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The Role of Geoinformation Technology for Predicting and Mapping Urban Change Detection: Wolaita Sodo town case study, Ethiopia

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Abstract

This study outlines the magnitude, rate and patterns of urban change over a period of 20 years using remotely sensed datasets with field work validation and integrated approaches of Remote Sensing and GIS tools. Remote sensing is a very useful tool for the affair of land use or land cover monitoring, which can be helpful to decide the allocation of land use and land cover. Mapping of LULC and change detection using remote sensing and GIS techniques is a cost effective method of obtaining a clear understanding of the land cover alteration processes due to land use change and their consequences. This study involves the assessment of land use or land cover changes beginning from the year 1999, 2009 and 2019 of Wolaita Sodo town. The study made use of Landsat imageries of 1999, 2009 and 2019. The images were classified using Maximum Likelihood classification algorithm in ERDAS IMAGINE 2014 and mapped using ArcGIS desktop 10.7. The images of the area have been categorized into five exceptional classes, specifically, agriculture, built-up, urban green, forest plantation and open space. The outcomes indicated that over the past 20 years, built-up land and forested land have been changed by 11.7% (1075.9ha.) and 6.5% (600.3 ha.) while agriculture, open areas and urban green have decreased by 5% (462.06), 5.6% (513.1 ha.) and 7.6% (700.4 ha.) respectively. The results indicated severe land use/cover changes over agricultural, built-up and unused open areas, constituted the most extensive type of land use/land cover in the study period. A number of factors such as socio-economic and political are responsible for the economic development and land use changes. The study reveals that that the town has experienced rapid changes in land use, particularly in terms of unplanned residential area and agricultural lands.

Article Info

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Keywords

Urban expansion, Land use/Land cover, GIS/Remote sensing, Change detection.

Introduction

Urbanization is an inevitable phenomenon, which put heavy pressure on land, reduces agricultural incomes and contributes excessive population increases in most developing countries of the world. The various natural and human induced environmental changes are of concern today because of deterioration of the environment and human health. Rapid urbanization and urban sprawl have significant impact on conditions of urban environments. The conversion of rural areas into urban areas through development is currently occurring at an unprecedented rate in recent human history and is having a marked effect on the natural functioning of ecosystems (Turner, 1994).

Land Use/land Cover change due to human activities is currently proceeding more quickly in developing

countries than in the developed world. Currently, changes in land use, especially in developing countries, have involved a decrease in the area of rural land use and an increase in the area of urban land use through urbanization (Dewan and Yamaguchi, 2009).

The continuous development of cities associated with more people pour into cities seeking variety of development opportunities. This has led the area of urban keep growing and area of forest, green and cultivated fields become reducing. This reality is very common in developing countries like Ethiopia where the rate of urbanization is exceeding 4.64 % annually(Samson*etal*, 2012).

Urban growth leads to the change of land use and land cover many areas around the world; especially in developing countries. Spatial distribution of land use land cover and its changes is desirable for any planning management and monitoring programmers at local and national levels. Land use and land cover change has become a central component in current strategies for managing natural resource and monitoring environmental changes. The study of land use/land cover (LU/LC) changes is very important to have proper planning and utilization of natural resources and their management.

Recent development in the use of satellite data is to take advantage of increasing amounts of geographical data available in combination with GIS to assist in interpretation. Geographic Information Systems within remote sensing have been useful as powerful and cost-effective tools for detecting and analyzing the spatio-temporal dynamics of processes and patterns of urban growth and land use/land cover change at local, regional, and global scales.

In particular, remote sensing based multitemporal land use change data provide information that can be used for assessing the structural variation of LULC pattern. In addition, accurate and comprehensive land use change statistics are useful for devising sustainable urban and environmental planning strategies. It is therefore very important to estimate the rate, pattern and type of LULC changes) in order to predict future changes in urban development. Thus, this study will attempt to identify the spatio-temporal pattern of LULC changes which occurred in WolaitaSodo town using satellite imagery periodically from 1999 to 2019 to understand the dynamical pattern of urbanization and identify key features for sustainable environmental management.

Study area

The study area, Sodo town is located in Wolaita zone of Southern Ethiopia. The town lies within the coordinates from 6^0 46' 00'' Northto $6^0$54' 0" North Latitude and 37^0 42' 00" East to 37^0 50' 00" East Longitude and it covers a total area of 91, 829 km2 (fig. 1). Regionally, the study area is located in Southern Ethiopia at a distance of 157 kms far from regional capital, Hawassa on the way to Addis Ababa -Arbaminch near Abaya, the southern rift valley lake. The area has been chosen because of the fast rate of urbanization and little studies were made on it. Uncontrolled urban growth is one of the main problems that reduce the limited highly fertile agricultural land surrounding the town. The altitudinal range of the town is between 1840 to 2660m a.m.s.l. The climatic condition of the study area is mainly sub-tropical in nature. According to the Office of Agriculture and Natural Resource Development of Wolaita Zone [ANRDZ] (2010), the study area experiences Woina-Dega (sub-tropical) Agro-climate. The annual average temperature of the study area is 17.5^0c. In addition, the area has an average annual precipitation of 1,225mm. (Tamirat, 1993) indicates that the majority of the soils of the study area were Vertisols black soils with characteristics of high clay content.

Materials and Methods

Data sources

This study involved utilization of Remote Sensing data for deriving spatiotemporal information on the urban land use of the study town. This allowed generation of information on important physical environmental parameters of urbanization including town infrastructural details. An area of 98.18km2 was delineated on the Landsat scene covering the study area. The LULC mapping for the area was based on Landsat 5 Thematic Mapper (TM) of December 1999 and January 2009, and Landsat 8 Operational Land Imagery(OLI) of February, 2019 data. Obtaining images at near anniversary dates is considered important for change detection studies (Jensen, 2007). This may reduce the problem of surface reflectance of land cover in haze condition. All-time series were from Landsat path 169, row 055 with spatial resolution of 30m*30m. The accomplishment of land cover change detection analysis by using multi-dates remote sensing images depend up on the accurate radiometric and geometric correction. Multi temporal Landsat imageries, geometric correction and radiometric correction are the most important. The images were

corrected to remove atmospheric effects and then geo-rectified using ground control points collected by GPS. The images were re-sampled to 30m pixel size for all bands using the nearest neighbor method. All the data were projected to a Universal Transverse Mercator (UTM) coordinate system, Datum WGS 1984, zone 37 North using 1:50 000 topographic map of the study area. The generalized methodology flowchart of study is as shown in figure 2.

Image classification and Accuracy assessment

Image classification

In this study, all Landsat images were compared supervised classification technique. Once the training sites were determined, a supervised classification was performed on the images using Maximum Likelihood algorithm in ERDAS IMAGINE 2014. The supervised classification technique was preferred, due to data availability and author's prior knowledge of the study area. This approach is considered to give very accurate results (Tolessa, 2016). Then with this technique the LULC maps were derived with the following five classes consists of agriculture, built up, forest or shrubs, open space/bare lands, green areas (Table 1).

Assessing classification accuracy

Classified land cover maps from satellite data were further used for validation using ground truth data obtained from a variety of sources. For the 1999, 2009, and 2019 land use/cover maps, a total of 125 pixels were generated using the stratified random sampling method. Then using the geographical locations of features available on the land use maps, high resolution images, and Survey of topographic maps, accuracy evaluation of the derived maps were performed. To assess the accuracy of 2009 and 2019 land use/cover maps, reference data obtained from the field were utilized. In doing so, 78 reference data for 2009 and 110 field data for 2019 were used to assess the classification accuracy. Finally, accuracy reports of each land cover data in terms of overall accuracy, producers/users accuracy, and kappa coefficient have been generated. The comparison of classification results and reference data was carried out statistically using error matrices. As can be seen in the error matrix (Table 2) all classification dates achieved satisfactory overall accuracies of 91.03% for1999, 85.9% for 2009 and 89.74 for 2019.

The data was classified into 5 land use land cover classes spread over a total area of 98.18km2 of the study town (the Municipal limits).

The trend and pattern of urban expansion was calculated and every polygon representing the particular class was quantified and displayed in respective maps. The aims of the this study is to produce a land use/ land cover map of Wolaita Sodo town at different year in order to detect changes that have taken place particularly in the built-up land and then to analyze the urban sprawl of the different time period and to predict the urban area growth in the same over a given period (1999-2019).

As can be seen from Table 3, lager proportion (4,986.5 ha.) of the study area was covered with agricultural land in 1999 which accounted for 54.3% of the land area while 1,656 ha. (18%) was open space and covered with grazing fields and light vegetation.

Only about 5.4 % were developed areas which are residential, commercial, recreational, industrial, or educational land uses, occupying just about 498.51 ha of land area. About 489.6 ha (5.3 %) was covered by forest plantation and scattered trees. This situation indicates the low level of development as of 1999 with a small compact urban area.

Next, the LULC classifications for the year 2009 in Figure 4shows, the percentage of built-up area had increased to 5.7 % (527.6 ha) forest (plantation) increased to 5.6% (511.11 ha) and agricultural area (cultivated& crop land) also increased to 5655.06 ha (61.6%) while the area covered by urban green reduced drastically to 1,223.7 ha (13.4%) and open field also reduced to 1265.5ha (13.7%). This shows that much of the green areas were cultivated while some of it gave way to further development and urban expansion through building constructions and provision of public utilities.

Figure 5 illustrates the LULC classifications for the year 2019.Inthefigure, the built-up area further increased to about 1,574.37 ha (17.2%) and forest plantationcovered1089.9 hectare (11.8%) while areas covered by agriculture, open space and urban green reduced to 4524.48 ha (49.3%), 1142.91ha (12.4%)and 851.4 ha (9.3 %), respectively. The land use for the built-up area continues to increase up to date while that of agriculture, open fields and area covered by green feature reduces.

Land Use Land Cover (LULC) Change Detection Analysisfor the Years 1999–2019

Post-classification change detection technique, performed in ArcGIS 10.7 was employed by the study. Post classification in urban environment has been effectively used by various researchers due to its efficiency in detecting the location, nature and rate of change (Hardin *et al.*, 2007). The LULC Classifications of the study town and the change detection analysis for the year 1999–2009, and 2009–2019 are presented in table 7 and Figure 3. From the table and figure, the percentage increase of agriculture (i.e., cultivated and crop land areas), built-up area and forest (plantation & scattered trees), as shown by its positive index, was higher between 1999 and 2009 than between 2009 and 2019. The percentage difference for built-up area was much higher between 2009 and 2019 while other land classifications have negative index. Urban green was highly depleted and taken over by plantation and built-up land uses as indicated by the negative index throughout the studying period. This is an evidence of consistent growth and rapid development witnessed in the town.

Urban built-up change detection analysis and future expansion

The spatial pattern of sprawling in the study town over a period of two decades (1999–2019), as shown in Figures 4–7, expresses the direction and extent of growth in the period examined. For instance, between 1999 and 2009, the growth navigates towards the south and the eastern parts of the region more than any other direction. These areas were reserved for the construction of government residential areas and institutions. Besides, the flat topography and followed by the high way which half way crosses the town to the north east and south direction attracted much influx into the area. The constructions of social infrastructures, educational institutions, such as, Federal University, were among the notable factors that play a prominent role in attracting people to the area. But the direction of growth thereafter diffused to other directions, probably due to congestion in this area and availability of cheap lands and good topography which favors construction in other parts of the town.

In conclusion, this paper aimed at investigating land use/land cover changes over the last two decades in Wolaita Sodo town between 1999 and 2019 using remote sensing and GIS techniques. The results clearly showed that LU/LC changes were significant during the period under study. There was significant expansion of built-up area noticed. On the other hand there is decrease in agricultural areas, open spaces and green fields.

The study focused on using geospatial techniques for combining geospatial themes to analyze the urban sprawl mapping and detect changes of urban land use/ land cover through different years in the environs of WolaitaSodo town. Thus, it proved the integration of GIS and remote sensing technologies is effective tool for urban planning and management. Satellite data are found to be useful in mapping and quantifying the extent of urban area in different time periods.

Table.1 Land use/cover classification scheme

SN	Theme		Associate Class
1	Agriculture	-	Lands covered with temporary crops followed by harvest period, crop fields and pastures,
2	Built-up areas	-	Land covered by buildings and other man-made structures. (Residential, commercial services, industrial area, mixed urban or built up lands, communications, utilities, industrial and, road, etc.
3	Open Space	-	Land areas of exposed soil and barren area influenced by human influence (Bare land, exposed soil, exposed rock, transitional areas)
4	Green areas	-	Urban green, Shrub/bush lands, grazing fields,
5	Forest	-	Mixed vegetation, forest plantation, Scattered trees,

Table 2: Accuracy assessment for the year, 1999, 2009 and 2019 (Accuracy Totals, 1999)

Class Name	Reference Totals	Classified totals	Number Correct	Producers Accuracy	Users Accuracy	Overall Kappa Statistics
Agriculture	14	12	11	78.57%	91.67%	0.8984
Built up	14	16	14	100.00%	87.50%	0.8477
Forest	12	10	10	83.33%	100.00%	1.000
Urban green	26	29	25	96.15%	86.21%	0.7931
Open space	12	11	11	91.67%	100.00%	1.000
Totals	78	78	71			0.8835
Overall Classification Accuracy		= 91.03%				
Accuracy Totals, 2009						
Agriculture	14	12	10	71.43%	83.33%	0.7969
Built up	16	16	13	81.25%	81.25%	0.7641
Forest	11	10	9	81.82%	90.00%	0.8836
Urban green	26	29	25	96.15%	86.21%	0.7931
Open space	11	11	10	90.91%	90.91%	0.8942
Totals	78	78	67			0.8165
Overall Classification Accuracy		= 85.9				
Accuracy Totals, 2019						
Agriculture	13	12	10	76.92%	83.33%	0.8
Built up	17	16	15	88.24%	93.75%	0.9201
Forest	11	10	9	81.82%	90.00%	0.8836
Urban green	26	29	25	96.15%	86.21%	0.7931
Open space	11	11	11	100.00%	100.00%	1
Totals	78	78	70			0.8664
Overall Classification Accuracy		= 89.74%				

Table.3 Summary of land use/cover classification statistics from 1999to2019 (area in hectares)

SN	Class Name	1999		2009		2019	
		Area (Ha)	**(%)**	**Area (Ha)**	**(%)**	**Area (Ha)**	**(%)**
1	Agriculture	4986.54	54.3	5655.06	61.6	4524.48	49.3
2	Built up	498.51	5.4	527.76	5.7	1574.37	17.2
3	Forest	489.6	5.3	511.11	5.6	1089.9	11.8
4	Open space	1656	18	1265.49	13.7	1142.91	12.4
5	Urban green	1551.78	17	1223.73	13.4	851.4	9.3
	Total	9182.43	100	9183.15	100	9183.06	100

Table.4 LULC area of the year 1999

SN	Class Name	Year_1999 Area (Ha)	(%)
1	Agriculture	4986.54	54.3
2	Built up	498.51	5.4
3	Forest	489.6	5.3
4	Open space	1656	18
5	Urban green	1551.78	17
	Total	9182.43	100

Table.5 LULC area of the year 2009

SN	Class Name	2009 Area (Ha)	(%)
1	Agriculture	5655.06	61.6
2	Built up	527.76	5.7
3	Forest	511.11	5.6
4	Open space	1265.49	13.7
5	Urban green	1223.73	13.4
	Total	9183.15	100

Table.6 LULC area of the year 2019

SN	Class Name	2019 Area (Ha)	(%)
1	Agriculture	4524.48	49.3
2	Built up	1574.37	17.2
3	Forest	1089.9	11.8
4	Open space	1142.91	12.4
5	Urban green	851.4	9.3
	Total	9183.06	100

Table.7 LULC change detection analysis for the years 1999–2019

SN	Class Name	2009 – 1999		2019 – 2009	
		Difference in Area (Ha)	Difference in Area (%)	Difference in Area (Ha)	Difference in Area (%)
1	Agriculture	668.52	7.3	-1130.58	-12.3
2	Built up	29.25	0.3	1046.61	11.5
3	Forest	21.51	0.3	578.79	6.2
4	Open space	-390.51	-4.3	-122.58	-1.3
5	Urban green	-328.05	-3.6	-372.33	-4.1
	Total	0.72	0	-0.09	0

Source: Landsat Satellite Imageries (1999, 2009 & 2019)

Figure.1 Location map of the study area

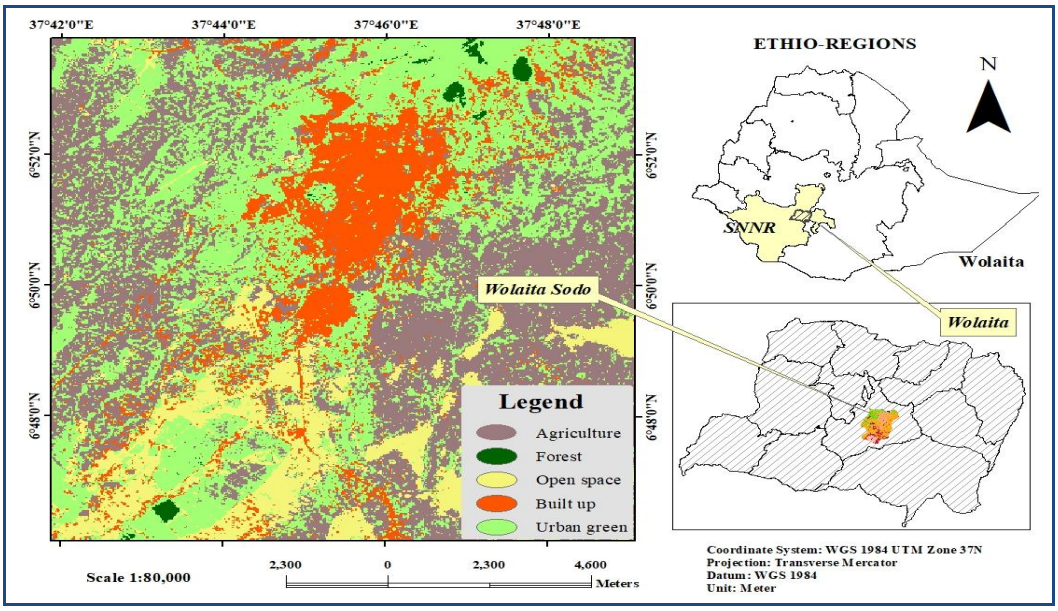


Figure.2 Methodology flowchart

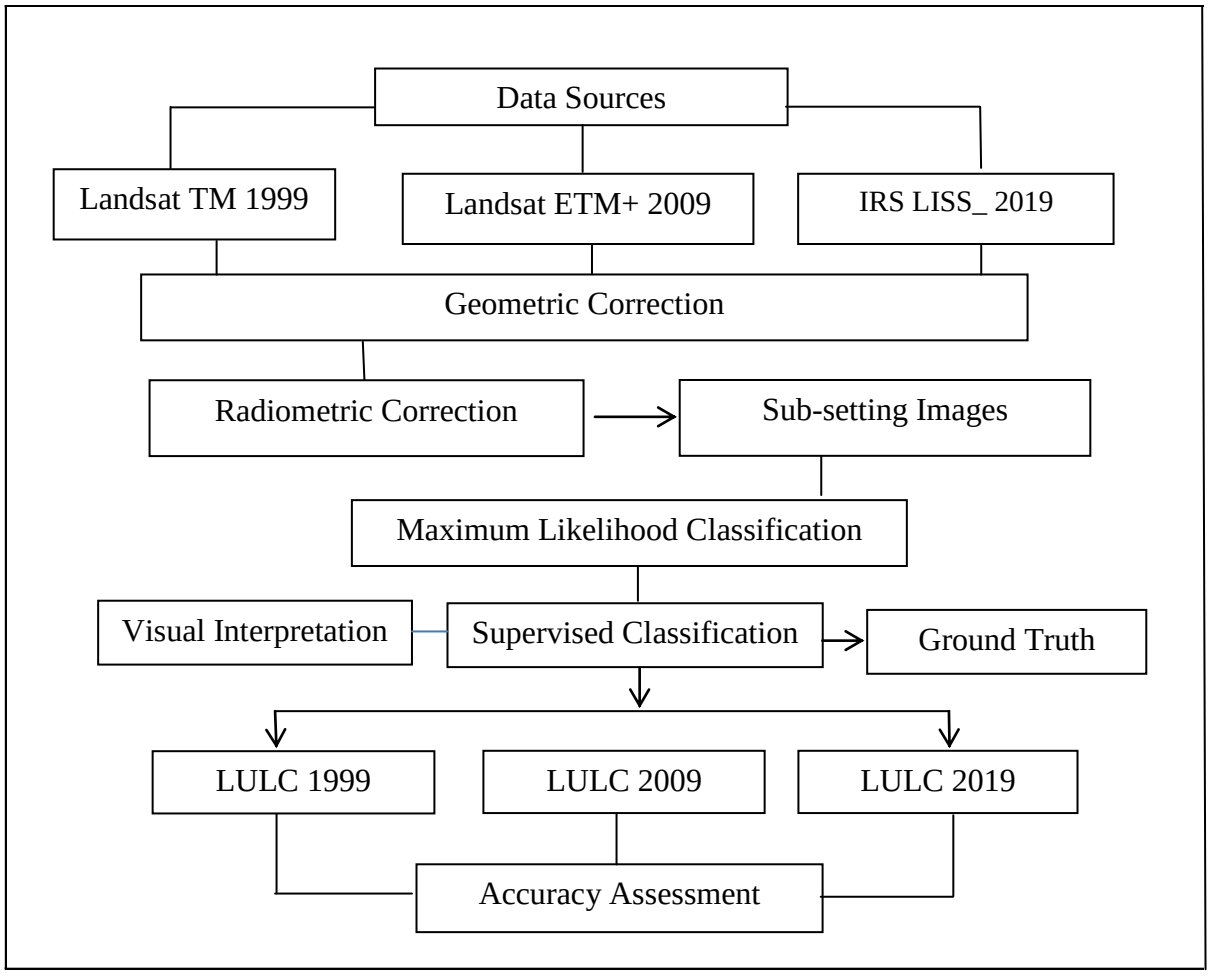


Figure.3 Land use/cover classes of the year1999, 2009 & 2019 for Wolaita Sodotown

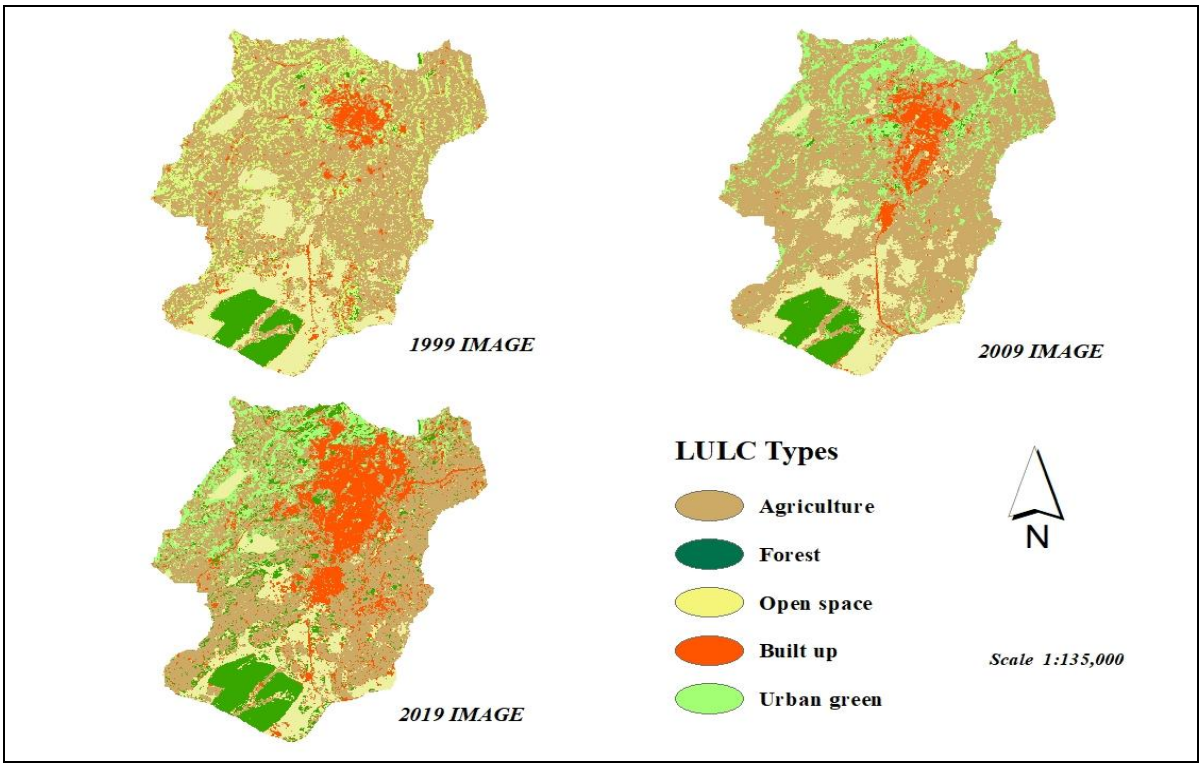


Fig.4 Land use/cover classes for 1999 image. Source Landsat 5 TM Imagery

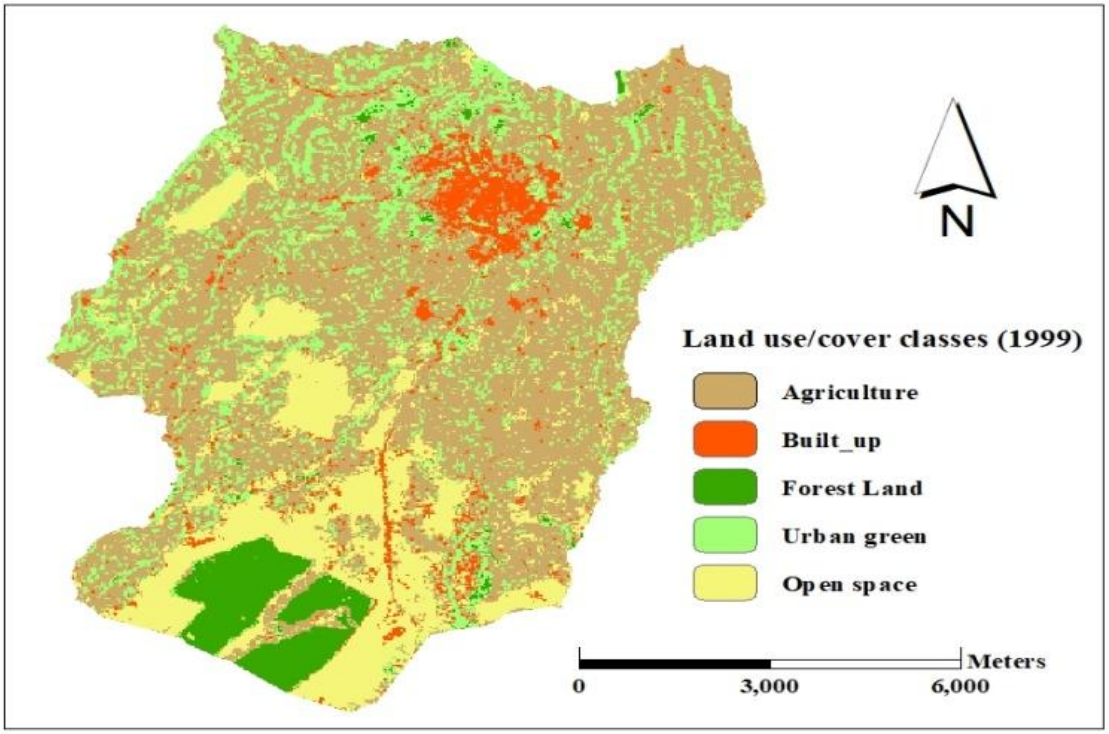


Fig.5 Land use/cover classes for 2009 image. Source Landsat 7 ETM+ Imagery

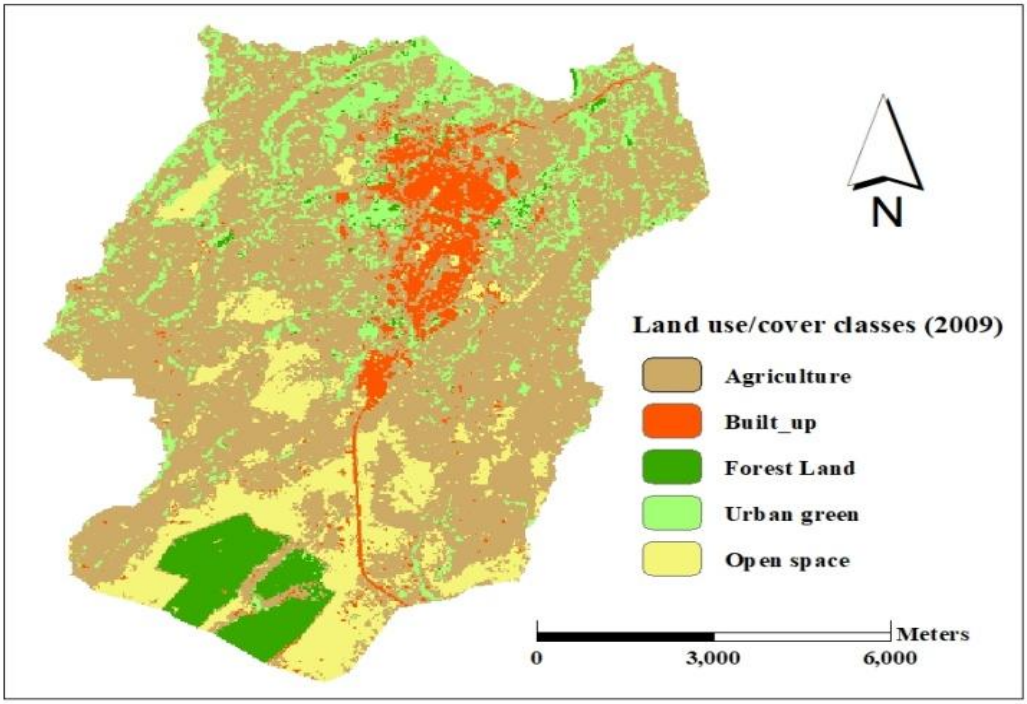


Fig.6 Land use/cover classes for 2019 image. Source Landsat 8 OLI Imagery

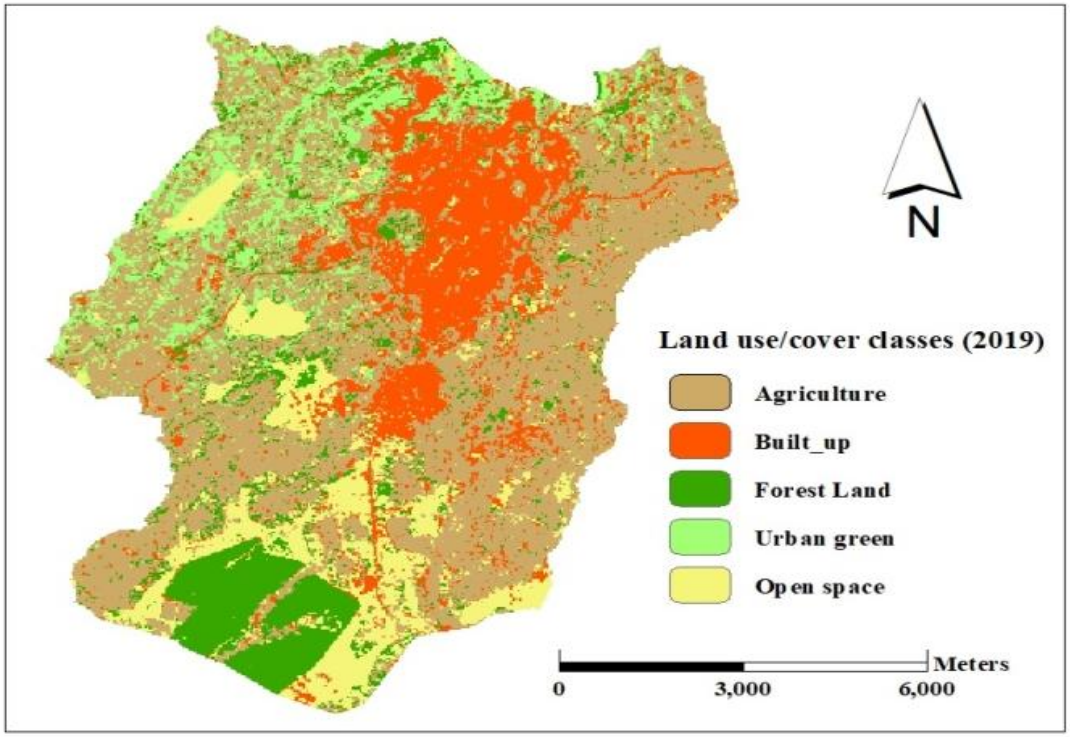
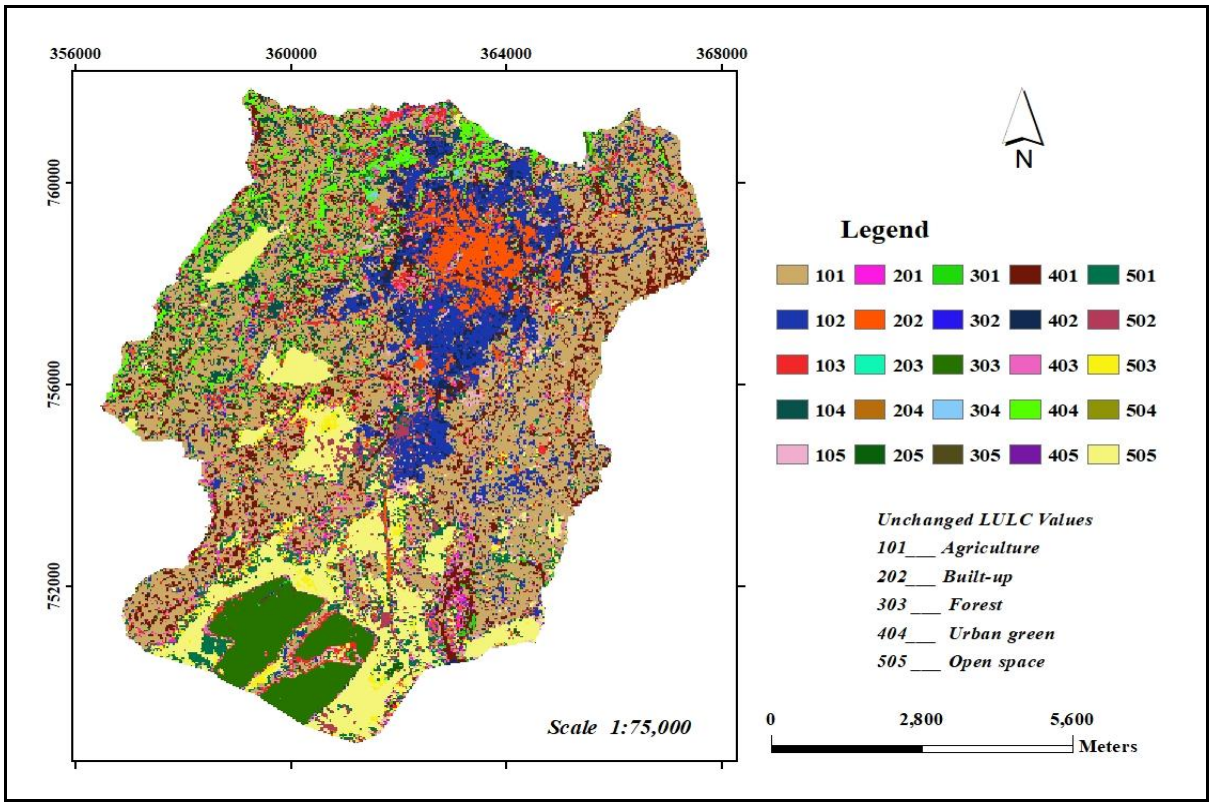


Figure.7 Change map showing LULC encroachments between 1999-2019



The above study provides a methodology for better estimation of urban growth and land use dynamics with time frame. New urban region developments are growing largely in all directions of the town while in the Lu/Lc mapping, agricultural land and open areas have been witnessed as the prime victim of this land transformation during the study period.

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