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ORIGINAL PAPER

Spatiotemporal analysis of urban expansion using GIS and remote sensing in Jigjiga town of Ethiopia

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Abstract
Urban expansion necessitates proper planning to avoid profound negative environmental and socioeconomic impacts. The main objective of the study was to analyze the spatiotemporal changes that occurred in Jigjiga town in the last three decades. To meet the intended objectives, geographic information system (GIS) and remote sensing technologies were employed. The results of the study disclosed that urban expansion of Jigjiga town was largely caused by the increasing built-up area from 4.2% in 1985, 5.2% in 2005 to 24% in 2015 out of Jigjiga's township area of 7492 ha due mainly to natural increase of the population, urban ward migration, and most recently, a change in status of the town from zonal capital to regional capital. This uncontrolled expansion towards peri-urban neighborhoods has exerted pressure on cropland and vegetation. Cropland has declined from 3836.6 ha (51.6% of Jigjiga's township area of 7492 ha) in 1985 to 2486.0 ha (33.2%) in 2015. Areas covered by forest increased by 84.8 ha in the first decade (1985–1995) and by 218 ha in the second decade (1995–2005), but towards the last decade (2005–2015), about 231 ha of forestland was converted to built-up area. The decline of grassland especially in the southern part of the town and its surrounding rural area was also very significant. In the last three decades, about 463 ha of grassland was converted largely to built-up areas. Therefore, controlling and monitoring of urban expansion using GIS and remote sensing technologies are vital solutions to protect peri-urban neighborhoods from adverse effects of urbanization.

Keywords Remote sensing · GIS · Spatiotemporal analysis of urban expansion · Jigjiga town · Ethiopia

Background

Urban sprawl, a consequence of socioeconomic development under certain circumstances, has increasingly become a major issue facing many metropolitan areas(Yuan et al. 2005). The extent of urbanization or its growth drives the change in land use/cover pattern. Land use and land cover changes may have adverse impacts on ecology of the area, especially the vegetation and biodiversity of the area (Herold et al. 2003; Liu and Lathrop 2002; Grimm et al. 2000). Increased research interest is being directed to the mapping and monitoring of urban sprawl/growth using geographic information system (GIS) and remote sensing techniques (Goetz 2013). Over the last three decades, the importance of GIS and remote sensing for studying urban sprawl, land use/cover patterns, and their dynamics; mapping land use classes; and monitoring their changes using different spatial resolution satellite data, including Landsat Thematic Mapper and spot images, has been increasing (Dewan and Yamaguchi 2008).

Population growth leads to a rapid expansion of urban growth, causing changes in land use/cover in many metropolitan areas. The rate of such change is obvious in developing countries with high population growth rates like Ethiopia currently growing annually at rate about 2.64% (Worldometers, www.worldometers.info). Rapid urban development and increasing land use changes due to increasing population and economic growth are being witnessed of in Ethiopia and other developing countries. The measurement and monitoring of these land use changes are crucial to understand land use cover dynamics over different spatial and temporal time scales for effective land management. Jigjiga town is one of Ethiopia's intermediate towns which is growing at a rate of 9.9% per year. This study assessed urban sprawl patterns in Jigjiga town using remote sensing and geospatial techniques during 1985–1995, 1995–2005, and 2005–2015.

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The use of GIS and remote sensing in urban sprawl research

The complexity of urban systems makes it difficult to adequately address their changes using a model based on a single approach (Allen and Lu 2003). Therefore, it is ideal to use a tool such as a GIS as part of the research on urban sprawl because of its capacity to handle many different types of spatial data. A GIS will not only allow for powerful visualization of urban sprawl within the study area by providing maps but also allows for an in-depth analysis of the data by providing the capability to examine all of the data in one system, therefore facilitating the measurement of urban sprawl. A GIS is also an extremely powerful tool for creating new data from existing data and is often referred to as a decision support system (Burrough and McDonnell 1998).

On the other hand, satellite remote sensing offers an essential gateway to the monitoring, modeling, and analysis of urbanization processes, particularly in developing countries, where it makes up for the scarcity of geographic data and up-to-date maps (Gadal 2009). Satellite images, which are rapidly accessible and have been available for the past 30 years or so from the Landsat satellite series and then from the Spot series4, are used to monitor at regular intervals, annually or more frequently, the dynamics of urbanization and land use transformation, particularly in countries which have very high rates of urbanization (Sudhiraet al. 2003). Satellite images can be used to monitor the development of urbanization continuously over geographic areas of differing sizes. Spatial modeling of urbanization processes is carried out apparently by historical analysis of remote sensing, i.e., by comparison of images or spatio-maps between two or more dates (Kumar et al. 2008).

Integrated into a geographic information system, structured and associated with other geographic information such as, for example, digital terrain models showing types of relief and roads, the geographic models produced give a specialized representation of the urban development of land areas. There is a growing tendency to combine satellite remote sensing and GIS into a single system for analyzing geographic space and its dynamics although it seems difficult to find a single definition for the approach (Mesev 2007). The use of integrated approaches combining satellite remote sensing and GIS to monitor, analyze, geographically model, and spatially represent urbanization is combined with two other approaches: the integration of 3D geo-visualization and dynamic cartography/representation, i.e., the representation of urban growth in the form of a 3D animation. Dynamic representation or cartography of geographic processes is used in physical geography to model and represent changes in relief, or a water course (Drogue et al. 2002; Pilouk and Abdul-Rahman 2007).

The research methods

A mixed visual and probabilistic classification was used to classify Landsat images of the area in 1985, 1995, 2005, and 2015 into the different land use/cover (Lu/Lc) types. The study of the long-term (1985–2015) land use/land cover patterns and changes and thus the urban expansion of Jigjiga town were carried out based on satellite imageries and base maps obtained from various sources. The land use land cover map of the area and the areal extent of the town at different times were depicted based on the Landsat imagery-Landsat TM 5 (1985 and 1995), Landsat TM 7 (2005), and Landsat 8 ETM+ (2015).

All of the scenes were taken on a bright day in January 1985, 1995, 2005, and 2015. A full scene (5 bands in 1985, 7 bands in 1995, and 8 bands in 2005 and 2015) of these Landsat imageries contained in path 171 and row 053 was taken from internet source—Earth Explorer (a USGS server for Landsat imageries). A false color composite (near infrared as red, red as green, and green as blue) for the portion of the scene covering the town and its surrounding was displayed as shown in Fig. 1. Though not combined in the display in Fig. 1, a very high-resolution and a recent (2015) imagery from Google Earth and GPS survey made on selected 50 training sample areas was used to improve the accuracy of the classification made on the 1985, 1995, 2005, and 2015 Landsat imageries.

Image interpretation and classification

The false color composites (FCC) of 1985, 1995, and 2005 displayed in Fig. 1 clearly show that built-up areas in cyan color were surrounded by vegetation (dark red color). The false color composite in 2015, however, shows no reddish color around the town indicating that the vegetation and other land cover categories have been replaced by rapidly sprawled Jigjiga town. The classification and interpretation of the satellite imageries into a certain land use/cover categories was done by image enhancement (by applying smoothing, sharpening, and contrast stretching), displaying bands in false color composition on Landsat imageries and natural color composition on a very high-resolution imagery of the area. A false color composite display of green, red, and near infrared bands of the imageries Landsat TM 5 (Jan 1985), Landsat TM 7 (Jan 1995), Landsat 7 TM (Jan 2005), and Landsat 8 ETM+ (Mar 2015) of the area was displayed. The main intention behind using a false color display of these bands was to differentiate water bodies, vegetation (grassland, shrub land, and forestland), and bare soils (cultivated and built-up areas) distinctively.

The enhanced FCC display of the Landsat imageries of the area combined with the very high-resolution imageries from

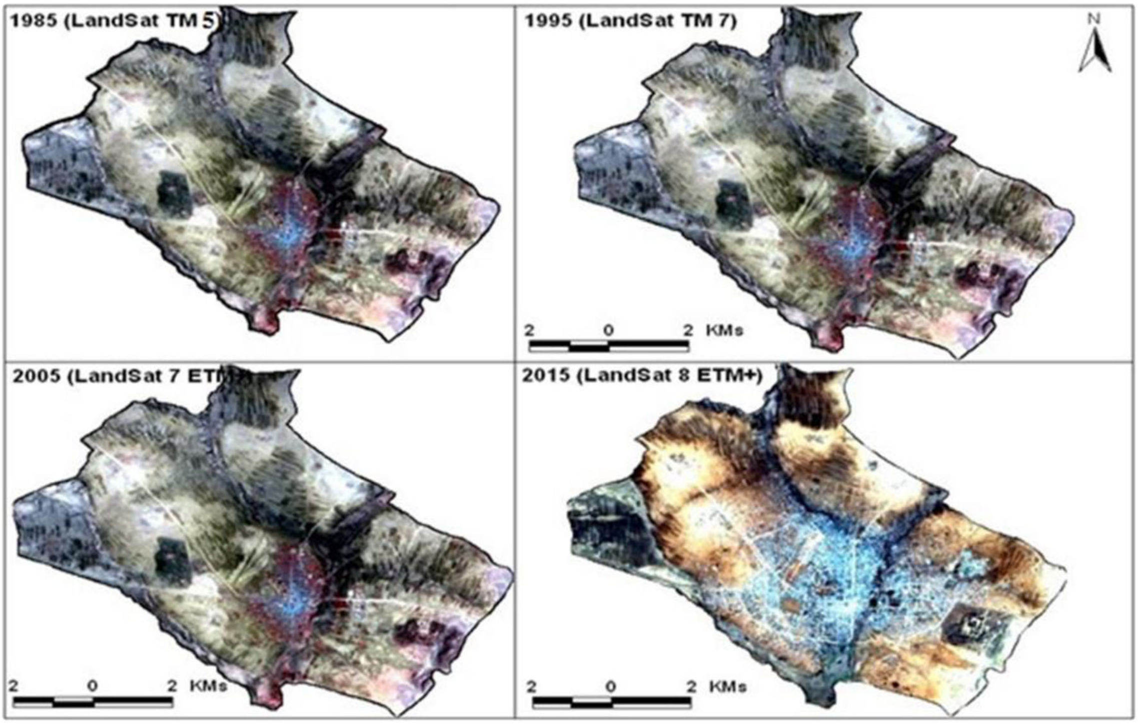

Fig. 1 False color composition of Landsat images for Jigjiga town

Google Earth (stacking panchromatic display of the very high-resolution Google Earth image with false color composites of the Landsat imageries), Jigjiga town, and the surrounding rural areas was classified into five major land use categories (forestland, plantation, grassland, cropland, and built-up areas) based on the USGS level I land use/land cover classification (Anderson et al. 1976) (Table 1).

As shown in the imageries of the area displayed on Fig. 1, an agglomeration of cyan (light bright blue)-colored areas were identified as built-up areas. Besides, the brighter red tone around the town area is clearly differentiated to be vegetation area (scrubland or plantations). Google Earth—displaying the current image of the area at a very high resolution—allowed the authors to classify the majority bare land area surrounding the town as cropland. On the FCC display of the 1995 and 2005 Landsat imageries, the red areas are clearly differentiated from the cyan color on the majority/central landscapes representing naturally grassland but now changed to either bare land or cultivated land.

Assessment accuracy of the classification

Following the procedures given by Lillesand and Ralph (2000), accuracy of the classification of the 2005 Landsat imagery and the 2015 Landsat imageries was assessed based on reference data which collected the very high-resolution imagery of the town and the surrounding area in 2005 and GPS data collected at 60 sample points from the town and the surrounding area in 2015. Accordingly, confusion matrix for the 2005 and 2015 was derived, and the user accuracy, producer accuracy, overall accuracy, and Kappa index of agreement were computed.

	2005		2015	
Lu/Lc category	Producer accuracy	User accuracy	Producer accuracy	User accuracy
Forestland	79.9	75.5	85.7	75.0
Bushland	75.6	76.9	78.6	78.6
Grassland	87.5	73.7	85.0	89.5
Cropland	80.0	91.4	88.6	88.6
Bare land	87.5	87.5	89.5	94.4
Built-up area	94.0	92.3	95.2	93.5
Overall accuracy	85.1		86.3	
Kappa index	0.86		0.88	

The overall accuracy of the classification of the 2005 and 2015 was computed to be more than 85%. The producer accuracy for the 2005 image classification ranges from 75.6 (bushland) to 94% (built-up area), and for the 2015 image classification, it ranges from 78.6 (bushland) to 95.2% (built-up area). Whereas the user accuracy for the 2005 image classification ranges from 75.5 (forestland) to 92.3% (built-up area), and for the 2015 image classification, it ranges from 75 (forestland) to 94.4% (built-up area). Accuracy assessment for the earlier years (1985 and 1995), however, was not carried out because of lack of information at the reference points in 1985 and 1995. The accuracy of the classification for these 2-years imageries is relied on only the authors' knowledge of the study area.

Table 1 Image classification land use and land cover description

Lu/Lc type	Description
Forestland	Areas covered with dense trees/woods, scrubs, and grasses—spatially not differentiable pattern—which appear to be a dark or a bright red continuum in FCC display of Landsat imageries
Shrub land	Scattered patches covered with trees, which appear to be a mix of dark and light red color in a FCC display of Landsat imageries.
Grassland	Areas covered with normally irregular shapes/strips in the cropland and rectangular inside built-up areas with a smooth light red color on a FCC display of dry season Landsat imageries.
Cropland	Areas covered with normally regular shapes/patterns of land lots with a smooth darker cyan color (but also reddish irrigated farms or perennial crops) on a FCC display of a dry season Landsat imageries.
Bare land	Exposed areas probably covered by sandy soils appear to be brighter cyan, and they are a continuum of amorphous-shaped areas and dominantly found on hilly and valley landscapes along Sudan border.
Urban built-up area	A cluster/block of houses bounded with network of roads/linear feature as towns which appear to be regularly shaped bright cyan in a FCC display of Landsat imageries.

Source: Anderson et al. 1976 and field observation 2015

Tabulation and charting of change matrices

ArcGIS version 10.2 was used to generate land use/land cover maps of Jigjiga town and its surroundings for the years 1985, 1995, 2005, and 2015. As described above, the data sources were Landsat TM imageries of 30 m spatial resolution for the years 1985 and 2005 and Landsat ETM+ of 30 m of spatial resolution combined with Google Earth imagery of 2.5 m resolution for the years 2005 and 2015. In addition to ArcGIS 10.2, Excel 2010 and SPSS version 20 were used to map expansion of the town over the past 30 years, derive change matrices, and create graphs showing which land use/land cover has remained persistent, gained, or lost its areal extent and which land use/land cover category has contributed to the expansion of the town.

Results and discussion

Patterns and extent of the major land use/land cover in Jigjiga town and surrounding rural area during 1985–2015

Numerically, since 1985, urban built-up area of Jigjiga town has been expanding at a faster rate especially in the last decade (2005–2015). Built-up area of the town was about 163 ha in 1985, 312 ha in 1995, 393 ha in 2005, and 1795 ha in 2015. On average, the rate of expansion of the town was 15 ha per annum in the first decade (1985–1995), about 8 ha in the second period (1995–2005), and 140 ha in the last decade (2005–2015). Although expected that urban built-up areas expand continuously, the rate of transformation of peri-urban or rural areas into a built-up urban areas in the last decade was very high compared to the mean annual changes in the first two decades. This big difference in the rate of change is due to the promotion of Jigjiga town into regional capital followed by establishment of regional offices, a university, and construction of commercial or business and residential buildings to accommodate the increasing population of the town.

As can be observed from Table 2 and Fig. 2, in 1985, 1995, and even in 2005, the majority of the area (about 54%, 51%, and 46%, respectively, out of 7492 ha of the study area) around Jigjiga town was cultivated. Compared to this coverage of cropland in the earlier times, the recent, particularly in 2015, area covered by cropland was as low as 33%. The percentage of the cropland in 1995 was larger than that in 1985 by about 2.6%, while grassland remained the same in the first decade (1985 to 1995). Areas covered by forest and shrub land have decreased together by a small percentage of about 3.5%.

Though declining sharply, the area cultivated remains the largest of the area with about 54% in 1985, 51% in 1995, 46% in 2005, and 33% in 2015 out of 7492 ha size of the study area. Regardless of the fluctuations, rural settlement has also declined from 4% in 1985 to 3.7% in 2015. These imply that the

Table 2 Percentages of Lu/Lc in Jigjiga town during the period 1985–2015

Lu/Lc type	1985		1995		2005		2015	
	Ha.	%	Ha.	%	Ha.	%	Ha.	%
Forestland	106.7	1.4	191.4	2.6	409.4	5.5	177.9	9.9
Shrub land	474.6	6.3	634.1	8.5	615.7	8.2	648.5	36.1
Grassland	1358.2	18.1	1357.6	18.1	1165.1	15.6	897.8	50.0
Bare land	786.2	10.5	786.4	10.5	928.0	12.4	897.9	50.0
Cropland	4029.1	53.8	3836.6	51.2	3460.6	46.2	2486.0	138.5
Rural settlement	303.1	4.0	373.6	5.0	520.5	6.9	280.4	15.6
Built-up area	163.2	2.2	312.2	4.2	392.8	5.2	1795.2	9.9
Total 1986	7492	100.0	7492	100.0	7492	100.0	7492	100.0

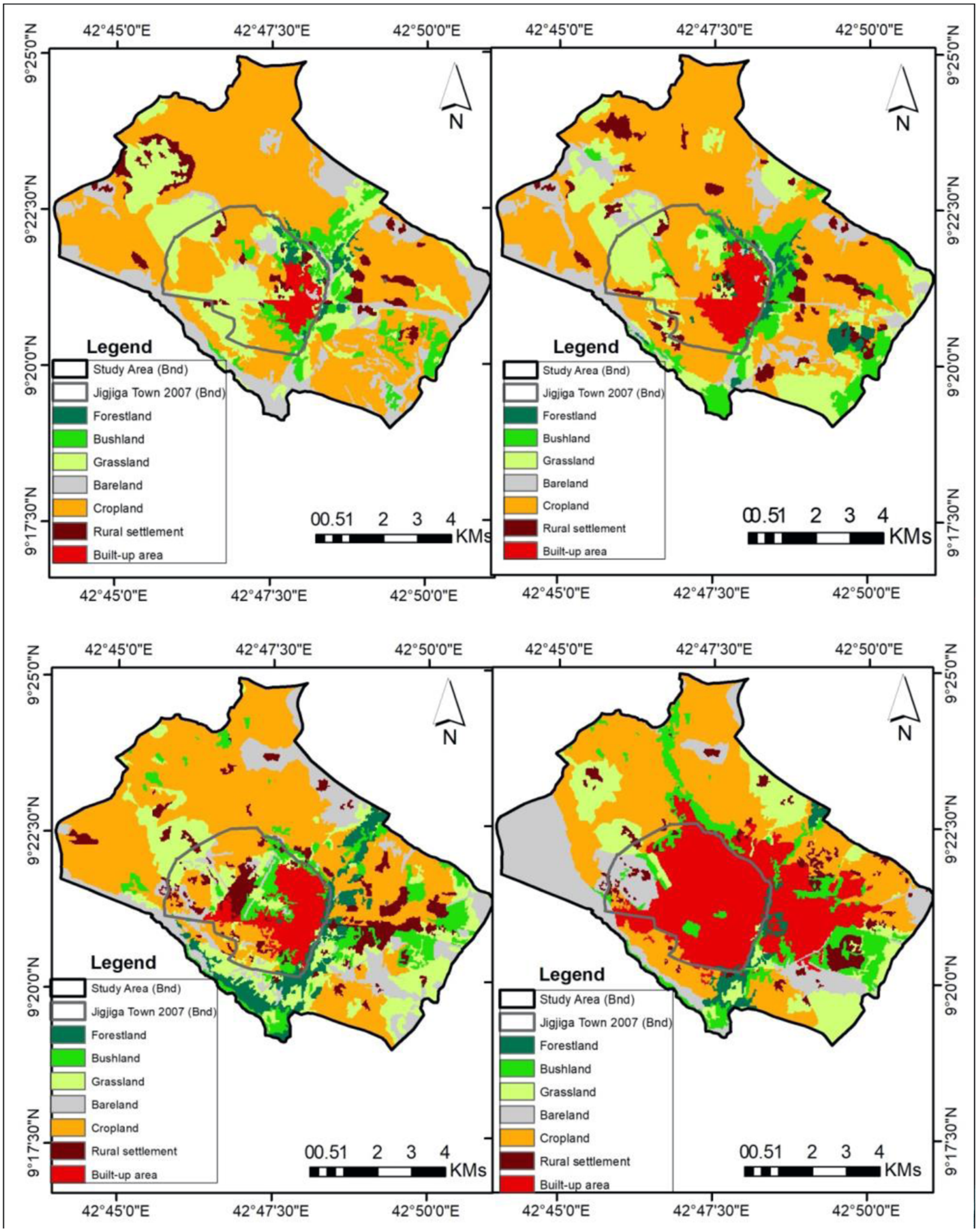

Fig. 2 Land use/land cover map of Jigjiga town in 1985, 1995, 2005, and 2015

transformation of natural vegetation, cropland, and rural settlement into urban built-up areas in the last decades was very high. Area covered by vegetation (shrub, forest, and grassland) in the town and the surrounding area was about 25.8%, 29.2%, 29.3%, and 23.1% in 1985, 1995, 2005, and 2015, respectively. As shown in Table 2 and Fig. 2, the area covered by grassland is the highest of the other vegetation categories. The area covered by shrub land has been increasing as a result of invading weed—*Prosopis juliflora*. Except for the year 2015, forestland was also increasing between 1985 and 2005 because of the maturing shrub. The decline in the forestland in 2015 was attributed to the massive construction taken place on peri-urban areas of the town.

The urban expansion of Jigjiga town was largely caused by the increasing built-up area of the town from 2.2% in 1985 to 4.2% in 1995 to 5.2% in 2005. This in turn is due to the natural increase of the population and rural to urban migration. However,

Table 3 Percentages of land use/land cover change in Jigjiga during the period 1985–2015

Lu/Lc type	Change in 1985–1995		Change in 1995–2005		Change in 2005–2015		Change in 1985–2015	
	Ha.	%	Ha.	%	Ha.	%	Ha.	%
Forestland	84.8	79.5	218.0	113.9	− 231.5	− 56.5	71.3	66.8
Shrub land	159.6	33.6	− 18.45	− 2.9	32.85	5.3	173.97	36.7
Grassland	− 0.6	0.0	− 192.5	− 14.2	− 267.3	− 22.9	− 460.4	− 33.9
Bare land	− 270.7	− 25.6	141.57	18.0	278.1	30.0	148.95	14.1
Cropland	− 192.5	− 4.8	− 376	− 9.8	− 974.6	− 28.2	− 1543	− 38.3
Rural settlement	70.5	23.2	146.88	39.3	− 240	− 46.1	− 22.68	− 7.5
Built-up area	149.0	91.3	80.55	25.8	1402.5	357.1	1632.1	1000.2
Total change	0.0	0.0	0	0.0	0	0.0	0	0.0

the 24% increase observed in 2015 is attributed to both natural causes and the transformation of the surrounding plain landscape (cropland and vegetation) into built-up area.

Analysis of the long-term land use/land cover dynamics

In the last three decades, the expansion of urban area (built-up area) was high. The built-up area has increased from 163.2 ha (2.2%) in 1985 to 1795.2 ha (24%) in 2015 (Table 3). The percentage of areal expansion of Jigjiga town during this period was as high as 1000%. On the other hand, cropland has declined from 4029.1 ha (54%) in 1985 to 2486.0 ha (33.2%) in 2015. The decline of cropland was largest, and it was as high as 38.2%. Built-up area of the town has increased by 232 ha from 1995 to 2005, by 80.6 ha from 1995 to 2005, by 1402.5 ha from 2005 to 2015, and totally by 1632 ha during the last three decades.

Areas covered by forest (plantation) have increased by 84.8 ha in the first decade (1985–1995) and by 218 ha in the second decade (1995–2005), but its change in the last decade (2005–2015) was very large with about 231 ha due to conversion into built-up area. The decline of grassland especially in the southern part of the town and its surrounding rural area was also very significant. In the last three decades, about 463 ha of grassland was converted largely to built-up area.

Spatial trend of urban area expansion in Jigjiga town

Figure 3 shows the spatial expansion of Jigjiga town over the last 30 years. On average, the town was growing (expanding outward) 54.4 ha per year over the last three decades. Its spatial growth was 15 ha, 8 ha, and 140 ha per year during the first (1985–1995), second (1995–2005), and third decade (2005–2015), respectively.

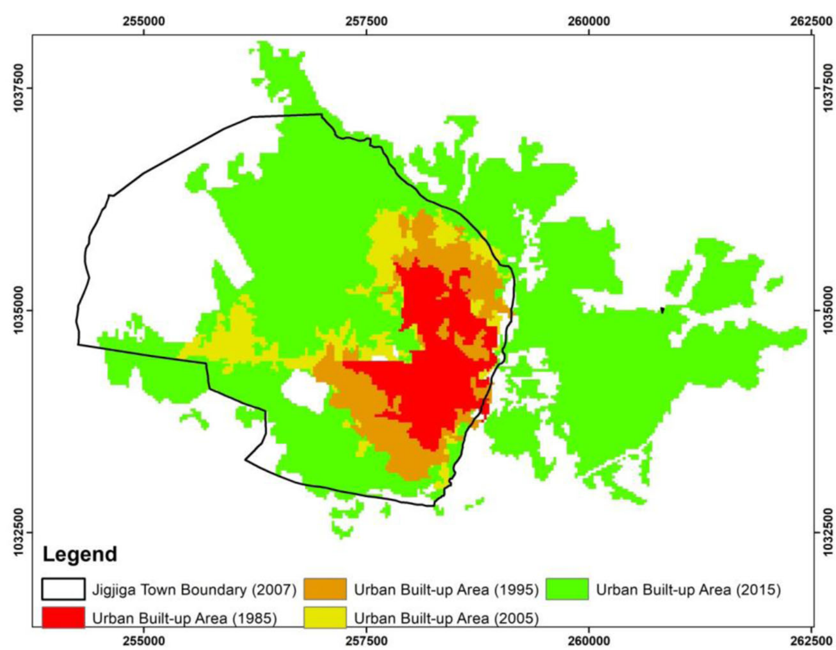

Fig. 3 Expansion of Jigjiga town in 1985–2015

The red color in the figure represents the urban area which was built before 1985. This urban built-up area of the town was expanded by about 3 sq. km, 4 sq. km, and 18 sq. km during 1985–1995, 1995–2005, and 2005–2015, respectively.

Discussion

The advancement of remote sensing, databases for satellite imageries like USGS and Google Earth, and GIS/RS software like ArcGIS downloading moderate (30 m) to high-resolution (1 m) geo-referenced satellite imageries for any part of the world and for the period since 1973 has become a reality. Besides, the technical and methodological progression and inclusion image-processing tools in GIS/RS software like the ArcGIS have enabled us to process satellite imageries, carry out analysis on the data, and use the result for practical application like assessing the long-term Lu/Lc change and urban sprawling as it was practiced in this paper. Lack of reference data for the past years (historical data) in developing countries like Ethiopia, however, hinders classifying images based on training sample areas and assessing accuracies of classification of images in the past years like the 1985 and 1995 in this research. The recent years' images like the 2005 imagery of the area were classified to a certain level of accuracies based on the information (reference Lu/Lc categories) extracted from the very high-resolution Google Earth images. The level of accuracies of the 2015 image of the area was assessed based on reference Lu/Lc categories obtained not only data collected from GPS but also data extracted from the 2015 high-resolution Google Earth image of the area.

Conclusions

The built-up areas in Jigjiga town have expanded dramatically, while cropland and vegetation cover shrunk. The sprawl of Jigjiga town was largely due to the rapid expansion of built-up area towards the surrounding peri-urban neighborhoods caused by natural phenomenon of population increase, rural-urban migration, and most importantly, the changing status of the town from zonal capital to regional capital. Such a phenomenal increase in the town's population has led to a construction boom in the surrounding peri-urban areas which in turn reduced the size of cropland and vegetation cover. Therefore, devising strategies to control urban sprawl effects is indispensible for a healthy development. To this effect, remote sensing and GIS technologies can play a crucial role in identifying and mapping of possible areas of interventions.

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