Evaluation of Urban Growth Using Remote Sensing and GIS Tools Case Study on Thanjavur City, Tamil Nadu, India

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ABSTRACT

Evaluation of urban expansion and its use play a vital role in effective urban management in terms of providing water supply, storm water drainage, sewerage and solid waste collection. In recent years, the significance of spatial data technologies, especially the application of remotely sensed data, has increased and geographical information systems (GIS) have been widely used. This study investigates the urbanization process in terms of land use, built up density and sprawl using remotely sensed images of Thanjavur City, located in Tamil Nadu State of India, as a case study and (GIS). The changes in the land use were analyzed from a topographical map of 1970, images from a ETM+ EarthSat 1999 and IRS P6, 2006. The results revealed significant changes in land use and proportion of high, medium and low density built up area. Further, it has been identified that in the study area dominates the leapfrog sprawl rather than low density and ribbon sprawl.

KEYWORDS: Urban sprawl, Urbanization, Remote sensing, GIS.

INTRODUCTION

Rapid urbanization of Indian cities and towns resulted in an increased impervious area and a reduced drainage network. The current scenario of urban growth in India has a haphazard pattern, especially in urban-rural fringe. The increasing urban area ultimately accelerates the urban runoff causing vast damage to urban infrastructure facilities. Besides this, the pressure of an ever growing population becomes a burden on the limited civic amenities which are almost collapsing. Any city depends as much upon its planners and administrators, as well as on the people dwelling in it. They play a vital role in drawing plans that should not only cater to the needs of current inhabitants, but should look at developing cities and townships, keeping in mind a minimum of 30-year time frame. It is essential that works like roads and construction and repair of drainage should be taken in a coordinated manner by adopting an integrated development framework for an area. Delineation of urban expansion by field survey is a long, tedious and expensive process. Urban land use, built up density as well as sprawl classification and urban expansion using an integrated approach of remote sensing and GIS are found to be cost-effective. Impervious surface in urban environment has been identified as a key parameter in assessing the urban growth and urban population density. Urbanization significantly alters the hydrology of the place both in terms of water quality and quantity over a range of temporal and special scales. Land use and land cover changes result in direct impacts on the

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hydrological cycle and water quality causing drought, floods, changes in river basins and groundwater regimes. In addition to these visible direct impacts on the environment, urbanization affects climate and has a subsequent impact on waters.

The integration of remote sensing and GIS has been widely recognized as a powerful and effective tool in detecting urban growth (Ehlers et al., 1990; Treitz et al., 1992; Harris and Ventura, 1995; Yeh and Li, 1996, 1997). A better understanding of the process of urban growth and the effects of this growth and land use change is essential for more efficient planning and management (Leao et al., 2004).

Satellite images have a wider spectral range than aerial photographs to classify land use, particularly for the urbanized and industrial coastal regions (Certin, 2009). Urban land-use/cover classification is still a challenge with medium or coarse spatial resolution remotely sensed data due to the large number of mixed pixels and spectral confusions among different land use/cover types (Lu and Weng, 2006). In hydrological and watershed modeling, remotely sensed data are found to be valuable for providing cost-effective data input and for estimating model parameters (Engman and Gurney, 1991; Drayton et al., 1992; Mattikalli et al., 1996). Imperviousness determines the amount of rainfall that becomes run-off in a packet of land. Therefore, the total amount of imperviousness in urban watershed directly relates to the run-off rates and volumes. This is most important to calculate the sizes of storage and drainage necessary for flood mitigation in the urban. These are generally collected using conventional practice of field survey and aerial photo-interpretation which need to be often conducted (every year) for accurate estimation. Satellite imagery is captured regularly and hence the same area can be observed over time. Furthermore, the satellite imagery's digital format can be directly studied with innumerable image processing programs. Miller and Small (2003) mentioned that remote sensing data combined with spatially referenced socioeconomic data will be useful for identifying, measuring, monitoring and ultimately managing the changes happening in the urban environment. Al-Rawashdeh and Saleh (2006) studied the spatial growth of Amman area of Jordan using remote sensing and GIS tools and assessed that fertile lands are being converted into urban area. Han et al. (2009) considered socioeconomic factors like population, GDP and transportation development as driving factors for land use change in Shanghai, China. Farroq and Ahmad (2008) carried out an urban sprawl study of Aligarh city using satellite remote sensing and GIS. Farroq and Ahmad (2008) used Landsat, IRS and Quickbird data to delineate the extent, pace and pattern of growth of the city area of Aligarh. The study revealed that the Aligarh urban area has increased almost three times since 1971. Jha et al. (2008) analyzed urban development of Haridwar city in India using entropy-based approach, and the findings of the study indicated that Haridwar city has experienced random urban development. Suribabu et al. (2012) studied the urban growth of Tiruchirappali city located in Tamil Nadu, India. They reported that built up area has increased three times in the span of 22 years. Feng and Hui (2012) studied the spatial patterns of urban sprawl of Jiangning and identified that the rapid urban expansion with low density land use pattern occurred toward the urban fringe. The quantitative and special analyses carried out by Sperandelli et al. (2013) showed the dynamics of the green spaces, vacant land and expansion of Atibaia, Brazil. The study highlighted the dynamics of green spaces, and the growth pattern was identified as one of the growing land use patterns as a result of the increase in forest lands which were incorporated with the green urban areas. This paper investigates the urban growth pattern of Thanjavur city, located in India in terms of land use, built up area density and sprawl pattern using the topographical sheet of 1970, as well as imageries of 1991, 1999 and 2006.

STUDY AREA

Thanjavur city is situated between 10^0 48' and 10^0

8’ of the northern latitude and 79^0 09’ and 79^0 15’ of the eastern longitude. The original municipality area as on the toposheet of 1970 was about 19 km^2. The township and its exterior suburbs extended to the total area of about 50 km^2. The soil is fertile because of the deltaic terrain and a greater part of the town consists of an undulating plain bisected by the valley of Grand Anaicut canal. The climate is tropical and the city falls under the category of medium and high rainfall regions with an average annual rainfall of around 958.8 mm (Bhaskar and Suribabu, 2014). The major portion of the rain is received during north-east monsoon (October to early December). The north-west and south-west parts of the town have an elevation of 78 and 30m above mean sea level, respectively. The population of the city as per 2001 population survey was 215725. In 2013, Thanjavur town has been upgraded as a city and it is likely to have an area of 110.27 sq. km with a population of 320828.

MATERIALS AND METHODOLOGY

In this study, TM EarthSat January 1991 with ETM+ EarthSat November 1999 and IRS P6_07 April 2006 data and the topographic map of 1970 with a scale of 1:50000 were used. EarthSat images have 28.50 m spatial resolution with seven spectral bands. IRS images P6 LISS 3 have 23.50 m spatial resolution with three spectral bands. ENVI 4.3 and ERDAS imagine v.8.4 are used to process the EarthSat and IRS images, respectively. ESRI ArcView v8.4 with spatial analyst module is used to create and handle the layers of the topographic map. Geometric transformation and geo-referencing are used to convert the implicit geometry of an image into a cartographic planimetry and assign the coordinates to the image pixels. For this study, the image was corrected using a polynomial function and ground control points kept as geo-reference on the topography map. The resulting geo-referenced image was used as a reference for the image-to-image geometric correction process. The base map was prepared from portions of 15’ of the topographic map. Town boundary locations were taken directly from the base map.

Image enhancement is essential to provide an effective display for image interpretation. Several techniques are available to improve the distinctness of the objects in images such as contrast enhancement, spatial filtering, image fusion,… etc. With the aid of ERDAS Imagine software, IRS image was enhanced using linear contrast stretching and histogram equalization in order to increase the volume of visible information. The image was then rectified to a common Universal Transverse Mercator (UTM) coordinate system based on the 1:50,000 scale topographic maps of NRSA province produced by the Indian government. No further enhancement was carried out in case of rectified EarthSat images as their clarity is good. The processed image of the town is presented in Fig.1.

Land Use Classification

Land use/cover monitoring is an indispensable exercise for all those involved in executing policies to optimize the use of natural resources and minimize the ill impacts on the environment (Mukherjee et al., 2009). In this study, an unsupervised classification with the maximum likelihood algorithm was conducted to classify the IRS images using bands 2 (green), 3 (red) and 4 (near infrared), and ENVI 4.3 was used for EarthSat images. The accuracy of the classification was verified by using Google Earth map. Common land use categories; namely built-up area, open scrub, water bodies and vegetation were considered for classification. The urban part of the study area includes high-density built up area, low-density built up area, infrastructure, roads and highways, industrial land use and also covers a very small part of monuments and temples within the city limit. Open space includes baren land, open area (playgrounds), unpaved area along the bitumen and concrete roads, dry river bed and dry cultivable land. Water bodies include water in the temple tanks, flowing water in the river, rainwater standing in the agricultural field and residential layout and standing irrigation water in the agricultural field.

Vegetation refers to the ground cover provided by the wide variety of plants. It includes cultivated gardens, lawns, road side weed patches and trees. The open scrub includes the area covered by grass and scrub. The processed image was verified with field data and also using Google image of the study area. Fig. 2 shows the classified images of Thanjavur city. Table 1 provides the details of the area coverage for each of the land use categories.

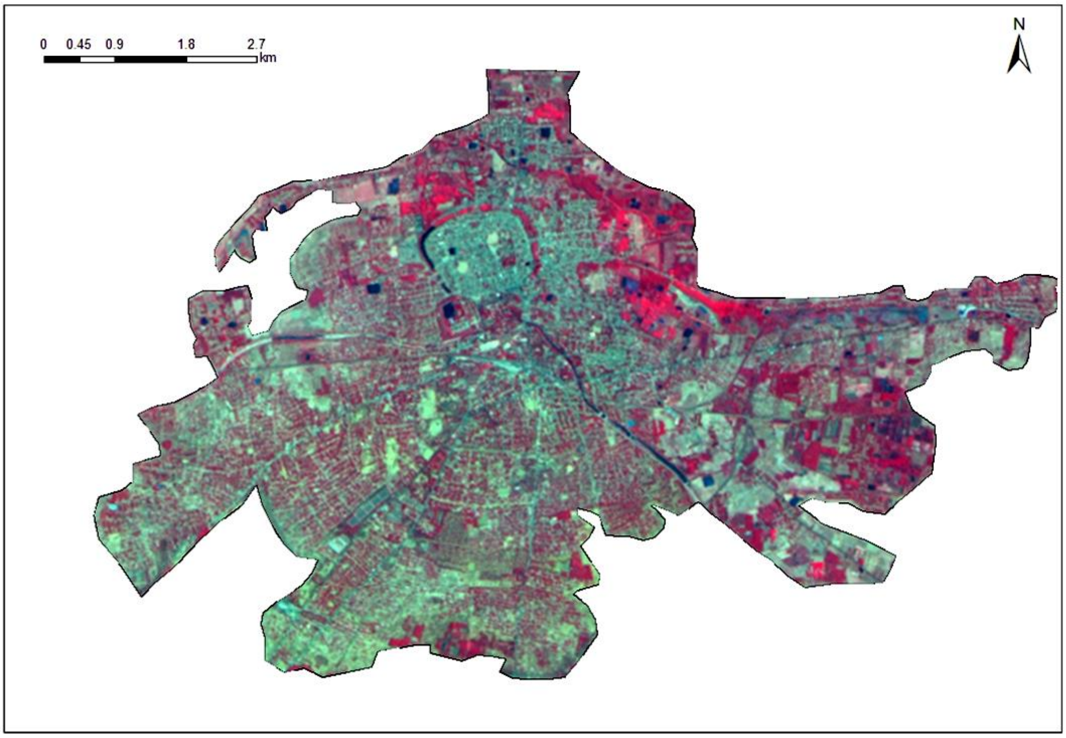


Figure (1): Satellite imagery for Thanjavur urban area IRS P6_07APR2006 data

Table 1. Details on area coverage for each of the land uses

Year	Area in km^2				
	Built-up	Open scrub	Open space	Vegetation	Water bodies
1991	9.12	9.98	4.37	22.60	1.65
1999	10.42	7.50	5.43	21.62	2.76
2006	22.34	7.56	8.29	8.93	0.78

Built-up Density

Three built-up density types were identified and used in this study: (1) high density, (2) moderate density and (3) low density. The threshold limit for each class of land use is generally assigned based upon the occurrence of impervious surfaces compared to permeable surfaces (Di Gregorio, 2005). The threshold limit for high density area is defined as 75% of the total surface consisting of impervious surfaces, 50 to 75% for medium density area and 50 to 30 % for low density area. The area of each land use in terms of built-up density is calculated using raster attributes. The raster attributes calculate the area of each pixel according to the land use it belongs to. Fig.3 shows the packet of built-up area spread over the town rural fringe. The computation of built-up density gives the distribution of high-, moderate- and low-density built-up clusters in the study area. High built-up density would refer to clustered or more compact nature of the built-up theme (Fig. 4a), while medium density would refer to relatively lesser compact built-up (Fig. 4b) and low density would refer to loosely or sparsely found built-up (Fig.4c). Table 2 presents the area of each built-up density for Thanjavur city as per year 2006.

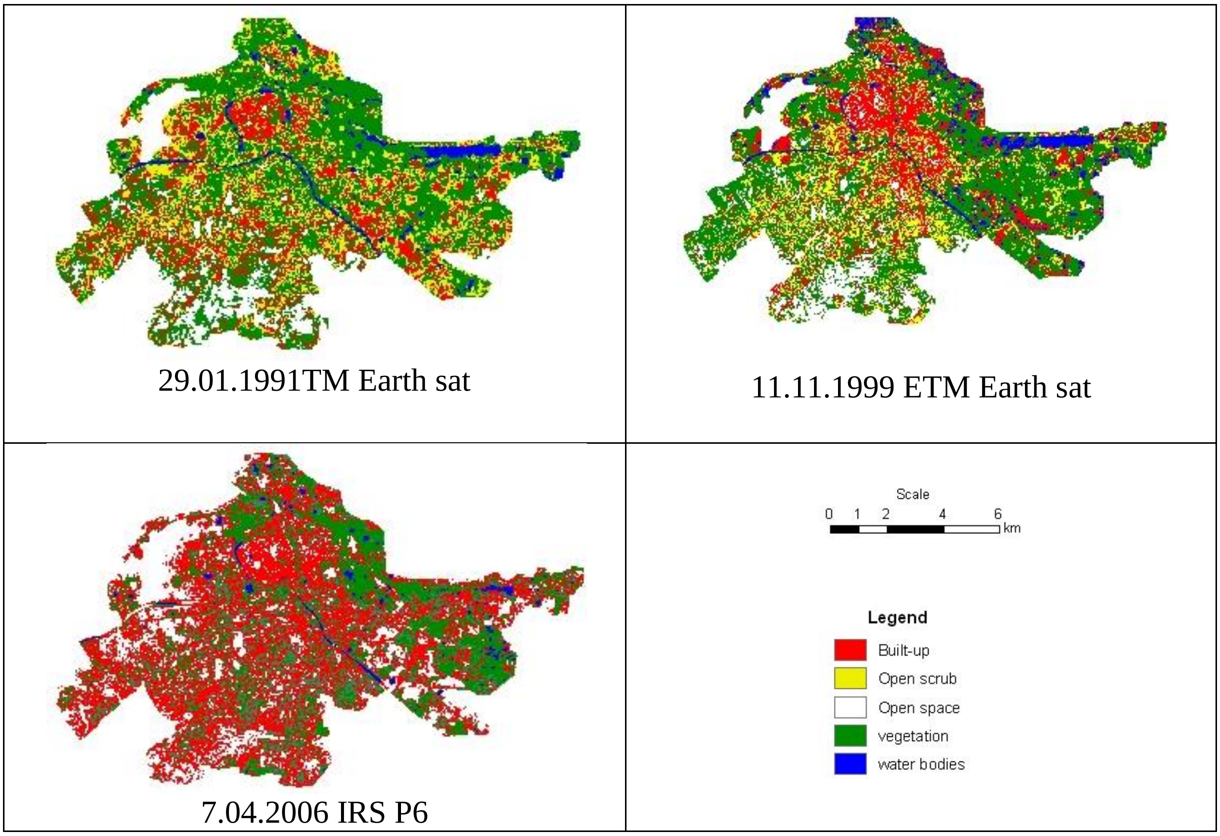


Figure (2): Classified satellite imageries

Table 2. Different densities of built-up and their areas

Class	Category	Area in sq.km
1	High density	10.62
2	Moderate density	9.31
3	Low density	2.41
		22.34

Urban Sprawl

The pattern and pace of land development and the rate of land devoted to urban purposes which exceeded the rate of population growth resulting in an inefficient and consumptive use of land and its associated resources, are termed sprawl (Farooq and Ahmad, 2008). It is to be noted that there is no single factor that determines how our landscape and settlement patterns change over time. Various policies and public decisions at the local, state and national level, as well as individual preferences and actions, have served to foster sprawl. Public investment in roads, government buildings, colleges, universities, water, sewer and other infrastructure in peripheral areas, increase in population, increase in cost of land near urban center are some of the factors that accelerate the growth of sprawl. Klug and Hayashi (2012) pointed out that urban density and housing density significantly influence the extent of local sewerage and road infrastructure.

Urban sprawls have been categorized into three classes based upon their forms and patterns. (Barnes et al., 2001). These classes are as follows:

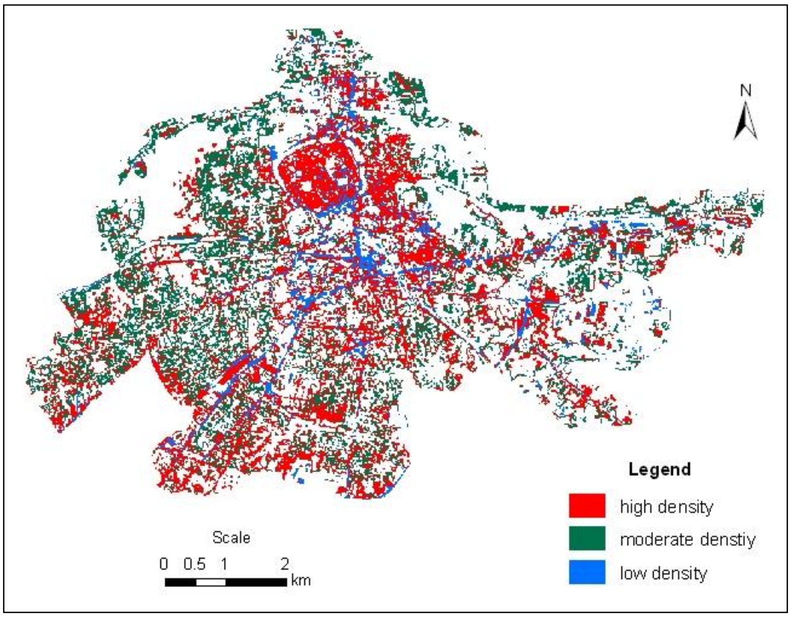


Figure (3): Different densities of built-up area in Thanjavur urban using IRS P6_07APR2006 data

a) Low-density Sprawl

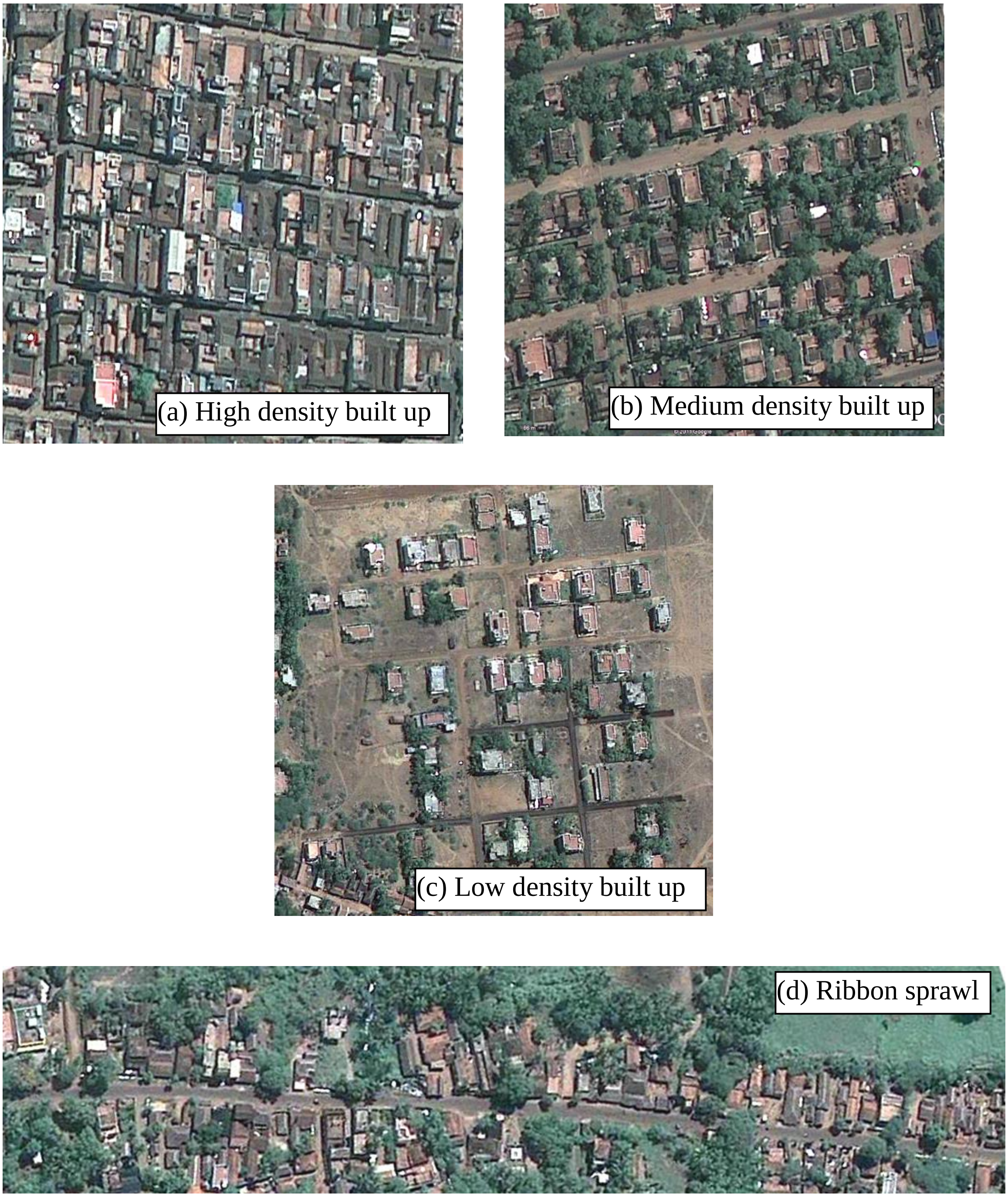
This type of sprawl is one in which there is consumptive use of land for housing purposes along the margins of existing urban areas. This type of sprawl is supported by piecemeal extensions of basic urban infrastructure such as water, sewer, power and roads. This kind of development takes up space and houses are situated in relatively larger lots and residence requires long driving to reach shopping centers and hence may increase the driving time.

b) Ribbon Sprawl

Development that follows major transportation corridors outward from urban centers is termed ribbon sprawl. Lands adjacent to major roads and highways are developed, while those distant from these remain a rural land use/land cover. Fig. (4d) and Fig. 5 show low-density sprawl and ribbon sprawl of the study area.

c) Leapfrog sprawl

A discontinuous pattern of urbanization is termed leapfrog sprawl. This consists of patches of developed lands that are widely separated from each other and from the outer margins of well-established urban centers. This form of development is the most expensive in so far as providing civic services such as water and sewerage is concerned. This kind of development occurs when real estate people develop lands and build new residences some distance away from an existing urban area, bypassing vacant lands available closer to the city. Housing in this type of development is more affordable as land prices are lower. Some people prefer to live at a far away location from the heart of the city for the sake of comfortable and low-priced housing. Fig. 5 shows leapfrog sprawl development of the study area. It can be seen from Fig.5 that development has been taking place certain distance away from the town centre.



Courtesy: Google Earth

Figure (4): Different built-up density land uses of Thanjavur town

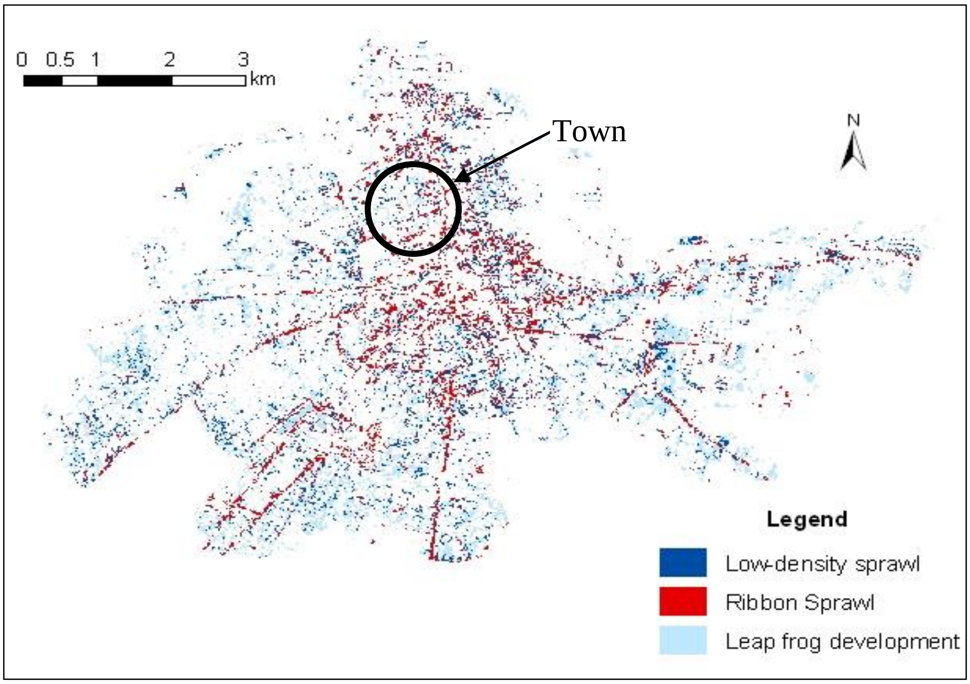


Figure (5): Urban sprawl in Thanjavur town, India

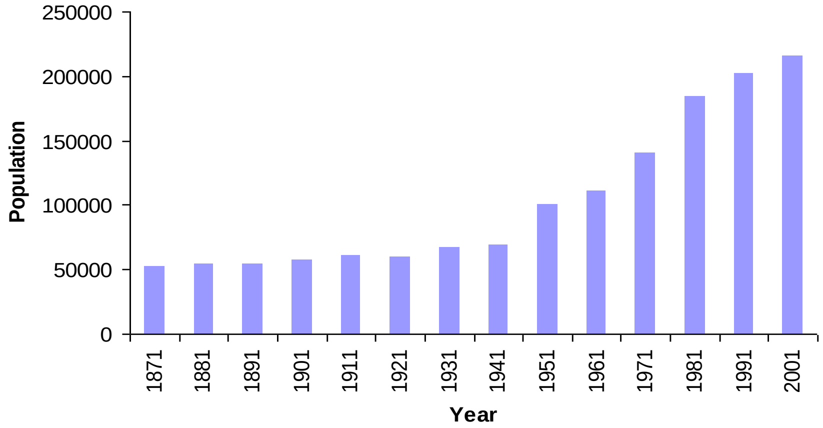


Figure (6): Historical population details for Thanjavur town

RESULTS AND DISCUSSION

Three satellite imageries and a topographical map are used in the present study to understand the land use/cover, built-up density and urban sprawl of Thanjavur city, India. The spatial mapping and evaluation of selected variables are conducted using unsupervised classification with the maximum likelihood algorithm. The main outcome of this study is the collection of relevant thematic information and evaluation of land use distribution in 1991, 1999 and 2006. While referring to the results of land use classification (Table 1), the built up area has increased from 9.12 to 22.34 sq.km within 15 years. City population census record shows that the population of the city has increased from 202013 in 1991 to 215725 in 2001. The projected population for 2006 is obtained as 222581 using linear interpolation between population of 1991 and of 2001. The population per sq.km of built up area for 1991 is 22150 which corresponds to 9.12 sq.km built up area, and assuming that the population density of 9.12 sq.km remains constant for the next 15 years, the expanding area has a population density of 1555 sq.km which is quite low compared to that of 1991. This indicates that there is a tremendous increase in the urban sprawl. This observation between population growth and land development indicates that land development is not in proportion with population growth. Fig.6 shows the historical population obtained from Wikipedia details on Thanjavur city. The changes which resulted in open space, scrub and water bodies are found to be insignificant, whereas the conversion from vegetation to built up area is quite large.

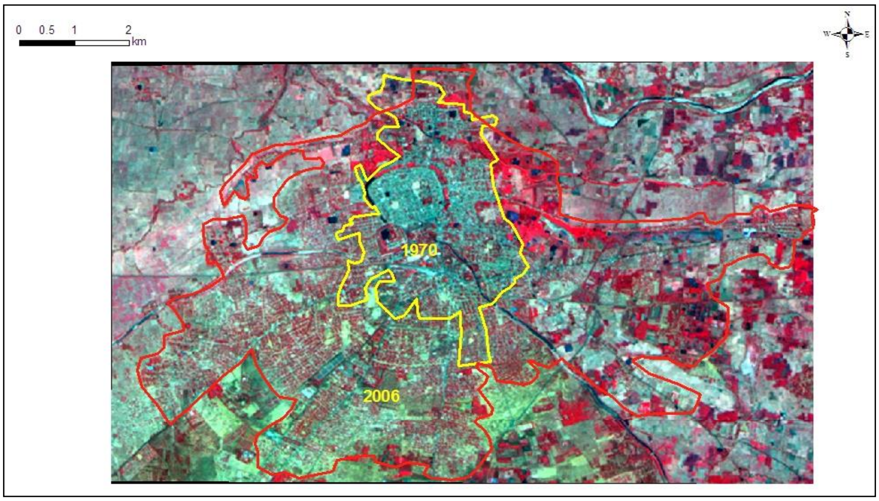


Figure (7): Layout showing urban expansion of Thanjavur town (1970-2006)

The coverage of high-density and medium-density built-up area is almost equal. While studying the classified images based on density, more compact or highly dense built up belongs to old city and moderate dense area which is shown as more dispersed to entire city boundary. An important inference that could be drawn out of this is that the high-density land use category was observed all along the urban roads and also at the heart of the city and closer to religious temples and palaces. However, moderate density and low density were also noticed mostly along the city periphery and also on highways. The development of low-density built-up area in Thanjavur city indicates the sign of rapid development in the new layouts. In the study area dominates the leapfrog sprawl rather than the low density sprawl and the ribbon sprawl. Creation of bypass roads around the city which connect state and nation highways brought big growth in the scattered sprawl pattern which is visible in the classification. In a span of thirty years, four universities and ten education institutions have been located along the state and national highways, which brought a scattered sprawl pattern as dominant sprawl instead of the ribbon sprawl of 1970.

a: Google imagery dated Dec 13 2001

b: Google imagery dated June 29 2009

c: Google imagery dated Dec 13, 2001

d: Google imagery dated Aug 28, 2007

e: Google imagery dated June 29 2009

Source: Google Earth

Figure (8): Selected parts of google imageries to mark changes in land use

Urban expansions around Thanjavur city and considerable change in different land-use categories over a period of 38 years are another concern of the present study. From the topographical sheet of 1970, urban area is demarcated and development area is measured. It was found that the urban spread out to an aerial extent of 18.93 sq.km only. The urban area corresponding to 2006 is measured from imageries, and it is found to be 47.142 sq.km. This shows that Thanjavur city expanded 60% more than it was in 1970. This urbanization resulted not only due to population growth but also to the development of the medical college and other facilities created in and around the town. Another important reason of such development is non-availability of land in the old city area which is seen as a high-density area in the imageries, and also the market cost of land in the old city is found to be very high which is actually unaffordable to the common man. High land cost and surging development activities forced people to move away from the older city area. While comparing the land use as per topographical sheet and 2006 imageries, most of the urban expansion took place in the agricultural area. Fig. 7 presents the demarcated urban area of Thanjavur town as in 1970 and 2006, respectively.

The circled area in (Fig.8a and b) shows the change in land use that resulted between 2001 and 2009**.** The circled area in Fig. 8a and the corresponding area in Fig. 8b indicate the growth of residential buildings. It is clearly seen from the imageries that the open uncultivated land is converted to a residential area and a large number of houses have come up within the span of 8 years. Further, while studying (Fig. 8c, d and e), the grain storage go-downs are found to be missing in Fig. 8d and same is converted into residential plots. The imagery corresponding to 2009 shows some houses in the circled area. This study reveals that the tremendous changes are happening all over the urban area and the surrounding urban fringes. Studying the dynamics of land use and cover over time can provide valuable and visible information to authorities of urban planning and development department of the country for preparing master plans. Further, remote sensing based studies enable the urban planner to prepare long-term plans for infrastructure investments and implementing poverty alleviation programs.

CONCLUSIONS

The study investigated the urban sprawl of Thanjavur city located in India using IRS and EarthSat images along with topographic map supported by Google Earth map. Three important parameters; namely: land use, built up density and sprawl are considered to evaluate the growth of the urban. From the study, it is found that the urban area expanded 60% more than it was in 1970. The results of the study show tremendous changes in the built up and vegetation land use compared to other land uses during the span of thirty eight years. This study shows that the city is experiencing a leapfrog pattern of urban sprawl and a ribbon sprawl along highways. Most of sprawl areas come up in the agricultural area available in and around the town. The decrease in the indigenous vegetation has been increasingly found in the study area. This study brings out the potential of remotely sensed data for urban growth studies and offers a rich source of information for better planning, management and development.

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