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Research Paper

Monitoring spatio-temporal dynamics of urban and peri-urban landscape using remote sensing and GIS – A case study from Central India

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ABSTRACT

In the study, an attempt has been made to map and monitor spatio-temporal dynamics of urban and peri-urban landscape of Nagpur city, Maharashtra, India using urban plan maps (1936), topographical sheets (1976), temporal Landsat 5 Thematic Mapper data for the years 1991 and 2010. Object Based Image Analysis (OBIA) technique has been followed to classify the temporal remote sensing data using eCognition software (*Ver* 9.8) in conjunction with topographic sheets in Geographic Information System (GIS). The analysis shows that urban area has increased from 2272 ha in 1936 to 17344 ha in 2010, this could be attributed to natural increase in urban population and inward migration from villages to city for better education, employment, recreation and living standards. During the urbanization process, about 2806 ha of land has been converted predominantly from double cropped area and degraded scrublands to housing or industrial needs. Interestingly area under water bodies slightly increased from 0.9 to 1.1 per cent of total geographical area (TGA) during the same period. The analysis of urban sprawl shows that eastern, southern and southwestern part of Nagpur city witnessed significant growth of urban sprawl. The generated spatio-temporal information on urban sprawl could be effectively used to monitor the land use/land cover changes and maintain sustainable urban environment of the Nagpur city. The study demonstrates the potential of temporal satellite data and GIS techniques in analysis of spatio-temporal dynamics of urban and peri-urban landscape for management of land resources on sustainable basis.

1. Introduction

Urbanization is a global phenomenon and continuous growth of built-up areas has direct impact on land use/land cover of urban landscapes (Fan, et al., 2017). The United Nations' World Urbanization Prospects report highlights the highest rate of urbanization in Asia increasing at 1.5 per cent per annum and estimated that between 2014 and 2050, the urban areas in India are expected to grow by 404 million people (United Nations, 2014). The rapid growth of urban agglomerations has raised the concerns to map and monitor the urban and peri-urban landscapes in the context of scientific land use planning (Maji et al., 2001), environmental and developmental agendas (Estoque and Murayama 2015; Mertes et al., 2015; Liu et al., 2016). Further, burgeoning population and unplanned development in cities increases competition for land and water resources, it in tern affects peri-urban agricultural areas (Van Rooijen et al., 2005). Urban sprawl is characterized by unplanned and uneven pattern of growth, driven by multitude of processes and inefficient of resource utilization (Bhatta, 2010). Ermer et al. (1994) defined urban sprawl as "the process of spilling-over of settlement areas and of excessive use of the open landscape by an unsystematic, mostly weakly condensed extension of settlement areas in the fringe of urban agglomeration". In India, about 27.8 per cent of population lives in towns and cities, urban sprawl is taking its toll on the natural resources at an alarming pace. India's urban population has grown tremendously in the last five decades from 79 million in 1961 to 350 million in 2010. The increasing human population coupled with increasing standards

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of living (United Nations 2014; World Bank Group, 2015), has placed tremendous pressure on India's land resources (Reddy et al., 2017) for food, fiber, fuel, and shelter. The major impact of urban sprawl is felt on the productive agricultural lands (Maji et al., 2010), surface and sub-surface water resources, changing urban hydrology and creating new hydrological environment of urban landscape (Alberti et al., 2000; Banzhaf et al., 2009). Monitoring of urban sprawl helps to identify the areas, where environmental and natural resources are critically threatened (Reddy et al., 2013) and to suggest likely future direction and pattern of sprawling growth (Simmons, 2000). Many authors studied urban sprawl (Epstein et al., 2002; Deng et al., 2009) and more particularly in China (Yeh and Li, 2001; Cheng and Masser, 2003) and India (Lata et al., 2001; Sudhira et al., 2003). The dynamics of urban sprawl need to be understood through analysis of land use/land cover changes and their dynamics in time scale.

Across the globe, remote sensing imageries and techniques are widely used for analysis of urban growth and urban sprawl (Jayaprakash et al., 2015; Aithal and Ramachandra, 2016). Further, remote sensing and GIS technologies together have immense potential to classify the types of urban land use changes and study their dynamics to optimize the land resources in planned urban development, provide cost affective and time efficient services. Temporal remote sensing data coupled with GIS and necessary collateral data helps to analyze the growth, pattern and extent of sprawl (Sudhira et al., 2004). The advances in remote sensing and GIS technologies has provided a platform to examine the landscape transformations throughout space and time (Estoque and Murayama, 2015, 2016). In urban environments, landscape transformations are dominated by anthropogenic activities and are greatly influenced by the spatial expansion of built-up lands (Bagan and Yamagata 2014; Estoque and Murayama, 2015, 2016). The extent and pattern of urban sprawl on landscapes can be clearly detected using temporal remote sensing and GIS (Rahman et al., 2011). Urban sprawl of Ajmer city of Rajasthan, India was studied for 25 years (1977–2002) using Landsat TM, MSS, ETM+, and IRS-ID LISS-III data (Jat et al., 2008). Ahmad and Goparaju (2016) analyzed the urban sprawl of Ranchi city, India using Landsat data from 1976, 2002 and 2015 and reported that spatial analysis of urban sprawl is pre-requisite for monitoring of unplanned urban growth and ensure sustainable urban development. Zhu et al. (2008) used object-oriented change detection method on high resolution images based on polygon automatic validating technique. Image segments have additional spectral information compared to single pixels, but of even greater advantage than the diversification of spectral value descriptions of objects (Blaschke and Strobl, 2001; Hay and Castilla, 2008). Many authors reported that when compared to the pixel classification approaches, Object-based image analysis technique (OBIA) provides the most accurate results (Yan et al., 2006; Whiteside et al., 2011). OBIA segmentation and classification algorithms were used for mapping land use/land cover in five cities in Saudi Arabia (Alqurashi, et al., 2016). OBIA-based decision tree process was followed to map thirteen land use types, further, visual modification was employed to improve the classification (Cao, et al., 2017). In the present study, an attempt has been made to demonstrate the capabilities of temporal remote sensing and GIS in mapping and monitoring the spatio-temporal dynamics of urban and peri-urban landscape of Nagpur city, Central India using OBIA technique.

1.1. Study area

The city of Nagpur as second capital of Maharashtra state, famously known as the orange city situated at geographically centre part of India. According to the census of India (2011) Maharashtra is home to the highest number of people living in urban areas and ranks 3rd after Tamil Nadu and Kerala states. Urban population growth has accounted for 62.8 per cent of total population growth in Maharashtra. The study area is located between 21°02′ to 21°16′ N latitudes and 78°56′ to 79°12′ E longitudes with total geographical area of 50,035.5 ha (Fig. 1). Nagpur is an emerging metropolis in Central India and as per 2011 census, Nagpur municipality had a population of 24.05 lakh and the urban agglomeration had a total population of 25.23 lakh.

2. Materials and methods

2.1. Data used

The demographic data of Nagpur city was collected from Census of India and as well as from Municipal Corporation of Nagpur city for the year 1951, 1961, 1971, 1981, 1991, 2001, and 2011. Based on the collected demographic data, the temporal trends in population growth of Nagpur city have been analyzed. The Survey of India (SOI) toposheets on 1:50,000 scales for the year 1976 have been registered in GIS as reference data and used to map the extent of urban sprawl for the year 1976. Urban development zones map developed by Nagpur Municipal Corporation (NMC) has been registered and digitized in GIS to analyze the urban sprawl at different sectors for the year 1991 and 2010. In order to map and monitor the urban sprawl of Nagpur city and its environs, Landsat 5 Thematic Mapper data (30 m) of 13th December 1991 and 28th September 2010 were download from USGS Earth Explorer (USGS, 2010) and analyzed to assess spatio-temporal dynamics of land use/land cover of Nagpur city and its environs for the year 1991 and 2010. In order to validate the results, filed survey was conducted in the study area during first week of November 2010 and handheld Global Positing System (GPS) based field data was collected regarding location and type of land use. The Google earth images were extensively used to label the classes and validation of the results during the field survey. The datasets used in the study area and their sources are shown in Table 1. The spectral bands of Landsat 5 Thematic Mapper sensor and their description are shown in Table 2.

2.2. Image classification and GIS analysis

Before analysis, the subset images for the study area were created from Landsat 5 TM images for the year 1991 and 2010 for subsequent classification. OBIA was carried out using eCognition Software (ver 9.8), and various land use/land cover classes were identified in Nagpur city and its environs. OBIA in eCognition is a bottom up region merging technique, merging smaller objects to form bigger ones by taking criteria of homogeneity in shape and color into account. Mainly, the size of the object is adjusted by the scale parameter, which determines the maximum allowable heterogeneity of the objects and the shape depend on segmentation parameters, such as color/shape, smoothness/compactness of input image, and the level of the segmentation. In an iterative process, smaller objects are merged into larger ones. This continues until the objects reach a maximum allowed heterogeneity. The vector layer of segments generated through OBIA along with layer statistics were exported from eCongnition to ArcGIS (*ver* 10.3). By using various GIS techniques like overlay, integration, change detection and area calculation, various land use/land cover classes pertaining to urban and peri-urban landscape of Nagpur city have been identified.

In the study, land use refers to man's activities and the various use, which are carried on a parcel of land, whereas, land cover refers to, natural vegetation, water bodies, croplands, artificial

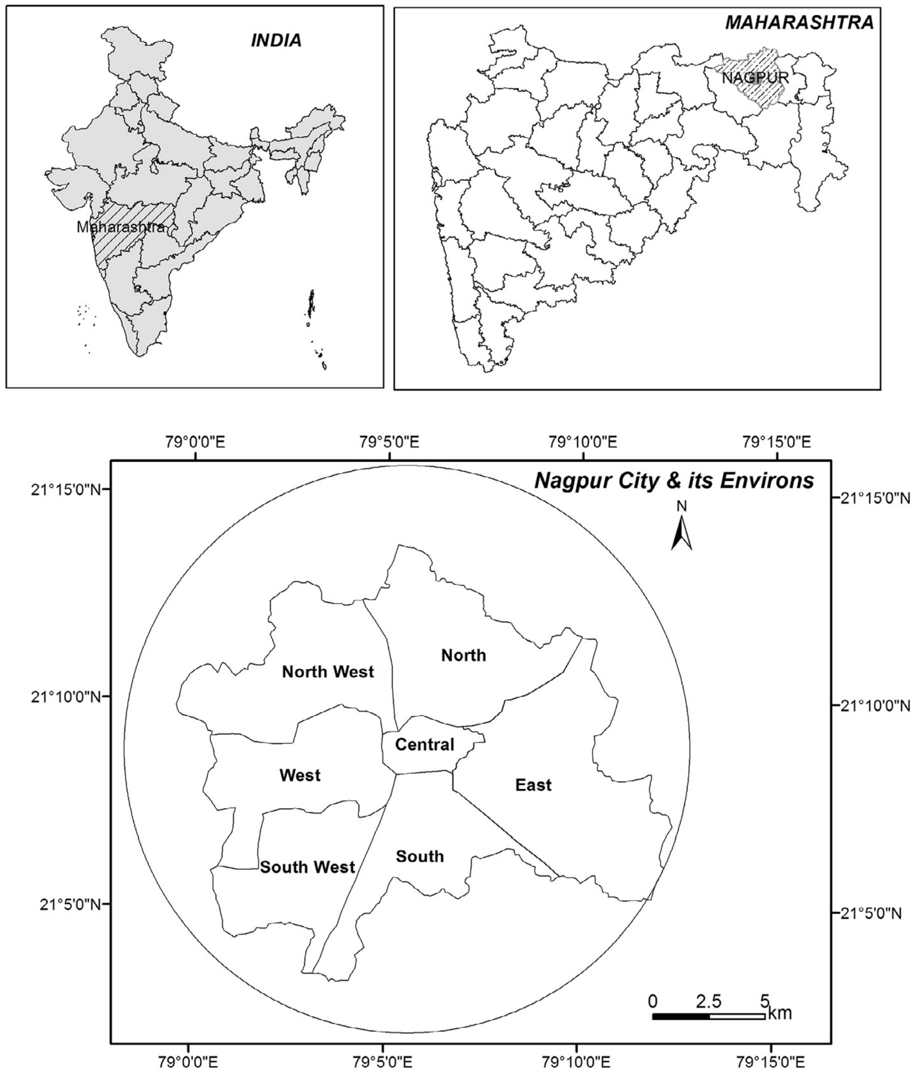

Fig. 1. Location of Nagpur city and its environs.

Table 1
Datasets used in the study and their sources.

S. No.	Datasets used	Data Source
1	Topographic maps (1976)	Survey Of India
2	Demographics and census data1951 to 2011	Nagpur Municipal Corporation
3	Urban development zones map	Nagpur Municipal Corporation
4	Landsat 5 Thematic Mapper (Path 144/Row 45)	Earth Exploration (USGS)
5	Google Earth images (2010)	Google Earth
6	Field observations	Handheld GPS

Table 2
Spectral bands description of Landsat 5 Thematic Mapper sensor.

Bands	Wavelength (μm)	Resolution
Band 1 – Blue	0.45–0.52	30 m
Band 2 – Green	0.52–0.60	30 m
Band 3 – Red	0.63–0.69	30 m
Band 4 – Near Infrared	0.76–0.90	30 m
Band 5 – Shortwave Infrared-1	1.55–1.75	30 m
Band 6 – Thermal Infrared	10.40–12.50	120 m
Band 7 – Shortwave Infrared-2	2.08–2.35	30 m

cover and others resulting due to land transformations have been mapped and assessed in around the Nagpur city. The logical aggregation and labeling of classes was carried out for identification and classification of different land use and land cover classes of the study area. At level I, broad land use/land cover classes like residential, agriculture, forest and other classes have been identified. These classes were further sub-divided at level-II and identified land use/land cover classes like highly dense settlements, medium dense settlements, low dense settlements, double cropped area, single cropped area, degraded deciduous forest, degraded scrublands, permanent fallows, urban vegetation, mining area, infrastructure and waterbodies in the study area. The land use/land cover classification schema used in the study is shown in Table 3. Urban dwellings density is context-specific and depends on a range of factors, which includes, land availability and costs, location and transport, social context and household size, cultural acceptance and environmental considerations. There are no clear unanimously agreed definitions for low, medium and high density of dwellings across the globe. In the United Kingdom, residential development with less than 20 dwelling units/ha is considered low density between 30 and 40 dwelling units/ha is considered medium density and higher than 60 dwelling units/ha is considered high density (TCPA, 2003). Whereas, in the United States of America, low density refers to 25–40 dwelling units/ha medium density refers

Table 3
Land use/land cover classification schema used in the study.

Level-I	Level-II
Built-up land	Highly Dense Settlements
	Medium Dense Settlements
	Low Dense Settlements
Crop land	Double cropped area
	Single Cropped Area
Forest	Degraded Deciduous Forest
	Degraded Scrublands
	Urban Vegetation
Fallows	Permanent Fallows
Mining area	Mining Area
Infrastructure	Infrastructure (Roads, Railways, Airports)
Water bodies	Water bodies (River, lakes, dams)

to 40–60 dwelling units/ha and high density refers to development with higher than approximately 110 dwellings/ha (Ellis, 2004). In the Indian context, especially in the context of Nagpur city, we consider approximately 40 or less dwelling units/ha as low density, approximately 40–100 dwelling units/ha as medium density and 100 or more dwelling units/ha as high density settlement areas. High density of built-up would refer to more compact nature of the built-up area, while medium density would refer to relatively lesser compact built-up and low density referred to loosely or sparsely spread built-up areas. In order to monitor the urban and peri-urban landscape of Nagpur city, the land use/land cover dynamics derived from Landsat TM datasets of 1991 and 2010 were analyzed. Area analysis for different classes has been carried out in GIS to analyze the spatio-temporal dynamics of land use/land cover classes of the study area for the year 1991 and 2010.

GPS based field survey was conducted in the study area and collected filed data for about 119 sampling locations (Fig. 2) covering all land use/land cover classes indentified in the classification schema. Samples were collected based on large homogeneous areas selected as sampling locations. Several parameters, such as single crop, double crop, urban extent including dense, medium and low settlements and open land, and other land cover including permanent fallow, and degraded scrublands were determined in the field. Kappa coefficient (k), a discrete multivariate technique (Cohen, 1960) was used to assess the accuracy of the results obtained through analysis of Landsat 5 TM data of 2010.

$$\text{Cohen'skappa}\, k = \frac{p_0 - p_e}{1 - p_e}$$

where: P_o = observed agreement and P_e = chance agreement. The Kappa statistic varies from 0 to 1, where 0 = agreement equivalent to chance 0.1–0.20 = slight agreement, 0.21–0.40 = fair agreement, 0.41–0.60 = moderate agreement, 0.61–0.80 = substantial agreement, 0.81–0.99 = near perfect agreement and 1 = perfect agreement.

The detailed methodology followed in the study is shown in Fig. 3.

3. Results and discussion

Spatio-temporal dynamics of urban landscape of Nagpur city and its environs for the year 1936, 1976, 1991 and 2010 were assessed using City Municipal Corporation and Topographical maps, temporal remote sensing and GIS. The analyses provide useful information to clearly understand spatio-temporal dynamics of urban growth of Nagpur city and assess the impact of urban sprawl on land use around the Nagpur city.

3.1. Status of urban sprawl in 1936

As per the availability of extent of urban development maps from City Municipal Corporation, it was estimated that the urban area of Nagpur city in the year 1936 was about 2272 ha. The urban sprawl boundary of 1936 was overlaid on the SOI Toposheet of 1976 in GIS to assess the extent of urban sprawl (Fig. 4a). The analysis shows that the urban area was mainly confined to the heart of the city. The development of linear growth has been noticed in the southern part of Nagpur city along the Wardha road and west side along with the Amravati road.

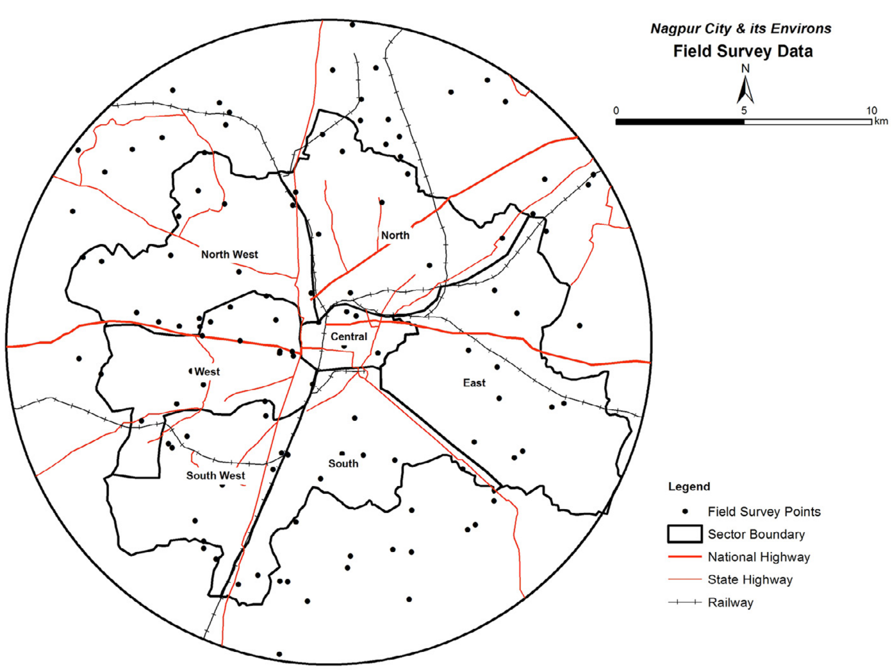

Fig. 2. Location of field survey points in Nagpur city and its environs.

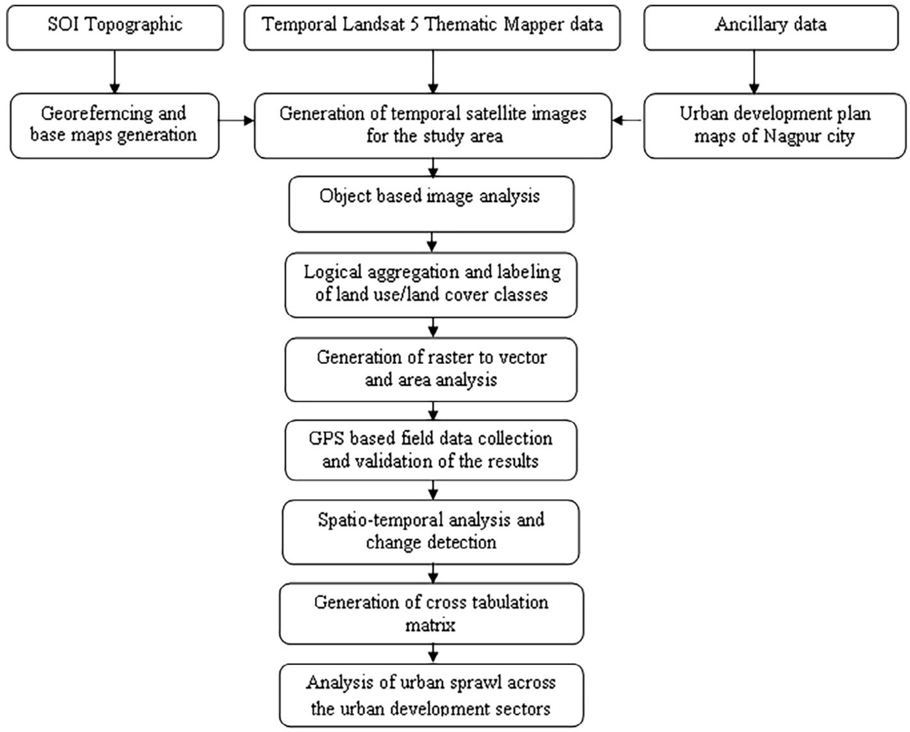

Fig. 3. The methodology followed in the study.

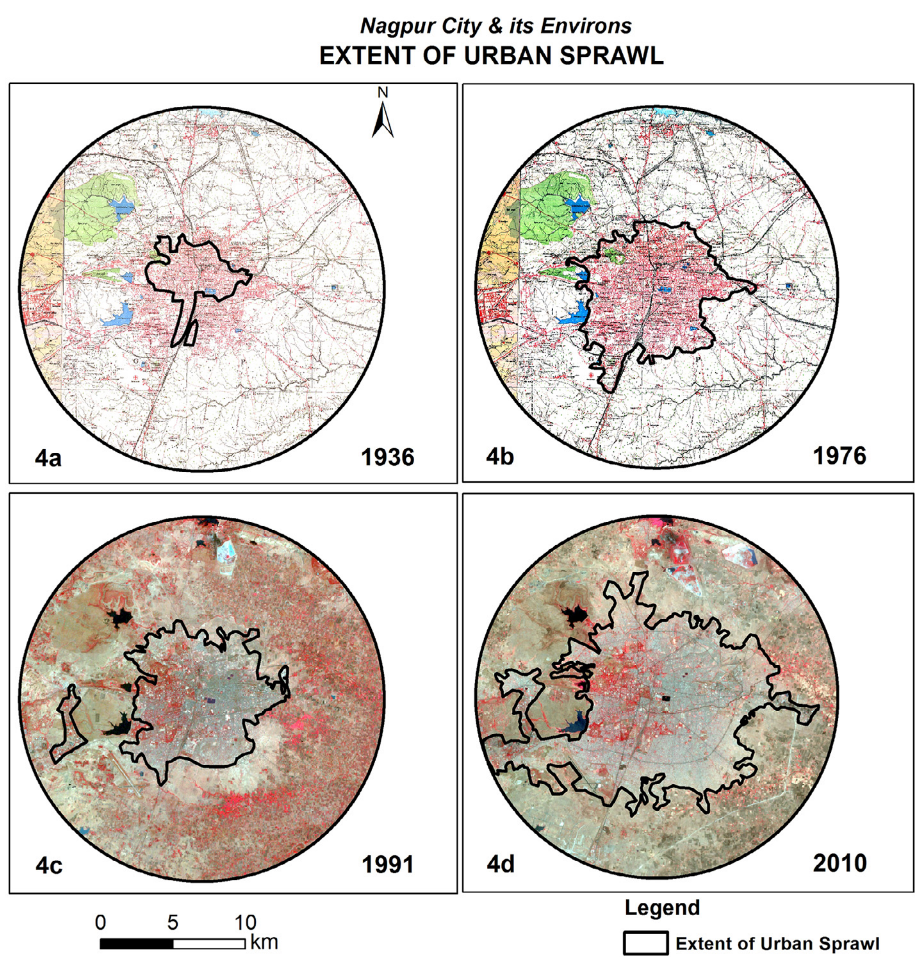

Fig. 4. (a–d) Spatio-temporal dynamics of urban sprawl of Nagpur city and its environs during 1936, 1976, 1991 and 2010.

3.2. Status of urban sprawl in 1976

The topographic sheets for the year 1976 have been used to map and analyzed urban sprawl (Fig. 4b). The analysis of urban sprawl over a period of 40 years from 1936 to 1976 shows that the urban areas have been increased considerably from 2272 ha to 7855 ha. The analysis indicates that the urban area was increased by nearly 71.0 per cent in almost all the directions, but more particularly along the highways leading to Wardha, Bhandara and Amravati. The availability of transport facilities, favorable terrain conditions and industrial development might be some of the reasons for this urban sprawl. It was observed that in comparison to the west, the urban growth of Nagpur city was more in southern and eastern parts of the city. In the process of urban sprawl, the peri-urban agricultural lands have been converted into urban settlements.

3.3. Status of urban sprawl in 1991

The analysis of Landsat 5 TM data (30 m) for the year 1991 clearly indicates that the development of urban sprawl at the cost of permanent fallows and peri-urban agriculture areas. The extent of urban sprawl in the year 1991 shows that it was extended in almost all the directions more particularly in southern and eastern parts of the city (Table 4 and Fig. 4c). Medium dense settlements have been mainly observed in southern and northern parts of the city. Permanent follows occupy predominantly in western, northern and southern parts of the study area with an area of 28.5 per cent of TGA. Analysis of peri-urban agriculture component of urban landscape of Nagpur city shows that single and double cropped areas are predominantly noticed in eastern, northern and southern parts with an area of 15.5 and 16.1 per cent of TGA. The analysis of Landsat 5 TM data of 1991 also shows that the development of industrial corridor in the western part of the city. Settlements development could be observed in the southwest part of Nagpur city leading to Hingna town, which has become an educational hub with various new Engineering and Medical institutions come up in this period.

3.4. Status of urban sprawl in 2010

The land use/land cover and spatial patterns of urban sprawl derived from the analysis of Landsat 5 TM data of 30 m resolution for the year 2010 are shown in Table 4 and Fig. 4d. Permanent follows mainly noticed in western and southern parts with an area of 22.5 per cent and single cropped area occupy mainly in eastern and northern parts with an occupy 21.8 per cent of TGA. The analysis clearly indicates that the development of urban sprawl took place at the cost of peri-urban permanent fallows, degraded scrublands and double cropped areas. The low dense settlements have been developed along the Hingna road and industrial corridor along the ring road in the western part of the Nagpur city. The area analysis has been carried out for each class to assess their spatial extent of land use/land cover classes in the study area.

3.5. Urban sprawl of Nagpur city between 1991 and 2010

The spatio-temporal dynamics of urban sprawl of Nagpur city derived from temporal satellite data for the period 1991 and 2010 shows that high dense settlement area is highly compact and mainly confined to the eastern part of Nagpur city. It predominantly consists of commercial and domestic areas, which occupies about 3.5 per cent in 1991 and increased to 10.1 per cent in the year 2010 (Table 4 and Fig. 5a and b). These developments were mainly observed in western, southern and northern parts of the city (Plate 1a) at the cost of permanent fallows and medium dense settlements (Table 5). Analysis of medium dense settlement areas shows that significant area has been increased from 3.4 to 13.1 per cent of TGA during the same period. It was noticed in almost all directions of Nagpur city at the cost of permanent fallows and low dense settlements (Table 5). It was observed that many areas of low dense settlements of 1991 have been converted into medium dense settlements in the processes of urban sprawl. Analysis shows that low dense settlements spread around the Nagpur city (Plate 1b) in all the directions and predominantly consists of commercial and industrial areas, which are coming up mainly in peri-urban double and single cropped areas and permanent fallows (Table 5). Development of new colonies and establishment of new industrial areas in peri-urban region increases the low dense settlement areas around the Nagpur city. When compared to 1991, the low dense settlement area has been increased from 6.5 to 6.6 per cent of the area.

Analysis shows that double cropped area in the peri-urban region is mainly noticed in eastern parts and to some extent northern and southern parts of Nagpur city area. The double cropped area has been reduced significantly from 16.1 to 4.5 per cent of TGA (Table 5 and Fig. 5a and b) due to development of industrial, commercial and residential areas (Table 5). Single cropped area in the peri-urban region mainly grows vegetables and some extent food grains to meet the demands of city population. These areas have been noticed mainly in eastern, northern and southern parts of city area. Interestingly, area under single cropped area has been increased from 15.5 to 21.8 per cent of TGA. Conversion of double

Table 4
Land use/land cover classes of Nagpur and its environs for the year 1991 and 2010.

S. No.	Land use/land cover class	1991		2010		% Area change
		Area (in ha)	% Area	Area (in ha)	% Area	
1	High dense settlements	1771.8	3.5	5036.3	10.1	6.6
2	Medium dense settlements	1712.3	3.4	6532.4	13.1	9.7
3	Low dense settlements	3261.1	6.5	3289.4	6.6	0.1
4	Double cropped area	8048.5	16.1	2227.2	4.5	−11.6
5	Single cropped area	7750	15.5	10923.5	21.8	6.3
6	Permanent fallows	14241.4	28.5	11243.3	22.5	−6
7	Degraded deciduous forest	3744.3	7.5	5244.8	10.5	3
8	Degraded scrublands	8198	16.4	2754.6	5.5	−10.9
9	Urban vegetation	321.2	0.6	583.5	1.2	0.6
10	Mining area	144	0.3	929.7	1.9	1.6
11	Infrastructure	393.9	0.8	742.2	1.5	0.7
12	Water bodies	449	0.9	530.6	1.1	0.2
	Total	**50035.5**	**100**	**50035.5**	**100**	

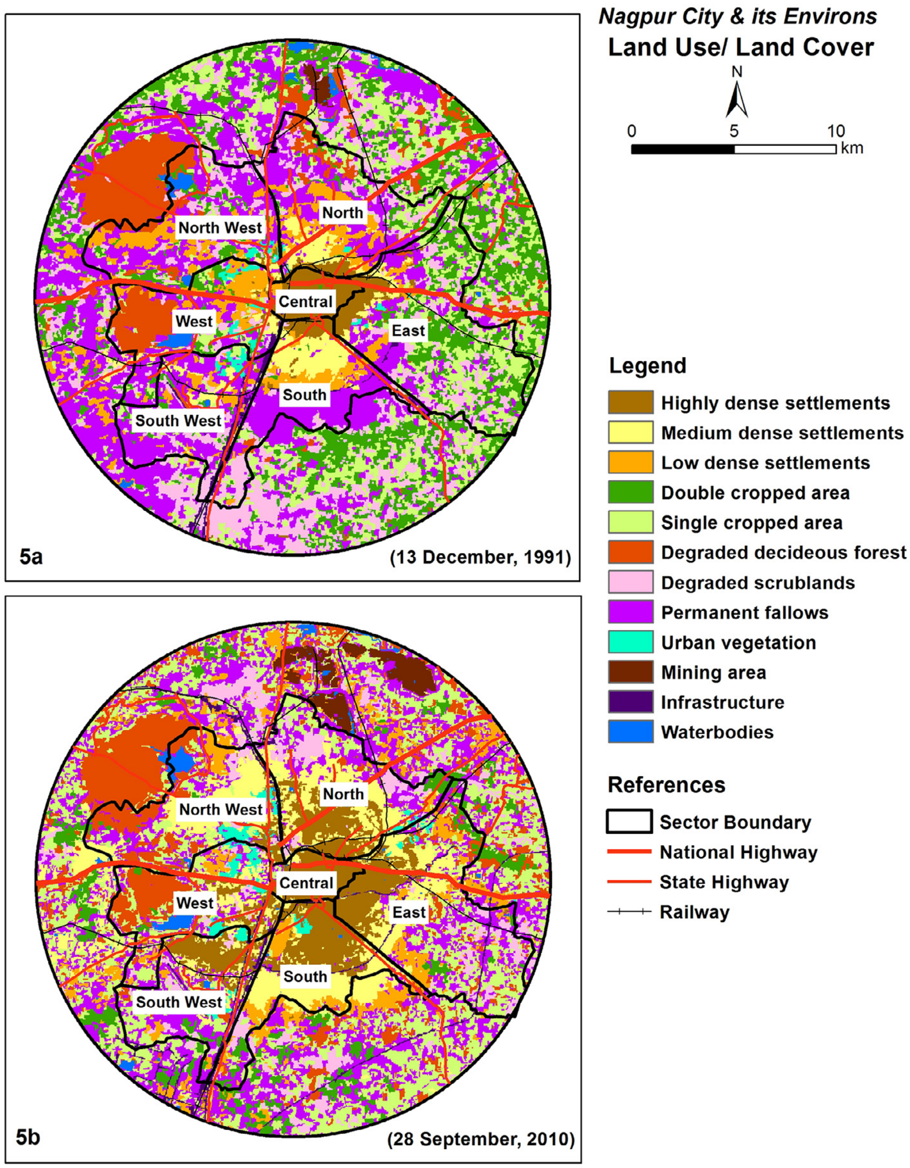

Fig. 5. (a and b) Spatio-temporal dynamics of land use/land cover dynamics of Nagpur city and its environs during 1991 and 2010.

cropped area and permanent fallows into single cropped area in the peri-urban region could be one of the reasons.

Analysis shows that the permanent fallows are mainly noticed in western parts of the city and occupy 28.5 per cent in the year 1991, whereas, it has been considerably decreased to 22.5 per cent in the year 2010 (Table 4 and Fig. 5a and b). The area under degraded scrubland areas has been considerably decreased from 16.4 per cent in 1991 to 5.5 per cent in the year 2010 and presently confined to southern and northern parts of the city. The area under urban vegetation occupies 0.6 per cent in 1991 and in absolute terms it has been increased to 1.2 per cent in the year 2010 mainly in western and southern part of the city. The increased area under open cost mining from 0.3 per cent in the year 1991 to 1.9 per cent in the year 2010 could be noticed in northern part of Nagpur city. The area under water bodies occupies 0.9 per cent in 1991 and it has been slightly increased to 1.1 per cent in the year 2010 and in absolute terms gained the area from single cropped area and permanent fallows. It is observed that in the year 2010, the eastern and southern sides of the city have recorded more urban growth as compared to the urban growth noticed in the year 1991. The city has witnessed urban growth and development in north-east, north-west, west and south from the core of the city. The two major National Highways of India ie., NH-7 (North to south) and NH-6 (West to east) passes through the Nagpur city, which serve as major transportation corridors in development of urban sprawl (Plate 1c). The mega establishments like Multimodal International Hub Airport at Nagpur (MIHAN) and International Airport already stimulated the growth of urban development and provide other urban amenities to meet the needs of the working population in and around these establishments. In the context of upcoming metro rail project, many industrial, educational and residential colonies coming up, future growth of urban landscape of Nagpur city is likely to be rapid in north-southern and east-west corridors at the cost of peri-urban agriculture and degraded scrublands.

3.6. Assessment of urban sprawl across the urban development sectors

The analysis of land use/land cover at sector level for the year 1991 shows that majority of highly dense settlements are in central sector, whereas in the year 2010 area under these settlements has been increased considerably in, north, south, south-west and eastern sectors (Table 6). Majority of the double and single cropped

Plate 1a

Plate 1b

Plate 1c

Plate 1. (a) High density settlements in central part of the city, (b) Low density settlements in central part of the city and (c) Road network development in southern part of Nagpur city.

Table 5
Spatio-temporal dynamics of land use/land cover classes of 1991 and 2010 of Nagpur city and its environs.

	Land use/ Land cover class	Land use/Land cover classes of 2010													
		High dense settlement	Medium dense settlement	Low dense settlement	Double cropped area	Single cropped area	Perma-nent fallow	Degraded deciduous forest	Degraded Scrublands	Urban Vege-tation	Mining area	Infra-structure	Water bodies	Total	Loss
Land use/ Land cover classes of 1991	High dense settlement	**1406**	143.3	31	4.9	48.5	99	7.4	7.9	5.6	17.6	35.6	15.2	**1771.8**	−**365.9**
	Medium dense settlement	1111.5	**263.5**	122.6	81.1	53.9	76.2	6.5	25.2	39.3	0	5.9	7.3	**1712.3**	−**14448.8**
	Low dense settlement	85.6	1153.9	**80.95**	63.1	193.3	379.3	252.5	89.8	140.9	0	13.1	20.6	**3261.1**	−**3180.2**
	Double cropped area	94.8	342.1	363.6	**388.4**	3030	2201.9	1017.5	400.2	69.2	48.4	60.3	31.8	**8048.5**	−**7659.8**
	Single cropped area	83.5	422.4	522.85	415.1	**2418**	2338.2	542.3	727	71.2	104.2	78.7	26.6	**7750.0**	−**5332**
	Permanent fallow	1102.9	3259.4	1264.1	683.6	2409.9	**3198.1**	702.2	811.4	129.1	426.1	208.4	46.4	**14241.4**	−**11043.4**
	Degraded deciduous Forest	17.5	665	95.2	223.11	653	435.5	**2225.6**	75.7	1.9	60.1	5.4	44.8	**3744.3**	−**1518.7**
	Degraded scrublands	186.5	772.7	760.1	589.5	2014	2449.1	460.1	**578.1**	79.9	145.9	145.2	17.6	**8198**	−**7620.7**
	Urban vegetation	120.7	42.6	19.7	0.5	25.7	24.8	4.3	31	**46.2**	0	6.8	0.0	**321.2**	−**275.5**
	Mining area	0.4	0	2	0.0	19	20.5	9.8	0.4	0	**83.7**	0	8.3	**144.0**	−**60.3**
	Infrastructure	39.8	52.9	22.2	0.0	29.8	50.8	7.5	6	0.3	0	**182.9**	1	**393.9**	−**211.1**
	Water bodies	17.3	13.7	5.2	0.0	28.4	20.4	9.4	1	0	42.8	0	**311**	**449.0**	−**138.1**
	Total	**5036.3**	**6532.4**	**3289.4**	**2227.2**	**10923.5**	**11243.3**	**5244.8**	**2753.6**	**583.5**	**928.7**	742.2	**530.6**	**50035.5**	-
	Gain	**3636**	**6269**	**3209**	**1813**	**8505**	**8045**	**3019**	**2176**	**537**	**845**	559	**220**	-	-

Note: The values in bold in the diagonal indicate no change in area of the land use/land cover classes in the year 2010 with respect to year 1991. The values in bold shown under gain and loss columns indicate net gain or net loss of land use/land cover classes in the year 2010 with respect to year 1991.

Table 6
Land use/land cover changes within urban development sectors for year 1991 and 2010.

Cluster	East		South West		West		North West		North		Central		South	
	1991	2010	1991	2010	1991	2010	1991	2010	1991	2010	1991	2010	1991	2010
Highly dense settlement	415	914	16	611	56	396	41	166	166	1082	714	691	242	1038
Medium dense settlement	210	964	178	374	141	532	45	1126	410	1223	3	44	640	975
Low dense settlement	187	478	212	114	612	180	730	170	661	49	48	0	426	398
Double cropped area	1466	208	137	70	251	39	382	48	255	90	3	0	48	83
Single cropped area	1408	1164	207	551	241	477	244	630	373	352	0	23	87	107
Permanent fallows	1048	1198	1439	765	792	504	1524	637	1413	700	12	23	1159	210
Degraded deciduous forest	14	341	73	102	694	702	348	775	265	45	0	6	27	36
Degraded scrublands	966	353	461	146	256	111	534	140	506	471	2	5	379	113
Urban vegetation	38	45	87	94	115	202	58	156	24	35	0	0	0	49
Mining area	0	0	0	0	0	0	0	0	5	5	0	0	0	0
Infrastructure	23	102	195	163	29	27	0	34	0	12	6	6	84	77
Water bodies	0	8	7	20	119	137	110	132	1	10	26	15	0	5

Table 7
Error matrix and accuracy assessment of land use/land cover classification using Landsat TM data of 2010.

LULC Class	1	2	3	4	5	6	7	8	9	10	11	12	Total	User Accuracy
1	10	0	0	0	0	0	0	0	0	0	0	0	**10**	**100.0**
2	0	8	3	0	0	0	0	0	0	0	1	0	**12**	**66.7**
3	0	0	7	0	0	0	0	0	0	0	0	0	**7**	**100.0**
4	0	0	0	8	0	0	0	0	0	0	0	0	**8**	**100.0**
5	0	1	0	0	10	0	1	0	1	0	1	0	**14**	**71.4**
6	0	0	0	0	0	10	1	1	0	0	0	0	**12**	**83.3**
7	0	0	0	1	0	0	8	0	0	0	0	0	**9**	**88.9**
8	0	0	0	1	0	0	0	9	0	0	0	0	**10**	**90.0**
9	0	0	0	0	0	0	0	0	9	2	1	0	**12**	**75.0**
10	0	0	0	0	0	0	0	0	0	6	0	0	**6**	**100.0**
11	0	0	0	0	0	0	0	0	0	0	6	0	**6**	**100.0**
12	0	0	0	0	0	0	0	0	0	2	1	10	**13**	**76.9**
Total	**10**	**9**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**10**	**119**	
Producer Accuracy	**100**	**88.9**	**70**	**80**	**100**	**100**	**80**	**90**	**90**	**60**	**60**	**100**		**Total Accuracy 84.9**

Observed agreement: 101; chance agreement: 9.9; **Kappa: 0.835.**
1. Highly Dense Settlements, 2 Medium Dense Settlements, 3. Low Dense Settlements, 4. Double cropped area, 5. Single Cropped Area, 6. Degraded Deciduous Forest,7. Degraded Scrublands, 8. Permanent Fallows, 9 Urban Vegetation, 10. Mining Area, 11. Infrastructure, 12. Waterbodies.

areas are noticed in eastern sector with an area of 1466 and 1408 ha, respectively. Majority of permanent fallows are observed in north-west, south-west and northern sectors. The analysis of land use/land cover at sector level for the year 2010 shows that majority of highly dense settlements are in central sector. Majority of the single cropped areas are located in eastern sector with an area of 1164 ha. Majority of permanent fallows are located in northwest, south west and northern sector. Degraded scrublands are mainly noticed in eastern sector. The analysis shows that majority of medium dense settlements are converted into high dense settlements.

3.7. Accuracy assessment and validation

Accuracy assessment and validation was performed by generating error matrix for whether a known land use/land cover classes of 2010 was correctly classified or not. This process was carried out using 119 field survey points collected during field survey, which referred to one of twelve classes, as summarized in Table 7. Kappa coefficient (Khat) value of 0.83 indicates that an observed classification is in near perfect agreement to the order of 83 per cent. The overall accuracies were 84.9 per cent. User's accuracy of individual classes was consistently high and it ranges from 66.7 per cent to 100 per cent. Whereas, the producer's accuracy of individual classes ranging from 60.0 to 100 per cent. Analysis shows that the classes like highly dense settlements, single cropped area, degraded deciduous forest and waterbodies were clearly mapped due to their distinct pattern and compactness. Whereas, the classes like low dense settlements, mining area and infrastructure have shown slight ambiguity in classification. The factors contributing to the misclassification includes similar spectral information, the spatial resolution of the satellite imagery, class areas smaller than the spatial resolution of the Landsat 5 TM data etc. However, these classes could be mapped in detail using finer spatial resolution data, which is beyond the scope of the work presented here and it could be explored through future work in this area.

4. Conclusions

The analysis of spatio-temporal pattern of urban sprawl of Nagpur city shows that in the year 1936 the urban area of Nagpur city was about 2272 ha only, however, it has been increased to 7855 ha in the year 1976, 8129 ha in the year 1991 and 17344 ha in the year 2010. The analysis indicates that the urban area was increased in almost all the directions, more particularly along the highways of Wardha, Bhandara and Amravati. The availability of transport facilities, favorable terrain conditions and industrial development might be some of the reasons for this urban sprawl. The area under high dense settlements in the year 1991 is mainly confined to the eastern part of Nagpur city, however, in the year 2010, these areas have been developed in western and northern part of the city. Analysis of medium dense settlement areas of Nagpur city in the year 2010 shows that these areas are mainly confined to surrounding areas of high dense settlement areas of Nagpur city. It was observed that many areas of low dense settlements of 1991 have been converted into medium dense settlements in the processes of urban development. Low dense settlement areas come up mainly in peri-urban wastelands and agricultural areas. During the transition process considerable area of peri-urban agricultural area has been converted as either housing or industrial establishments. In accuracy assessment, Kappa coefficient (k) value of 0.83 indicates that an observed land use/land cover classification of 2010 is in near perfect agreement to the order of 83 per cent. The study demonstrates the potential of medium coarse resolution satellite data like Landsat 5 TM in monitoring the urban and peri-urban landscapes. The generated useful information in the study on various land use/land cover categories of urban and peri-urban landscape of Nagpur city could be effectively used for implementation of various urban planning activities for sustainable urban development. However, in future investigations, the high resolution temporal data, incorporation of zoning policies and development plans of the study would help to further improve the accuracy of the results, urban utilities planning, assess environmental impacts from the changes occurred through urban sprawl and preserve socio-environmentally important areas.

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References

Ahmad, F., Goparaju, L., 2016. Analysis of urban sprawl dynamics using geospatial technology in Ranchi City, Jharkhand, India. J. Environ. Geog. 9 (1–2), 7–13.
Aithal, B.H., Ramachandra, T.V., 2016. Visualization of urban growth pattern in chennai using geoinformatics and spatial metrics. J. Indian Soc. Remote Sens. 44, 617–633.

Alberti, M., Booth, D., Hill, K., Marzluff, J., Avolio, C., Coe, S., Donelly, R., Spirandelli, D., 2000. The Impacts of Urban Patterns on Ecosystem Dynamics. Univ. Washington, Seattle, WA.
Alqurashi, A., Kumar, L., Sinha, P., 2016. Urban land cover change modelling using time-series satellite images A case study of urban growth in five cities of Saudi Arabia. Remote Sens. 8, 838.
Bagan, H., Yamagata, Y., 2014. Land-cover change analysis in 50 global cities by using a combination of Landsat data and analysis of grid cells. Environ. Res. Lett. 9, 1–13.
Banzhaf, E., Grescho, V., Kindler, A., 2009. Monitoring urban to peri-urban development with integrated remote sensing and GIS information A Leipzig, Germany case study. Int. J. Remote Sens. 30 (7), 1675–1696.
Bhatta, B., 2010. Analysis of urban growth and sprawl from remote sensing data. In: Book series on Advances in Geographic Information Science. Springer-Verlag, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-05299-6_2.
Blaschke, T., Strobl, J., 2001. What's wrong with pixels? Some recent developments interfacing remote sensing and GIS. GIS–Zeitsch Geoinfor. 14, 12–17.
Cao, H., Liu, J., Fu, C., Zhang, W., Wang, G., Yang, G., Luo, L., 2017. Urban expansion and its impact on the land use pattern in xishuangbanna since the reform and opening up of China. Remote Sens. 9, 137.
Cohen, J., 1960. A coefficient of agreement for nominal scales. Educ. Psychol. Meas. 20, 37–46.
Cheng, J., Masser, I., 2003. Urban growth pattern modelling a case study of Wuhan City PR China. Landscape Urban Plan. 62, 199–217.
Deng, J., Wang, K., Hong, Y., Jia, G., 2009. Spatio-temporal dynamics and evolution of land use change and landscape pattern in response to rapid urbanization. Landscape Urban Plan. 92, 187–198.
Ellis, J.G., 2004. Explaining residential density. Places 16 (2), 34–43.
Epstein, J., Payne, K., Kramer, E., 2002. Techniques for mapping suburban sprawl. Photogramm. Eng. Remote Sens. 63 (9), 913–918.
Ermer, K., Mohrmann, R., Sukopp, H., 1994. Stadt und umwelt. In: Buchwald, K., Engelhardt, W. (Eds.), Band 12 des Handbuches "Umweltschutz – Grundlagen und Praxis". Economica Verlag, Bonn, p. 125.
Estoque, R.C., Murayama, Y., 2015. Intensity and spatial pattern of urban land changes in the megacities of Southeast Asia. Land Use Policy 48, 213–222.
Estoque, R.C., Murayama, Y., 2016. Quantifying landscape pattern and ecosystem service value changes in four rapidly urbanizing hill stations of Southeast Asia. Landscape Ecol. 31, 1–27.
Fan, C., Myint, S.W., Rey, S.J., Li, W., 2017. Time series evaluation of landscape dynamics using annual Landsat imagery and spatial statistical modeling evidence from the Phoenix metropolitan region. Int. J. Appl. Earth Obs. Geoinf. 58, 12–25.
Hay, G.J., Castilla, G., 2008. Geographic object-based image analysis (GEOBIA) a new name for a new discipline. In: Blaschke, T., Lang, S., Hay, G. (Eds.), Object Based Image Analysis. Springer, Heidelberg, Berlin, New York, pp. 93–112.
Jat, M.K., Garg, P.K., Khare, D., 2008. Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. Int. J. Appl. Earth Obs. Geoinf. 10, 26–43.
Jayaprakash, M., Senthil Kumar, R., Giridharan, L., Sujitha, S.B., Sarkar, S.K., Jonathan, M.P., 2015. Bioaccumulation of metals in fish species from water and sediments in macrotidal Ennore creek, Chennai, SE coast of India A metropolitan city effect. Ecotoxicol. Environ. Saf. 120, 243–255.
Lata, K.M., Sankar Rao, C.H., Krishna Prasad, V., Badrinath, K.V.S., Raghavaswamy, V., 2001. Measuring urban sprawl a case study of Hyderabad. GIS Dev. 5 (12).
Liu, F., Zhang, Z., Wang, X., 2016. Forms of urban expansion of Chinese municipalities and provincial capitals, 1970s–2013. Remote Sens. 8, 930.
Maji, A.K., Nayak, D.C., Krishna, N.D.R., Srinivas, C.V., Kamble, K., Reddy, G.P.O., Velayutham, M., 2001. Soil information system of arunachal pradesh in a GIS environment for land use planning. Int. J. Appl. Earth Obs. Geoinf. 3, 69–77.
Maji, A.K., Reddy, G.P.O., Sarkar, D., 2010. Degraded and Wastelands of India, Status and Spatial Distribution. ICAR and NAAS Publication, pp. 1–158.
Mertes, C., Schneider, A., Sulla-Menashe, D., Tatem, A., Tan, B., 2015. Detecting change in urban areas at continental scales with MODIS data. Remote Sens. Environ. 158, 331–347.
Rahman, A., Agarwal, S.P., Netzband, M., Fazal, S., 2011. Monitoring urban sprawl using remote sensing and GIS techniques of a fast growing urban centre. India IEEE J. Sel. Top. Appl. Earth Obs. Remote Sens. 4 (1), 56–64.
Reddy, G.P.O., Sarkar, D., Prasad, J., Ramamurthy, V., 2013. Geospatial modeling in assessment of biophysical resources for sustainable land resource management. Trop. Ecol. 54 (2), 227–238.
Reddy, G.P.O., Patil, N.G., Chaturvedi, A. (Eds.), 2017. Sustainable Management of Land Resources- An Indian Perspective. Apple Academic Press, USA, pp. 769.
Simmons, C., 2000. Ecological footprint analysis A useful method for exploring the interaction between lifestyles and the built environment. Routledge, London, pp. 223–235.
Sudhira, H.S., Ramachandra, T.V., Jagadish, K.S., 2003. Urban sprawl pattern recognition and modelling using GIS. Paper presented at Map India, 2003, New Delhi. January 28–31.
Sudhira, H.S., Ramachandra, T.V., Jagadish, K.S., 2004. Urban sprawl metrics, dynamics and modelling using GIS. Int. J. Appl. Earth Obs. Geoinf. 5, 29–39.
TCPA, 2003. TCPA Policy Statement Residential Densities. Town and Country Planning Association (TCPA), London.
United Nations, Department of Economic and Social Affairs, Population Division, 2014. World urbanization prospects the 2014 revision, highlights (ST/ESA/SER. A/352). (accessed 05.07.17).
United States Geological Survey, 2010. Earth explores. Available https://earthexplorer.Usgs.Gov/ (accessed 10.08.10).
Van Rooijen, D.J., Turral, H., Wade Biggs, T., 2005. Sponge city water balance of mega-city water use and wastewater use in Hyderabad India. Irrig. Drain., 54
Whiteside, T.G., Boggs, G.S., Maier, S.W., 2011. Comparing object-based and pixel-based classifications for mapping savannas. Int. J. Appl. Earth Obs. Geoinf. 13, 884–893.
World Bank Group, 2015. Global Economic Prospects, June 2015 The Global Economy in Transition. World Bank Group, Washington, DC. 10.1596/978-1-4648-0483-0.
Yan, G., Mas, J.F., Maathuis, B., Xiangmin, Z., Van Dijk, P., 2006. Comparison of pixel-based and object-oriented image classification approaches A case study in a coal fire area, Wuda, Inner Mongolia, China. Int. J. Remote Sens. 27, 4039–4055.
Yeh, A.G.O., Li, X., 2001. Measurement and monitoring of urban sprawl in a rapidly growing region using entropy. Photogramm. Eng. Remote Sens. 67 (1), 83.
Zhu, X., Zhang, H., Pang, G., 2008. A change detection method with high resolution images based on polygon automatic validating. Int. Arch. Photogramm. Remote Sens. Spatial Inf. Sci. XXXVII (Part B7), 841–846.