Centre for Research on Settlements and Urbanism

Journal of Settlements and Spatial Planning

Journal homepage: http://jssp.reviste.ubbcluj.ro

Spatial Monitoring of Urban Growth of Nagpur City (India) Using Geospatial Techniques

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K e y w o r d s: *geospatial techniques, land use/cover, urban expansion, change detection, directional expansion*

A B S T R A C T

This study illustrates the use of remote sensing and geographic information system (GIS) techniques (i.e. geospatial techniques) for mapping and evaluating urban sprawl in the case of Nagpur city, Maharashtra (India). We used the Landsat Thematic Mapper (TM) imagery of 1998 and 2010 for quantifying land use/cover and urban growth changes. Maximum likelihood algorithm was used to classify satellite images in ERDAS Imagine software. The spatial analysis of urban sprawl was performed in Arc GIS package using change detection, change matrix and road buffering. The results obtained from the classified Landsat TM image of year 1998 revealed that the total built-up area of Nagpur city was of 83.11 km² (34.53 % of total geographical area of a city) and increased up to 120.29 km² (50.0 %) in 2010. Therefore, the spatial expansion of built-up area over a 12 year period (from 1998 to 2010) was estimated at 37.18 km². The study also reveals that the built-up area has maximally expanded towards east, with about 8.94 km², whereas the minimum expansion has occurred towards west, with about 2.6 km². This paper also highlights the changes in other land cover categories during the period under analysis. This study may provide reliable inputs for urban planners who are planning to provide basic amenities such as water, sanitation, electricity, etc. in the Nagpur city.

1. INTRODUCTION

Urban expansion or sprawling is the greatest challenge of this century in the developing countries where it takes place due to rapid population growth, economic development and infrastructural development initiatives.

Urban sprawl has always remained an important area of research in academic circles over the world [1]. Gordon and Richardson (1997) have described urban sprawl as a leapfrog development. This phenomenon usually takes place either in radial direction around city center or linear direction along the highways and drives the change in land use patterns [2], [3].

The global urban population has increased from 13% (220 million in 1900) to 49% (3.2 billion in 2005) and it is projected to escalate to 60% (4.9 billion) by 2030 [4]. Urban sprawl has been criticized for the inefficient use of land resources and energy and large-scale encroachment on agricultural land [5]. Several scholars have criticized this phenomenon for the loss of open space, environmental damage, loss of surface water, depletion in groundwater, loss of biodiversity and increased congestion [7], [8], [9], [10]. The unplanned urban growth and expansion has had serious impacts on the urban ecosystem and on the sustenance of natural resources [6].

Rapid urbanization with high population density often face severe crisis due to inadequate infrastructure and lack of basic amenities. In order to achieve proper management of urban sprawling, the measurement, mapping and monitoring of urban sprawl are crucial for government officials and planners in any region. The reliable and updated information on spatio-temporal pattern of urban sprawl is a perquisite for the sustainable urban development planning and management. Other scholars have considered the built-up as the parameter for quantifying urban sprawl [11], [12].

The use and application of remote sensing and GIS in urban development, sprawl analysis and sustainable planning form a major field of research all over the world among the researchers [13]. The application and use of Remote Sensing and GIS provide an alternative for urban sprawl to be effectively mapped and monitored [14].

Remote sensing and GIS techniques are useful in identifying pattern, extent, nature and rates of urban sprawl. This technology has emerged as a popular viable substitute due to its cost effectiveness and technological soundness [15] and that offers permanent and authentic record of spatial patterns [16]. The repetitive data acquisition, synoptic view and formats processed by computers have made remotely sensed products suitable for change detection applications.

The convergence of GIS, remote sensing and database management systems has helped in quantifying, monitoring, modeling and subsequently predicting this phenomenon. A number of studies on urban sprawl were attempted in the developed countries [17], [18], [19].

Many remote sensing techniques have been developed for change detection [20], [21], [22] but there is no consensus as to a single technique/algorithm that is universally applicable. The most commonly used change-detection methods are either spectrally based (image-to-image) or classification-based (map-to-map) method [23], [24], [25].

Most urban land use/land cover change and sprawl studies utilized Landsat data due to the uniqueness of the dataset as the only long-term digital archive with a medium spatial resolution and relatively consistent spectral and radiometric resolution. Urban change studies using Landsat Multispectral Scanner (MSS) or Landsat Thematic Mapper (TM) data have been conducted at a regional scale encompassing either several urban areas [26] or a single metropolitan area [27].

Recently, long-term urban land use/land cover change (over two decades or longer) have been studied using the methodology of post-classification comparison using the Landsat archive as a baseline data source [28], [29]. Rawat et al. (2013, 2014) carried out a study on land use/land cover of five major towns (i.e. Ramnagar, Nainital, Bhimtal, Almora, Haldwani) of Kumaun Himalaya in Uttarakhand (India). Based on 20 years of satellite data from 1990 to 2010 of land use/land cover change, they found that built up area has sharply increased due to the construction of new buildings on agricultural and vegetation lands [30], [31], [32], [33], [34].

Keeping in view the potential of remote sensing and GIS in urban sprawl studies and their importance in urban development planning, present study is an attempt to measure the urban expansion or sprawl and analyze their spatial pattern and dynamics of Nagpur city (India) during the period from 1998 to 2010 using integrated approach of remote sensing and GIS.

2. THEORY AND METHODOLOGY

2.1. Objectives

The study was undertaken with the following objectives:

- to map out and quantify the urban sprawl;
- to detect changes in urban sprawl comparing satellite images of Landsat TM of 1998 and 2010 and analyze spatio-temporal dynamics of urban sprawl;
- to measure urban sprawl along the major roads;
- to identify the directional growth of built up area.

2.2. Study area

Nagpur city, Maharashtra (India) is located between 21° 2' 59" N to 21° 13' 57" N latitudes and 78° 59' 29" E to 78° 12' 13" E longitudes (fig. 1) with an altitude of 310 m above mean sea level. Nagpur is the largest city in central India and third largest city in Maharashtra after Mumbai and Pune. According to census 2011, Nagpur city has a population of 4,653,171 people. It is situated on the Deccan plateau of the Indian Peninsula and spread over an area of 239.33 km². Nagpur has tropical wet and dry climate with dry conditions prevailing most of the year. It registers an annual rainfall of 1,205 mm (47.44 inches) from monsoon rains from June to September. Summers are extremely hot, lasting from March to June, with May being the hottest month. Winter lasts from November to January, during which temperatures can drop below 10 °C (50 °F).

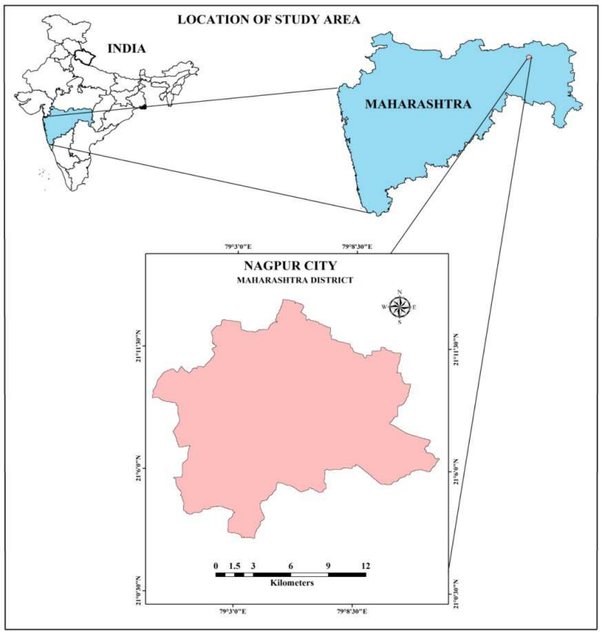

Fig. 1. Location map of the study area.

2.3. Data acquisition and preparation

Present study is based on analysis of Landsat Thematic Mapper (TM) images of dated 14 November 1998 and 15 November 2010. TM images have a resolution of 30 m, which is enough to provide information on urban expansion.

These satellite images were acquired from Global Land Cover Facility (GLCF). The Landsat data provided by Global Land Cover facility were radiometrically and geometrically corrected (ortho-rectified with UTM/WGS 84 projection). Initially, different bands of the Landsat images were stacked to get false color composite image.

The vector layers of Nagpur Municipal Corporation (NMC) boundary were used to subset the Landsat imageries from a complete scene. The subset images were then re-projected and co-registered to the UTM (WGS84) coordinate system with root mean square errors less than 0.4 pixels per image.

2.4. Image classification and data generation

The digital classification of the satellite images was required for the purpose of change detection and spatial pattern analysis.

Image classification is the process through which the total pixels in the image are categorized into a land use class or theme. In order to extract the land cover types and built-up area, the supervised digital image classification scheme was applied in this study. It is pertinent to mentioned that this technique is based on identification and location of land cover types known priori through a combination of field work and experience. Therefore, a field survey was conducted for collecting the training data. Survey of India topographic sheet, Landsat Thematic Mapper (TM) data and Garmin GPS 76 handset were used during the field survey. During the field work, we attempted to locate specific sites in the remotely sensed data that represent homogenous examples of these known land cover types known as training sites.

The past land use/ land cover information was gathered by informal interviews with the local people and the state government department. The GPS points were downloaded and overlaid on the imagery and used for further image processing in the laboratory. The clipped images (years 1998 and 2010) of study area were then classified using a Maximum likelihood algorithm, nonparametric parallelepiped classifier [35] in ERDAS Imagine software.

The training data collected from various training sites are applied to entire image during image classification processes. For better classification results some indices such as normalized difference vegetation index (NDVI), normalized difference water index (NDWI) and normalized difference built-up index (NDBI) were also applied. Multi-spectral pixels of the study area were classified and mapped into four broad land cover classes i.e., (1) water (4) forest (3) barren and 4) urban or built-up land.

The accuracy of classified map was assessed by randomly taking 150 points on the reference image. The accuracy assessment was computed using user, producer, overall and Kappa (Khat/K) statistics. Finally, the resultant classified images were vectored using raster to vector conversion tool with ERDAS IMAGINE software.

The pair-wise comparisons of the output maps as well as their statistical inventories were made. In order to land use/land cover change analysis during 1998 to 2010, a conversion matrix was generated in ENVI software. This matrix is frequently used to indicate the details of land-use conversion.

3. RESULTS AND DISCUSSION

3.1. Land cover status

To work out the land use/cover classification, supervised classification method with maximum likelihood algorithm was applied in the ERDAS Imagine 9.3 Software. The accuracy assessment of the classified images were performed in ERDAS imagine software and results obtained an overall accuracy of 91.29% for 1998 and 92.34% for 2010. The Kappa coefficients for 1998 and 2010 maps were of 0.893 and 0.841. Four land use/cover types were identified and used in this study, namely (1) built-up land (2) vegetation cover (3) barren land and (4) water bodies. Figure 2 and Table 1 reveal that in 1998, about 34.53% (83.11 km²) area of Nagpur municipal corporation (NMC) was under built-up land, 39.87% (95.96 km²) under vegetation, 24.18% (58.20 km²) under barren land and 1.42% (3.42 km²) was covered by water bodies.

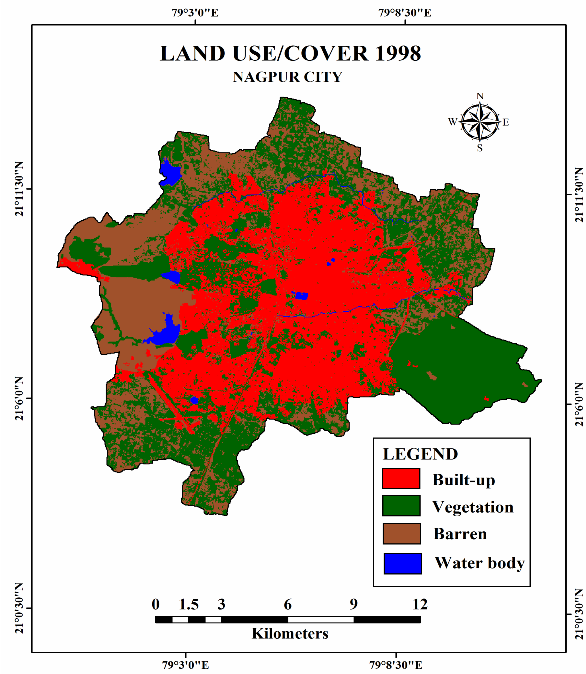

Fig. 2. Land use/land cover map of 1998.

In 2010 the area under these land cover classes was found 50.0% (120.29 km^2) under built-up land, 34.67% (83.46 km^2) under vegetation, 13.75% (33.12 km^2) under barren land and 1.58% (3.82 km^2) under water bodies (fig. 3).

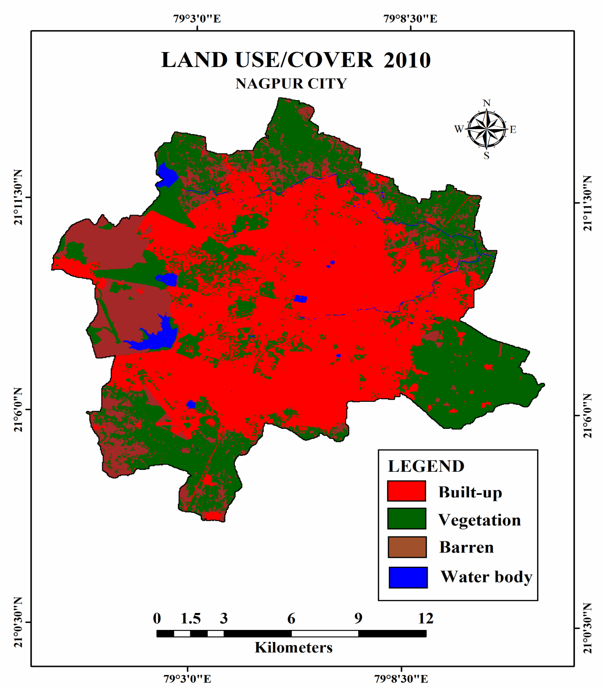

Fig. 3. Land use/land cover map of 2010.

Table 1. Land use/cover status and change of Nagpur city during 1998 to 2010.

Land use/cover category	1998		2010		Change during 1998 to 2010	
	km^2	(%)	km^2	(%)	km^2	(%)
Water body	3.42	1.42	3.82	1.58	0.40	0.16
Built up	83.11	34.53	120.3	50.0	37.18	15.47
Barren	58.2	24.18	33.12	13.75	-25.08	-10.43
Vegetation	95.96	39.87	83.46	34.67	-12.5	-5.2

3.2. Changes detection

In the past few decades a number of techniques have been formulated, applied, and evaluated for accomplishing change detection using satellite imagery. These techniques can be broadly grouped into two general categories [36], [37], [38]. First category of applied techniques is the based on spectral classification of the satellite image such as post-classification comparison [39] and direct two-date classification [40] and the second category is based on radiometric change between different acquisition dates, including image algebra methods such as band differencing [41]. Based on a mixture of categorical and radiometric change information, hybrid approaches have also been proposed and evaluated. The selection of an appropriate change-detection technique, in practice, often depends on the requirement of information, data availability and quality, time and cost constraints, and analysis skill and experience. Among those radiometric change-based approaches, change-vector analysis is a useful method for land use/land cover change detection because it not only can avoid the shortcomings of those type approaches, such as cumulative error in image classification of an individual date, but it can also find changed pixels using more, even all, the bands and provide “from-to” type of change information.

It is evident from the table 1 that both positive and negative changes occurred in the land cover pattern in the study area. During the last twelve years (1998-2010), the built-up area has increased by about 15.47% (37.18 km^2) of the total sprawl area (fig. 4). This dramatic increase in built-up area is the result of rapid population growth, continuous establishment of national and multinational companies and development of roads etc. during the study period of Nagpur city in the fringe area. During the study period vegetation cover has been decreased by 5.2% (12.5 km^2) of the total NMC area. The barren land has also decreased by about 10.43% (25.08 km^2) of the total municipal area. The vegetation and barren land are decreasing due to rapid increase in the built up area. The water body slightly increased up to about 0.16 % (0.40 km^2) of the total land cover area.

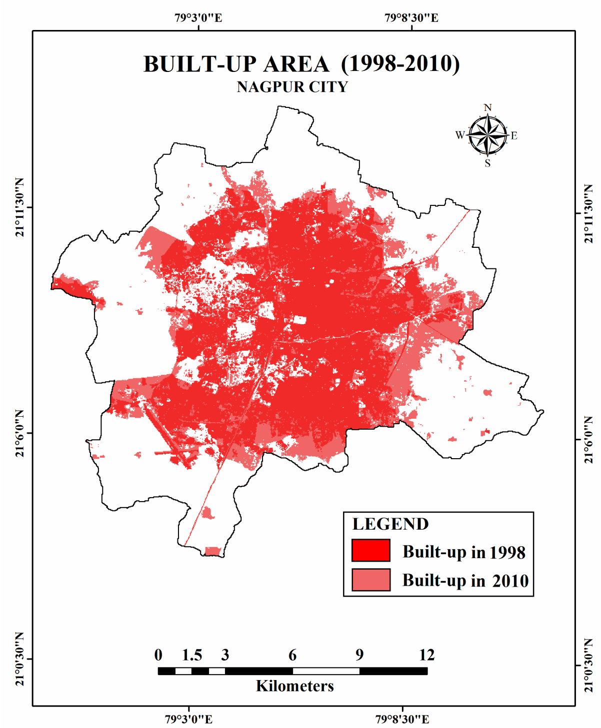

Fig. 4. Built-up area during 1998 and 2010.

3.3. Change detection matrix

To understand land encroachment in different land categories, we elaborated a change detection matrix (Table 2) and a map (fig. 5). The land encroachment matrix reveals that during 1998 to 2010:

a). About 0.42 km^2 of area of water body has been converted into built-up area, 0.05 km^2 area under barren land and 0.31 km^2 area into vegetative area.

b). About 0.66 km² area of barren land has been converted into water body, 14.39 km² area into built-up land and 19.72 km² area into vegetative area.

c). About 0.53 km² area of vegetation cover has been converted into water body, 22.38 km² area under built-up land, 9.63 km² area under barren land.

Table 2. Land use/cover change matrix showing land encroachment (in km²) of Nagpur city area.

Land use/cover Categories		1998			
		Water	Built Up	Barren	Vegetation
2010	Water	2.62	0	0.66	0.53
	Built Up	0.42	83.11	14.39	22.38
	Barren	0.05	0	23.43	9.63
	Vegetation	0.31	0	19.72	63.42

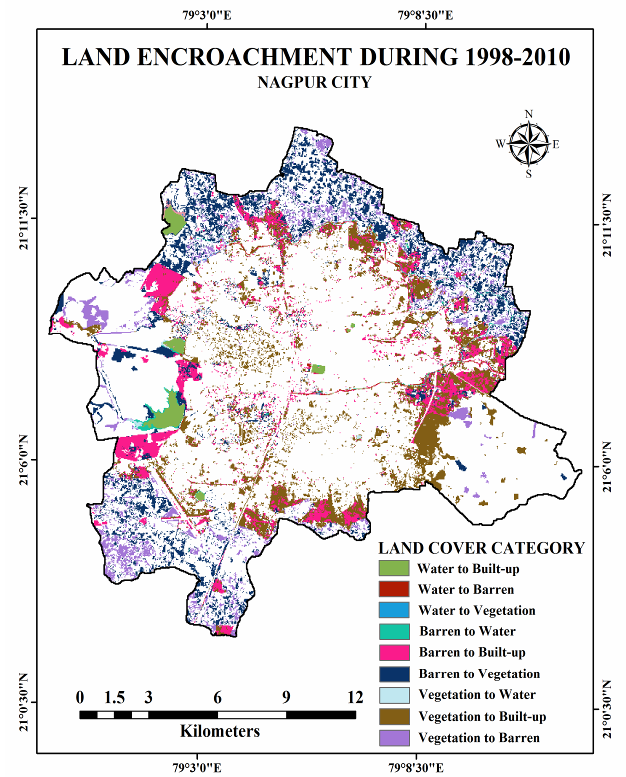

Fig. 5. Land Encroachment by various land cover categories during 1998 and 2010.

3.4. Directional change

The directional change of built-up area has been calculated from the heart of the city. The results are presented in figure 6, diagrammatically illustrated in figure 7 and also registered in Table 3.

During the research period, the built-up area has maximally expanded towards the eastern direction by about 8.94 km² while the minimum expansion has occurred towards the western direction which was of about 2.6 km². During the study period (1998-2010) the non-built-up land has been converted into built-up land maximally in the eastern direction at the rate of 0.75 km²/year and minimum in the western direction at the rate of 0.22 km²/year. The main reason behind the maximum growth towards the eastern direction was the availability of suitable land on which the built up area was expanded whereas in the western direction the maximum land is covered by water body which hinders the built up growth.

3.5. Urban expansion along major roads

Urban expansion processes in the Nagpur city during the period of 1998 to 2010 are further examined by analyzing a distance decay concept from major roads (fig. 8).

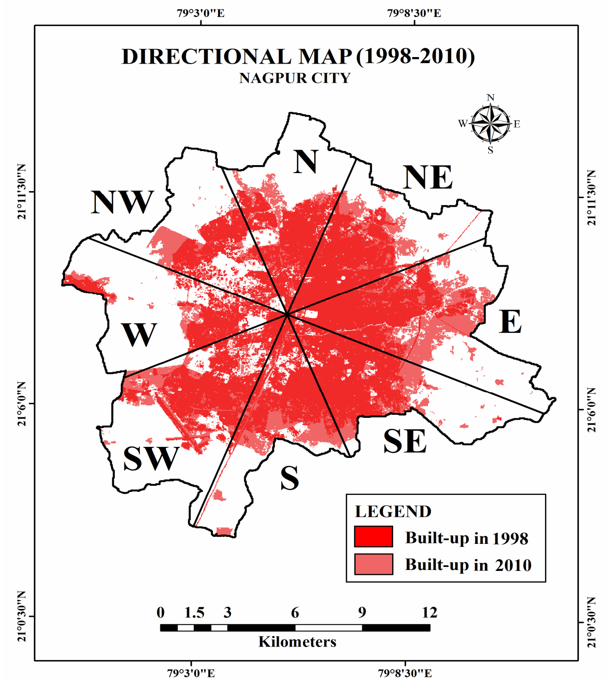

Fig. 6. Directional change in Built-up area during 1998 and 2010.

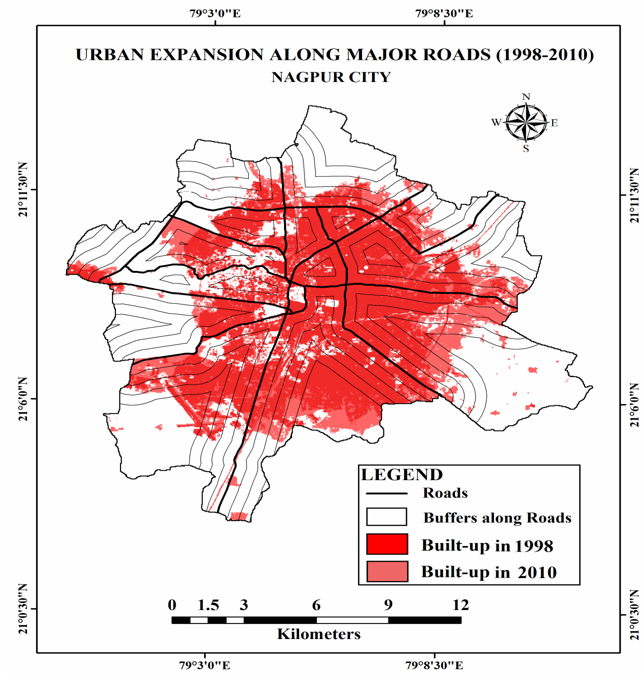

Fig. 7. Expansion of urban area along the major roads during 1998 and 2010.

For this purpose National Highway 6, National Highway 7, National Highway 69, State Highway 248, State Highway 255, State Highway 264 etc. has been taken for analysis. For analyzing urban expansion, four buffer zones were created along these roads with a width of 500 meters each.

The result indicates that the area and density under urban land is decreasing while going away from the major roads. Most urban expansion (48 %) can be observed within a distance of 500 m from major roads (Table 4).

The rate of expansion of built up area was maximum (1.13 km²/year) within a width of 500 meters from the major roads. The built up density is also higher which is of about 0.66 built up area/km² within a distance of 500 m.

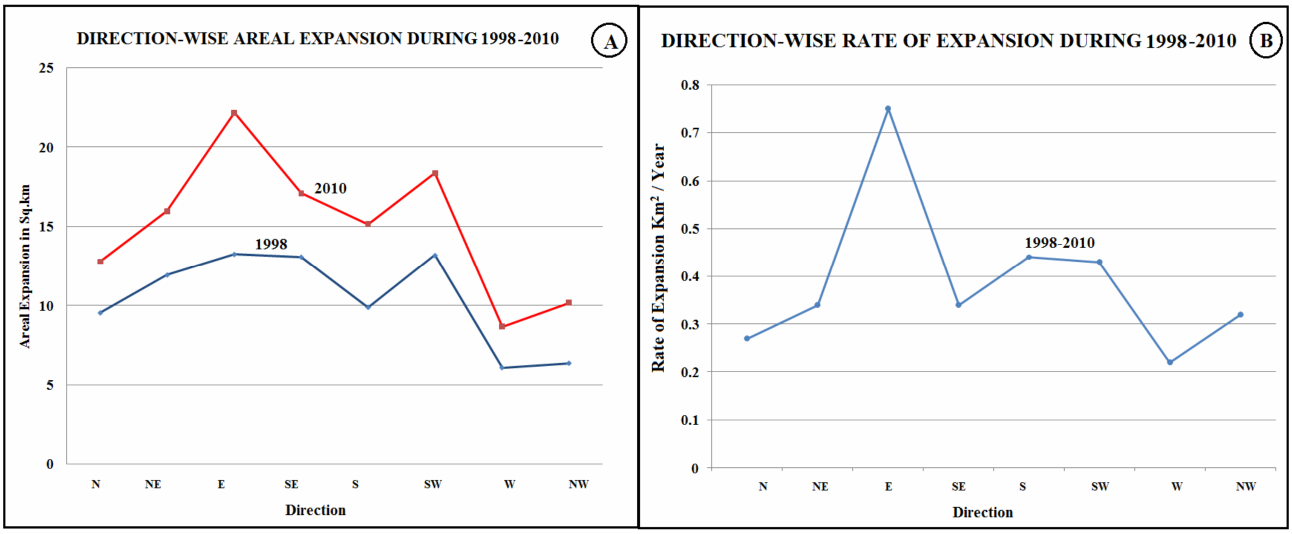

Fig. 8. Diagrammatic illustration of direction-wise Areal Expansion (A) and Rate of Expansion (B), of built-up area during the last two decades (1998-2010) in the Nagpur city area.

Table 3. Directional expansion of built up area (in km²) during 1998-2010.

Year	Direction							
	N	NE	E	SE	S	SW	W	NW
1998	9.51	11.91	13.23	13.06	9.86	13.16	6.05	6.33
2010	12.78	15.95	22.17	17.08	15.15	18.35	8.65	10.16
Change 1998-2010	3.27	4.04	8.94	4.02	5.29	5.19	2.6	3.83
Rate of expansion (km²/year)	0.27	0.34	0.75	0.34	0.44	0.43	0.22	0.32

Table 4. Nagpur City: Urban Expansion along Major Roads.

Proximity to road (m)	1998		2010		Change during 1998-2010	
	Urban Area (km²)	Urban Density (Urban area per km²)	Urban area (km²)	Urban density (Urban area per km²)	Urban area (Km²)	Rate of expansion of urban area (km²/year)
0-500	39.05	0.49	52.68	0.66	13.63	1.13
500-1000	22.21	0.41	32.86	0.61	10.65	0.88
1000-1500	10.65	0.30	16.13	0.46	5.48	0.45
1500-2000	5.51	0.23	8.71	0.36	3.2	0.26

4. CONCLUSION

The present study reveals that geospatial techniques play an important role in quantifying spatial and temporal phenomena. The study was conducted in one of the largest growing cities of the Maharashtra state. The study reveals that the major land use in the Kanpur city is the built-up area. During the period from 1998 to 2010, the area under built-up land has increased by 15.47% (37.18 km²). This increase in built-up area is due to construction of new buildings on vegetation and barren land. As a result, the area under vegetation, and barren land has decreased by 5.2% (12.5 km^2) and 10.43% (25.08 km^2) respectively, during the study period. The urban expansion along the major roads reveals that occupancy of area and built-up density are decreasing while going away from major roads. Approximately, half of urban expansion can be observed within a distance of 500 m from major roads while other half can be observed within a distance of 0 to 500 m. The approach adopted in this study clearly demonstrated the potential of GIS and remote sensing techniques in measuring change pattern of land use/cover in city area. The study not only provides the scientific way to understand the future urban growth but it also provides a methodology for assessing urban land use cost effectively and in less time period. The present study is useful for decision making process and helpful for planners and authorities to formulate suitable plan for sustainable urban development in the region.

5. ACKNOWLEDGEMENTS

The authors are thankful to the NRDMS Centre, Department of Geography, Kumaun University, SSJ Campus, Almora, Uttarakhand (India) and NRDMS Centre, Sultanpur (India) for their assistance and constant technical support.

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