to 3.62 km² in 2015. Overall the highest growth occurred in the built-up land cover with a growth rate of 53% during 2005-2015.

Such rapid built-up growth and reduction in agricultural, fallow land and water body land cover indicates the prevalence of urban sprawl. The transition matrix was computed to investigate “from-to” land cover conversions (Table 4).
The major land cover contributing to the built-up growth was agriculture (65.47%) and fallow land (54.03%) during 2005 to 2015. There was a minimal conversion of vegetation and water body land cover to built-up growth. Overall, the built-up growth in Raipur UA had occurred primarily through the conversion of agricultural fields and fallow lands located at the peripheral areas.

### 4.2 Predominant built-up growth direction

The built-up growth pattern was analyzed using the cardinal direction approach. The built-up area of Raipur UA was divided into 8 cardinal directions, as shown in Figure 6. The higher built-up area during 2005 and 2015 was observed in NW-N and W-NW directions primarily due to urban growth surrounding the Urla Industrial Area, Bhanpuri-Rawabhata Industrial area and Birgaon which acted as growth magnets (Figure 7a). However, the growth rate was observed higher in E-SE and SE-S directions during 2005-2015. The major growth driver to attract rapid urban growth was the construction of Naya Raipur (now Atal Nagar) as the capital city post 2005, located 17 km south-east of Raipur city (Figure 7b).

### Table 4. Land cover contribution to built-up growth in Raipur UA (2005-2015)

| S. No. | Land cover     | Contribution to built-up area (2005-2015) |
|--------|----------------|------------------------------------------|
| 1      | Agriculture    | 65.47%                                   |
| 2      | Fallow Land    | 54.03%                                   |
| 3      | Vegetation     | 5.63%                                    |
| 4      | Water body     | 2.92%                                    |

![Raipur UA built-up growth direction map](image-url)
4.3 Urban sprawl detection and characterization

The degree of urban sprawl was detected using Shannon’s entropy index. The entropy value if approaches zero indicates compact growth while values close to $\log_{e}(n)$, i.e., 2.07, indicates urban sprawl. The entropy values are presented in Table 5.

The degree of urban sprawl during 2005 as per entropy index was 2.00 and further increased to 2.02 in 2015. As the entropy values are closer to $\log_{e}(n)$, i.e., 2.07, the prevalence of urban sprawl in Raipur UA was clearly detected. Due to the lack of urban sprawl control measures, there was continuous increasing trend. The characteristics of urban sprawl was detected using landscape metrics. The growth in mean patch size (MPS) from 12.78 in 2005 to 27.83 in 2015 implies the occurrence of outward expansion. The growth of landscape patch index (LPI) values from 44.58 in 2005 to 48.75 in 2015 highlights the prevalence of monocentric development. The rise in area-weighted mean patch fractal dimension (FRAC_AM) from 1.29 in 2005 to 1.31 in 2015, exhibits an increase in shape irregularity, i.e., haphazard urban growth.

Table 5. Shannon’s entropy index and Landscape metrics for Raipur UA (2005 & 2015)

| S.No. | Method                                      | Year 2005 | Year 2015 |
|-------|---------------------------------------------|-----------|-----------|
| 1     | Shannon’s entropy index ($H_n$)             | 2.00      | 2.02      |
| 2     | Mean patch Size (MPS)                       | 12.78     | 27.83     |
| 3     | Largest patch index (LPI)                   | 44.58     | 48.75     |
| 4     | Area-weighted mean patch fractal dimension (FRAC_AM) | 1.29      | 1.31      |

4.4 Implications of economic policies on urban growth pattern of Raipur UA

There is a strong effect of economic reforms adopted post-liberalization in Raipur UA. The entry of Foreign Direct Investment (FDI) and the encouragement of the private sector by the government to set up industries helped in the industrial growth in and around the city. This is evident through rapid built-up growth (real-estate and industrial) in the northern and southern direction of Raipur UA. Moreover, the location of Bhilai and Durg steel plants facilitated the rise in the industrial areas. The availability of raw steel ore in the state further boosted industrial growth. Further, the repeal of Urban Land Ceiling and Regulation Act (ULCRA) Act post 2005 as a reform under Jawaharlal Nehru National Urban Renewal Mission (JNNURM) facilitated the supply of land in urban areas [45]. The minimum size of housing projects for FDI was reduced to 30 acres only and 100% FDI was allowed in the...
integrated townships and infrastructure projects [46]. This has led to the rise in real-estate growth and institutions in and around Raipur UA during 2005 to 2015.

In addition to the policies mentioned above, the city of Raipur is an administrative headquarters of Raipur district and an existing capital city of the Chhattisgarh state of India. Moreover, the city being a political and administrative center along with the location of nearby industries, attracted rapid urban growth. The major urban growth drivers in case of Raipur UA has been the Industrial areas like Urla, Bhanpuri- Rawabhata in the northern direction and the location of new capital city Atal Nagar in the south-eastern direction.

5. Conclusions
This study monitors the urban growth and assesses the urban sprawl pattern of Raipur UA, a fast-developing mid-sized city of central India during 2005 and 2015. It demonstrated the effective use of modern research methods in the urban planning domain to investigate urban sprawl. The pattern of urban sprawl in the city revealed growth in built-up areas at the cost of prime agricultural land and fallow land covers. Such a pattern has a strong negative effect on the natural environment. NW-N and W-NW directions exhibited higher built-up growth, whereas higher built-up growth rate occurred in SE-S and E-SE directions, due to its nearness to the new capital city. A rise in Shannon’ entropy index indicated the prevalence of urban sprawl, mostly due to the unsustainable utilization of land resources. Overall the characteristics of urban sprawl exhibited the prevalence of outward expansion, monocentric development, and haphazard urban growth. The urban development policies adopted lacked an effort to control urban sprawl; instead, it promoted haphazard urban growth. Raipur UA has benefitted from the high industrial growth, better infrastructure, and connectivity, but unplanned urban growth has led to sprawl. Hence to promote the goal for sustainable cities and communities, there is an urgent requirement of sustainable urban planning practices in such mid-sized cities.

The government of India has come up with various popular schemes and policies such as Smart city and Atal Mission for Rejuvenation and Urban Transformation (AMRUT) to channelize urban growth in the proper direction, and Raipur has been a part of it. Therefore, the results of this study would benefit planners and authorities while preparing relevant strategies to promote urban sustenance. In this era of rapid urbanization, sustainable means to incorporate rising population within the limited city area is a challenge for policymakers and city planners. Future studies can incorporate the identification of growth containment strategies suitable to mid-sized cities of developing nations.

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