

TREES OF BENGALURU



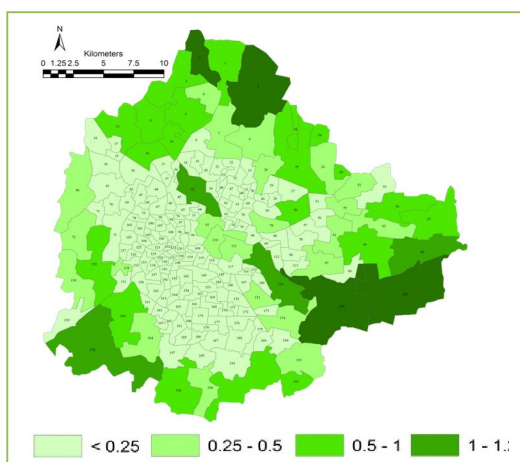
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Environment Information System [ENVIS]

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TREES OF BENGALURU

Summary

Urban vegetation includes trees, shrubs and, herbs in public and private lands (parks, streets, backyards) in the landscape dominated by paved surface. Urban vegetation plays a vital role as it moderates micro climate apart from sequestration of green house gases (CO₂, etc.) and aid in the percolation of water. World Health Organization recommended minimum green space of 9.5 m²/person) considering the services (oxygen, moderation of micro climate) and goods in the urban environment. Estimates indicate that about 6 tons of carbon is sequestered by 1 hectare forests annually and this accounts to 6 kg/tree/year. Per capita respiratory carbon ranges from 192 to 328 kg/year depending on physiology of humans (525-900 gms/day/person depending on the physiology). This means 32 to 55 trees per person in a region is required to mitigate respiratory CO₂ only.

Bengaluru / Greater Bangalore / Bruhat Bengaluru / Bangalore (77°37'19.54'' E and 12°59'09.76'' N) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. Bangalore city population has increased enormously from 6,537,124 (in 2001) to 9,588,910 (in 2011), accounting to decadal growth of 46.68%. Population density has increased from as 10,732 (in 2001) to 13,392 (in 2011) persons per sq. km. The vegetation of Bangalore was classified as dry deciduous forest-type under the *Terminalia-Anogeissus latifolia-Tectona* series. The city enjoyed salubrious climate throughout the year prior to industrialization era.

Land use analysis based on the fusion of Resourcesat-2 MSS data with Cartosat 2 show that the spatial extent of tree vegetation in Bangalore is 100.02 Hectares (14.08%). Spatial extent of vegetation is minimum (less than 1 hectare) in wards such as Chickpete, Shivajinagara, Kempapura agrahara, Padarayanapura, while wards such as Varthur, Bellandur, Agaram have higher vegetation cover (> 300 hectares). The wards such as Hudi, Aramane nagara and Vasantha pura have higher vegetation density (spatial extent of area under vegetation to the geographical are of a ward) of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower density with less than 0.015. Bangalore has an average vegetation density of 0.14. Mapping of trees based on canopy delineation coupled with field data show that wards such as Vathuru, Bellanduru, Agaram, Aramane nagara have the

trees greater than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards have trees less than 100 trees. Based on these, total number of trees in Bangalore is about 14,78,412 trees. Computation of trees per person show that Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara wards have very less number of trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people. Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, Aramane nagara have trees more than one per person indicating the presence of one tree for every person. Intra city analysis show that major cities such as Gandhinagar, Bangalore, Ahmedabad, Brihan Mumbai are with spatial extent greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people followed by Bangalore with 17 trees, Brihan Mumbai with 15 trees and Ahmedabad with 11 trees. Reduced vegetation cover with urbanization has serious implications for the city's environmental and ecological health. This highlights the city has crossed the threshold of urbanization evident from a range of psychological, social and health impacts for residents including dramatic increase in recent times of instances such as higher instances of domestic violence, obesity, enhanced asthma levels, traffic bottlenecks, road accidents, etc. Overall improvements in human well-being and community vitality necessitate urban planners to maintain at least 33% green cover in the region. In such a case there would be at least 1.15 trees/person in the city.

Keywords: Benagaluru, Bangalore, trees, tree density, vegetation density, trees per person

1.0 Introduction

Urban vegetation includes trees, shrubs and herbs in public and private lands (parks, streets, backyards) in the landscape dominated by paved surface. Urban vegetation plays a vital role as it moderates micro climate apart from sequestration of green house gases (CO_2 , etc.) and aid in the percolation of water. Enormous environmental, ecological, economic and social benefits from urban vegetation documented that include removal of air pollutants such as Sulphur dioxide (SO_2), Nitrogen oxides (NO_x), Carbon dioxide (CO_2), particulate matter by leaf stomata and by the leaf surfaces especially if their surfaces are waxy, spiny or hairy (Li et al., 2014; Vailshery et al., 2013; Ghose et al., 2005; Khan and Abbasi 2000; Chaturvedi et al., 2013; Ghauri et al., 2007; Yang et al., 2005; Harris and Manning 2010; Dwivedi et al., 2009; Inkilainen et al., 2013; Secon, 2010), dust removal by leaves of Mango (*Mangifera indica*), Ashoka (*Polyalthia longifolia*), Pongamia (*Derris indica*) and Umbrella - *Thespepsia populnea*

(Shetye and Chaphekar, 1980, Ghose et al., 2005). Trees act as a barrier which helps to reduce noise pollution by absorbing and blocking urban noise, reducing stress for people living and working around trees (Zannin et al., 2006). Furthermore, urban trees function as natural 'air conditioners' which affect the use of local energy use (electricity and cooling) in the residential areas and offices (Akbari et al., 2001; Sudha and Ravindranath 2000).

Vegetation helps in altering the amounts of heat energy absorbed, reduction of the solar heat gains on windows, walls, roofs through shading, increase the latent cooling by addition of moisture to the air through evapotranspiration and reducing the long-wave exchange with the sky as building surface temperatures are lowered through shading (Dimoudi and Nikolopoulou 2003; Taha et al., 1988; Grimmond and Oke 1991). Vegetation helps in the hydrologic cycle as about 30% of the precipitation absorbed by leaves gets back to the atmosphere through evaporation. Significant part of precipitation through root system gets infiltrated and recharge ground water aquifers. Thus vegetation helps in mitigating flooding in the landscape. The extent of vegetation cools the urban climate mainly depends upon the type and composition of the vegetation. The leaf temperatures depend upon the anatomical, physical and physiological factors (Monteith and Unsworth, 1990). Studies have substantiated temperature moderation by vegetation (Myrup et al., 1993; Shashua-Bar and Hoffman, 2004; Doick and Hutchings 2013). Reports reveal unshaded suburban area is approximately 2.5°C warmer than compared to the open rural area and unshaded suburban site warmer by 1°C compared to the shaded area..

All the tree species does not have the same cooling effect, it varies in their ability to reduce the air temperature which may be due to the tree size and tree canopy characteristics. World Health Organization recommended minimum green space of 9.5 m²/person) considering the services (oxygen, moderation of micro climate) and goods in the urban environment (Kuchelmeister, 1998). Trees play major role in accommodating arboreal species of insects, birds, etc. Trees also have aesthetic value which adds beauty to the surrounding by adding color, softening harsh lines of building and contributes to the character of their environment.

Industrialization, coupled with deforestation and other anthropogenic activities have increased the emission of greenhouse gases such as Carbon dioxide (CO₂), Methane (CH₄), Nitrogen oxide (NO_x), Sulphur dioxide (SO₂). About 75% of CO₂ is emitted due to the burning of fossil fuels during the past 20 years (Schneider, 1989) and the atmospheric carbon dioxide concentration increased (Trenberth and Kevin 2007) from 280 ppm (preindustrial) to 382 ppm,

(2006), and to 390 ppm (2011). This has led to an increase in the atmospheric temperature by trapping the certain wavelength of radiation in the atmosphere. Trees and soil in the urban area serves as sink to capture and store the atmospheric carbon dioxide (Negi and Gupta 2013; Nowak and Crane 2002). Estimates indicate that about 6 tons of carbon is sequestered by 1 hectare of forests annually and this accounts to about 6 kg/tree/year (Secon, 2010). The per capita human respiratory carbon ranges from 192 to 328 kg/year, which means 32 to 55 trees per person in a region is required to mitigate respiratory CO₂.

Rapid pace of urbanization is the dominant anthropogenic phenomenon in the worldwide (Ramachandra et al., 2012). Unplanned urban development have telling impacts on the environment in the developing countries, evident from higher pollutants in air, contamination of water and land (Gairola 2013). Population in India has increased from 63 (1950) to 377 million (2011). India's urban population stands next to China and the demand of land has increased substantially for various human needs. The vegetation cover, wetlands and other natural ecosystem have been retreating with the expansion of cities (Gairola 2013; Zhou et al., 2011). Urbanization being a global phenomenon involving unprecedented expansion of land cover which in turn led to rapid increase in urban extent and growth of unplanned regions (Ramachandra and Bharath, 2012). Unplanned urbanization and lack of optimal management of natural resources by city officials has lead to the gradual decline in the urban service such as water quality, air quality, inadequate infrastructure, poor quality of life, etc (Escobedo et al., 2011; Ramachandra et al., 2012). Trees have potential to moderate air temperature through shading, reduction of surface temperature and through evaporative cooling (McPherson et al., 1994). Urban heat island refers to the trend in which urban areas are warmer than rural area, which is caused by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities coupled with decrease in vegetation and water bodies (Ramachandra and Uttam 2010; Song 2013). Table 1 lists the efforts towards quantification of ecological services.

Trees have potential to moderate air temperature through reduction of surface temperature and evaporative cooling (McPherson et al., 1994). In order to understand the current tree cover traditional practices of tree counting has inherent problems such as requirement of extensive labour and biased. Remote sensing and geographic information system (GIS) makes timely unbiased spatial information accessible. Spatial information refers to extraction of various land

form features (Bhatta, 2009; Ramachandra et al., 2013). Multi resolution remote sensing data aid in capturing this dynamics. Fusion of data from multiple sensors aids in delineating objects with comprehensive information due to the integration of spatial information present in the high resolution (HR) panchromatic (PAN) image and spectral information present in the low resolution (LR) Multispectral (MS) images. Image fusion techniques integrate both PAN and MSS and can be performed at pixel, feature and decision levels.

Table 1: Benefits of trees

Benefits	References
Improves urban microclimate and reduces emission of SO ₄ and Suspended Particulate Matter in the atmosphere	Vailshery et al., 2013
Carbon sequestration and reduces the air pollution	Yang et al., 2005
Reduces the atmospheric emission and carbon sequestration	McPherson et al., 2013
Carbon sequestration	Thomas et al., 2007
Reduce consumption of electricity, pollution, ameliorating air borne and water pollution.	Brack 2002
Reduce the use energy for cooling and heating.	Simpson 1998
Reduces the atmospheric CO ₂ concentration	Yousif and Tahir 2013
Reduces the surface water runoff	Armson et al., 2013
Mitigation of Urban heat islands	Sung 2013;
Improve air quality	Vos et al., 2013
Aesthetic value, reduction of storm water runoff, energy saving	McPherson et al., 2011
Mitigation of urban heat island effect	Zhang et al., 2013
Flood control	Sung and Li 2010
Improves the microclimate and reduces the carbon emission from electricity.	Donovan and Butry 2009

This work optimises multi-resolution data analysis to understand green cover in Greater Bangalore. Remote sensing image fusion techniques are useful to integrate a lower spatial resolution MSS image with a higher spatial resolution PAN image. Fusion of multi resolution data aided in taking advantage of spectral and spatial resolutions for identification of features in urban areas because the characteristic of urban objects are determined not only by their spectra but also by their structure. The main aim of the study is to map the current vegetation cover in Greater Bangalore. Assessment of vegetation involved (i) mapping of trees in each ward and (ii) computation of metrics such as population density, trees per person, etc.

2.0 Study Area

Bengaluru / Greater Bangalore / Bruhat Bengaluru / Bangalore (77°37'19.54'' E and 12°59'09.76'' N geographically located at the south eastern part of Karnataka state) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state (fig.1). The city is subdivided 8 zones with 198 wards under the jurisdiction of BBMP. Bangalore is geographically extends from 12°49'5''N to 13°8'32''N and 77°27'29'' E to 77°47'2'' E encompassing an area of 741 km². Spatial extent of Bangalore has increased over 10 times between 1949 (69 km²) to 2006 (741 km²) (figure 2) and is the 5th largest metropolis in India (Ramachandra et al, 2012; Sudhira et al., 2007). The population (figure 3) of Bangalore urban (BBMP limits) has increased by 48%, from 5.84million in 2001(Census, 2001) to 8.64 million (Census, 2011) in 2011. The population distribution in past two decades ward wise is as depicted in figure 4. The population density in the region (figure 4) has increased from 7881 persons/km² (2001) to 11664 persons/km² (2011).

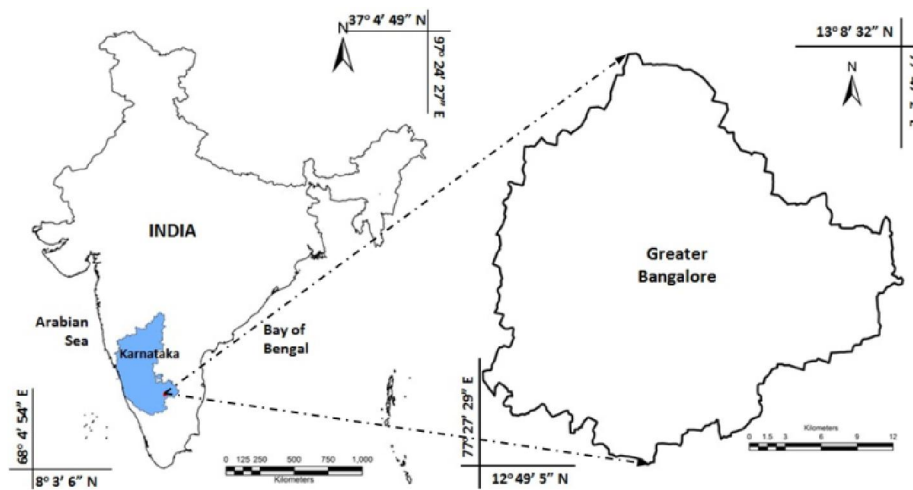


Figure 1: Study area Greater Bangalore / Bengaluru / Bruhat Bengaluru / Bangalore

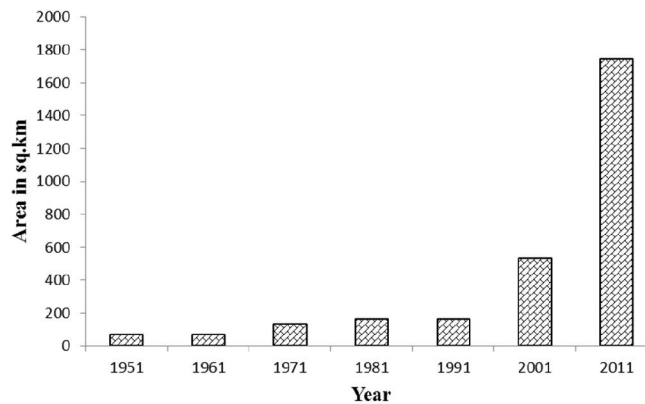


Figure 2: Spatial growth of Bangalore

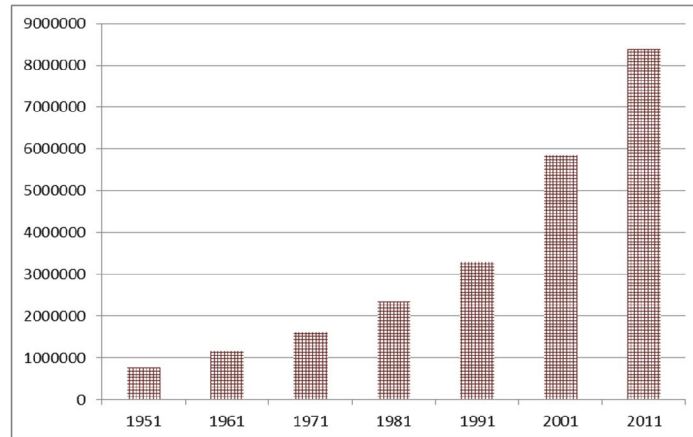


Figure 3: Escalating Population of Bangalore

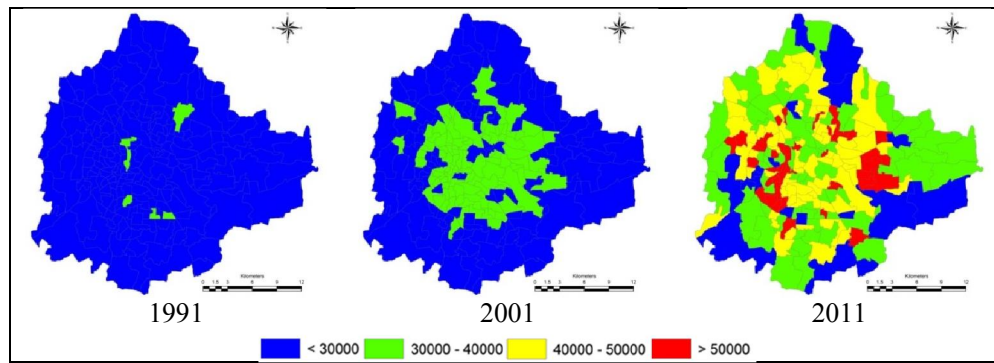


Figure 4: Ward wise population distribution

The topography (figure 5) of the region is undulating, the altitude varies from about 740 m to over 960 m above mean sea in the region is main cause for formation of large number of drainages and storage tanks. These water bodies and open green spaces are responsible for moderating local climate. Temperature varies from 22 °C to 38 °C during summer and 14 °C to 27 °C in winter. Bangalore receives an annual average rainfall of about 800 mm.

Bengaluru (77°37'19.54'' E and 12°59'09.76'' N) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. The present name Bengaluru has its origin to 'benga', the local term for *Pterocarpus marsupium*, a species of dry and moist deciduous tree, and ooru, meaning town (Ramachandra and Mujumdar, 2006; Sudha and Ravindranath, 2000). Bengaluru (Bangalore) was known as 'Garden city of India' due to its vast green cover, fauna and two nationally recognized botanical gardens - Cubbon Park and Lalbagh. Currently Bangalore is second fastest and fifth largest metropolis in India and has

experienced unprecedented expansion of urban area 69 km² in 1949 to 741 km² in 2010 (Ramachandra and Kumar, 2010; Ramachandra et al., 2012). Bangalore city population has increased enormously from 6,537,124 (in 2001) to 9,588,910 (in 2011), accounting to decadal growth of 46.68% . Population density has increased from as 10,732 (in 2001) to 13,392 (in 2011) persons per sq. km (Ramachandra et al., 2012). The vegetation of Bangalore was classified as dry deciduous forest-type (Champion and Seth, 1968) under the *Terminalia-Anogeissus latifolia-Tectona* series (Puri et al., 1983). The city enjoys the salubrious climate throughout the year.

In the early 17th century, Bangalore comprised natural thorny forests (Kamath 1990). Green vegetation within the Bangalore city was initiated by Hyder Ali, a ruler of Mysore city. He also established Lalbagh with an area cover of 100 hectares as his private garden which is now public garden. Since then the Bangalore city identified as ‘Garden city’. Subsequently in 1831, British further established greening the city with the creation of Cubbon Park (Issar 1998, Iyer et al., 2012).

During the British tenure, park culture was introduced, which was a new perspective to the use of social spaces. The park culture got integrated slowly among Indians, through the elite and educated. For instance, Malleshwaram is one of the oldest area in the city. It has readily adopted the park culture and also retained Indian traditional practices. They started to grow vegetables and fruits in their home gardens and also planted trees along the roads. Some streets in Malleshwaram derived their names from the trees that were grown along the entire stretch like “Sampige” (*Michelia champaka*) and “Margosa” (*Azadirachta indica*) roads.

From 1965 onwards, the city began to evolve into a city of small-scale industries. By 1998, it was recognized as IT hub. Bangalore also houses IT and IT based industries and numerous leading commercial and educational institutions, industries like textile, aviation, space, and biotechnology have come up. The immediate consequence of this growth also created pressure on infrastructure and basic amenities like water supply, energy, public transportation, land etc. Large plots and colonial bungalows with home gardens gave way to multi-storied apartment blocks with just small patches of lawn. In terms of natural flora, Bangalore city had 979 species in 542 genera, 133 families (Ramaswamy and Razi, 1973). Due to the rapid unplanned urbanization and urban sprawl, the spatial extent of Bangalore increased from 69 sq.km (1949)

to 741 sq. km (2010). Now Bangalore is the fifth largest metropolis in India with a population of about 8.4 million (census, 2011).

Bangalore's urban vegetation comprises of trees are *Alstonia scholaris*, *Artocarpus heterophyllus* (Jack fruit), *Azadirachta indica* (Neem), *Bombax cieba* (Red silk cotton), *Butea monosperma*, *Ficus bengalensis* (Alada mara), *F. religiosa* (Ashwatha), *Gmelina arborea*, *Kigelia pinnata* (Sausage tree), *Lagerstroemia speciosa* (Pride of India), *Mangifera indica* (Mango), *Madhuca longifolia* (Mehwa or Ippe), *Melia composite* (Malabar Neem), *Michelia champaca*, *Neolamarkia kadamba* (Kadamba), *Pongamia pinnata* (Honge), *Pterocarpus marsupium* (Honu), *Syzigium cumini* (Jaamun), *Saraca indica* (Seeta Asok), *Swetenia* sp (Mahogani), *Terminalia arjuna* (Arjuna), *T. bellerica* (Tare), *Tabebuia spectabilis* etc.

Some of the gracious exotic trees found as avenue trees are: *Delonix regia* (Gulmhur), *Enterolobium saman* (Rain tree), *Parkia biglandulosa* (Badminton ball tree), *Peltophorum pterocarpum* (Copper pod), *Spathodea companulata* (African tulip tree), *Tabebuia spectabilis*, *Polythia longifolia* etc. Trees have various important roles to play in the ecosystem, few are as listed in **Annexure I**. In recent years, the increase in vehicular traffic has also increased the Carbon dioxide, Nitrogen, Sulphur dioxide and suspended particulate matter in the environment. Air pollution and reduction in the green vegetation induced the urban heat island effect which results in variation in microclimate.

Bangalore is also known for their lakes which are paradise for ecology. In 1962 Bangalore had 265 water bodies due to the rapid urbanization the water bodies decreased to 98 in 2010. As the city grew over the space and time, inner areas got more crowded and congested (Ramachandra et al., 2012). Road network has increased and also being widened by axing the numerous road trees. Many lakes and tanks were encroached and converted to residential layouts, multi-storey buildings, playgrounds, bus stands etc. and some lakes were used for dumping of municipal solid waste or building debris (Sudhira et al., 2007). It has been observed that about 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74% (Ramachandra et al., 2012).

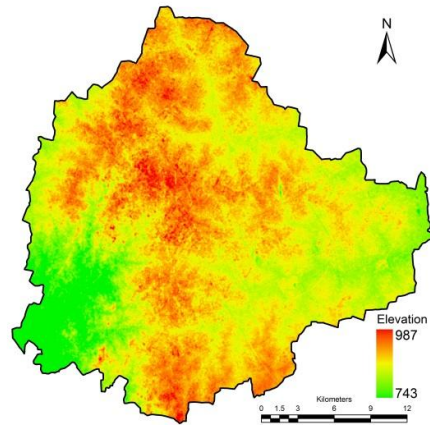


Figure 5: Topography

Bangalore is located on a ridge with natural water courses along the three directions of the Vrishabhavaty, Koramangala-Challaghatta (K&C) and Hebbal-Nagavara valley systems. The drainage allows the flows to cauvery through its tributaries Arkavathi (East flowing), Pinakini/Pennar (East Flowing) and Shimsha (West Flowing). The central, northern and eastern portion is undulating with the upland tracts occupied by scrubs, while the low lands occupied by series of tanks formed by embanking the streams along the valley for irrigation purposes. These valleys vary in size from small ponds to large lakes. The southern portion of the land consists of hills that are close together and are surrounded by scrub jungles and forests. Geologically the area consists of Granitic and Gneisses rocks in large scale (Bangalore District Gazetteer, 1981; Sekhar and Mohan, 2009), and other rocks include dykes, dolerites, schist's. As the city grew over the space and time, inner areas got more crowded and congested. Road network has increased by axing the numerous road trees. Many lakes and tanks were encroached and converted to residential layouts, multi-storey buildings, playgrounds, bus stands etc. and some lakes were used for dumping of municipal solid waste or building debris (Ramachandra et al., 2012; Sudhira et al., 2007).

Land use dynamics: Table 1 and Fig 6 gives an insight to the temporal land use changes. The built-up area has increased from 7.97% in 1973 to 58.33 % in 2012 (Ramachandra et al, 2012a; Ramachandra et al, 2011; Bharath S et al, 2012). The sudden increment in urbanization post 1990's could be observed due to the industrial revolution towards Peenya, Rajajinagar.

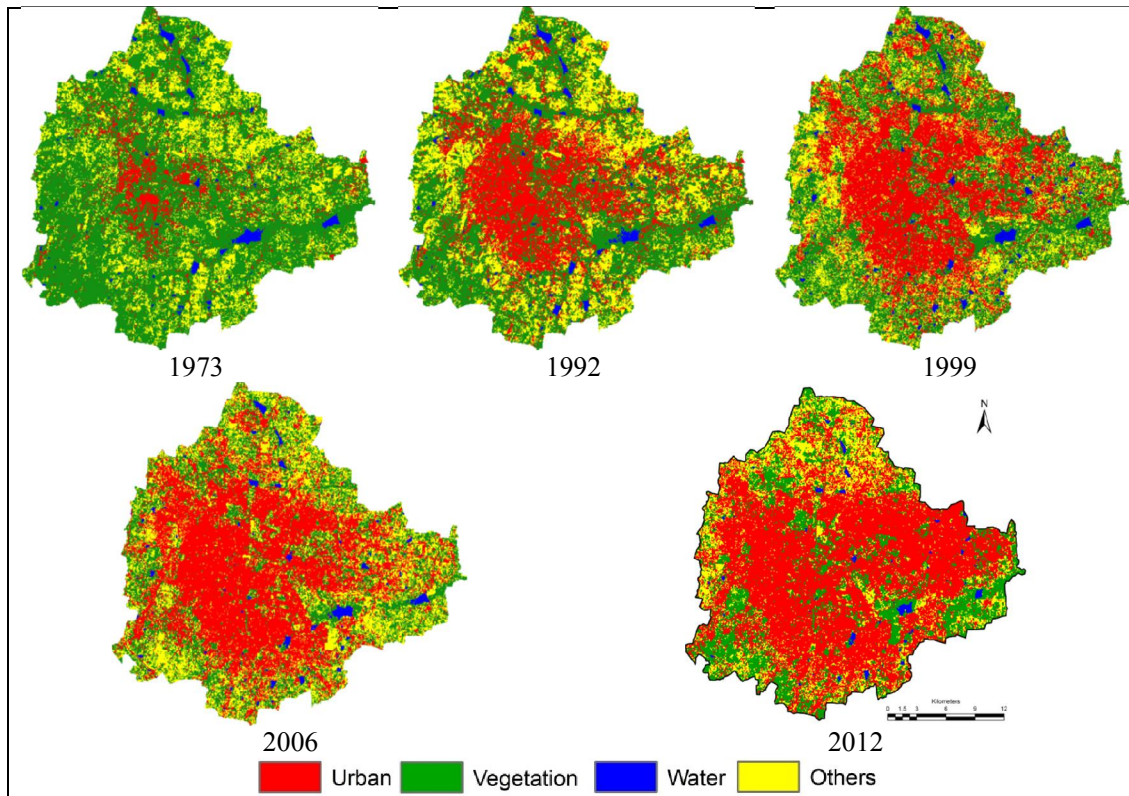


Figure 6: Land use dynamics

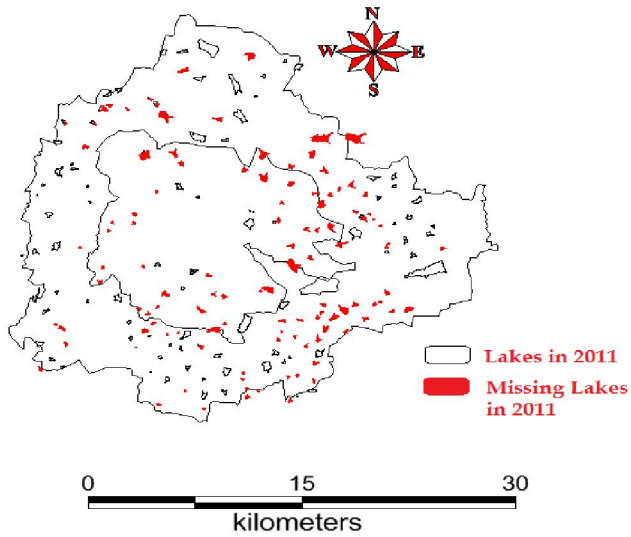


Figure 7: Lakes of Bangalore

Table 1: Temporal Land use dynamics

Class	Urban		Vegetation		Water		Others	
	Ha	%	Ha	%	Ha	%	Ha	%
1973	5448	7.97	46639	68.27	2324	3.4	13903	20.35
1992	18650	27.3	31579	46.22	1790	2.6	16303	23.86
1999	24163	35.37	31272	45.77	1542	2.26	11346	16.61
2006	29535	43.23	19696	28.83	1073	1.57	18017	26.37
2012	41570	58.33	16569	23.25	665	0.93	12468	17.49

Post 2000, due to the evolution of the software sectors led to the large scale land use changes with urbanization at White field, Electronic city, Domlur, Hebbal, due to private players and development of Special Economic Zones. Bangalore, once branded as the Garden city due to dense vegetation cover, which has declined from 68.27% (1973) to less than 25% (2012). Similar to vegetation, Bangalore was also known as city of lakes for numerous lakes that were present (209 lakes). The impact of urbanization has diminished lake bodies (93 lakes as per 2011) (fig 7) and also loss of feeder canals (rajakaluve). The water bodies have reduced from 3.4% (1973) to less than 1% (2012). Other land uses has changed from 20.35% (1973) to 17.49% (2012).

3.0 Objective: Objective of this study is to map trees in Bangalore city (Bruhat Bangalore) and computation of ward wise tree density and trees per person.

4.0 Data: Indian remote sensing (IRS) satellite data (Resourcesat 2, Cartosat 1) procured from the National Remote Sensing Centre, Hyderabad (<http://nrsc.gov.in>) were used in the analysis. The remote data was supplemented with datasets such as i) Survey of India topographic maps of 1:250,000, and 1: 50000 scale, ii) online data such as Google earth (<http://earth.google.com>), Bhuvan (<http://bhuvan.nrsc.gov.in>) and field data collected from wards using pre-calibrated GPS. These supplementary data sets were used for delineating and extracting administrative boundaries, geometrical correction of remote sensing data, classification, verification and validation of classified outputs. The GPS based field data along with the virtual online better spatial resolution remote sensing data were used for estimating number of trees per ward. Census of trees with canopy in select wards helped in assessing the tree distribution in each ward of Greater Bangalore. Table 2 gives the summary of the data used for inventorying and mapping of trees in Bangalore.

Table 2: Data used for inventorying and mapping trees in Bangalore

Data	Year	Description
IRS Resourcesat 2 – multi spectral data, 5.8 m spatial resolution	2013	Land Use Land Cover Analysis
IRS Cartosat 1, 2.7 m spatial resolution	2013	Land Use Land Cover Analysis(Resolution 2.7 m)
SOI – The survey of India Topographic maps (http://www.surveyofindia.gov.in)		1:250000 and 1: 50000 topographic maps for delineating administrative boundaries, and geometric correction
Bhuvan (http://bhuvan.nrsc.gov.in)		Support data for Site data, delineation of trees in selected wards
Field Data		For classification, frequency distribution analysis and data validation
Google Earth (http://earth.google.com)		Support data for Site data, delineation of trees in selected wards
Census of India (http://censuuindia.gov.in)	1991, 2001, 2011	Population census for growth monitoring and forecasting

5.0 Method

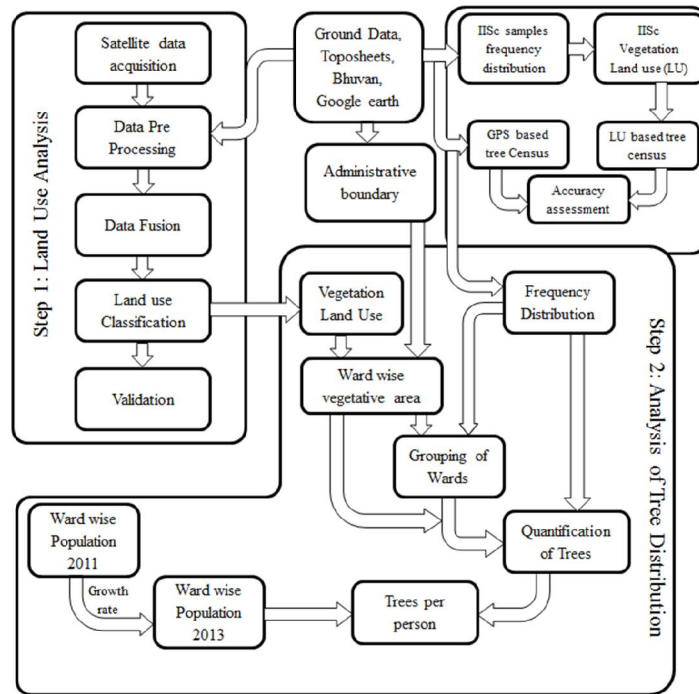


Fig 8: Method used for data analysis

To quantify the number of trees per person in each of the ward in Bangalore, the following steps were followed: i) Land use analysis using remote sensing, ii) deriving tree canopy, iii) canopy distribution in each ward, iv) field data analysis – tree canopy distribution, v)

computation of number of trees in all wards based on field knowledge using remote sensing data, vi) computation of metrics (tree density, number of trees per person).

Land use analysis using remote sensing data: The land use analysis of the acquired remote sensing data was carried out using the following steps: a) data pre-processing b) data fusion c) classification d) validation.

- a) **Data Pre-processing:** The multi spectral remote sensing data (Resourcesat 2) and Cartosat 1 were geometrically corrected using ground control points collected from topographic maps, virtual remote sensing data as well as using GPS. This involved rectification of horizontal shifts.

Land use analysis: The method involves i) generation of False Colour Composite (FCC) of remote sensing data (bands – green, red and NIR). This helped in locating heterogeneous patches in the landscape ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, iii) loading these training polygons coordinates into pre-calibrated GPS, vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, iv) supplementing this information with Google Earth v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. Land use analysis was carried out using supervised pattern classifier - Gaussian maximum likelihood algorithm. This has been proved superior classifier as it uses various classification decisions using probability and cost functions. Mean and covariance matrix are computed using estimate of maximum likelihood estimator (Ramachandra et al, 2013; Ramachandra and Bharath, 2013; Vinay et al, 2012; Ramachandra et al., *in press*). Accuracy assessment to evaluate the performance of classifiers, was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients and proportion of correctly allocated cases. Recent remote sensing data (2012) was classified using the collected training samples. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's)

accuracies. The classification of the data has been completed using “GRASS” – Geographic Resource Analysis Support System (<http://ces.iisc.ernet.in/grass>) open source GIS software by considering four land use classes.

- b) **Data Fusion:** Data fusion was performed using algorithms - Hyperspectral Color Space resolution (HCS) merge, High Pass Filter (HPF) fusion, Modified Intensity Hue Saturation (MHIS) fusion, Wavelet Fusion.
- c) **Classification:** Fused remote sensing data was classified into four categories: i) built up; ii) vegetation; iii) water; iv) others, the landscapes under these four categories are described in table 3, all these four classes were combined to two land use classes i.e., Vegetation (Trees) and non-vegetation. The fused high resolution satellite images were classified using the Gaussian Maximum Likelihood Classifier (MLC) algorithm (Lillesand et al, 2004) to classify each pixel into a particular land use class.

Table 3: Land use categories

Land use Class	Land use included in class
Urban	Residential Area, Industrial Area, Paved surfaces, mixed pixels with built-up area
Water	Tanks, Lakes, Reservoirs, Drainages
Vegetation	Forest, Plantations
Others	Rocks, quarry pits, open ground at building sites, unpaved roads, Croplands, Nurseries, bare land

Fused data was classified using MLC with help of training data sets that were acquired from the field and supplementary data from Bhuvan and Google earth.

- d) **Validation:** The validation of the classified land use image was completed though the accuracy assessment and kappa statistics, for measuring the level of agreement between the classified land use image and a reference land use image and to assess the performance of the classifier (Ramachandra et al., 2012a; Bharath et al., 2012; Ramachandra and Bharath, 2012).

Analysis of Tree Distribution: The analysis of tree distribution was carried out based on frequency distribution of the tree canopy area. The method involved in assessing the distribution includes: a) Data Collection, b) Frequency distribution, c) Trees distribution in each ward.

- a) **Data Collection:** Trees with its canopy (spatial extent) were mapped in select wards using pre-calibrated GPS and also tree canopy of these trees weredelineated using better

resolution virtual data (Bhuvan, Google Earth). This gave information such as species wise canopy spatial extent and number of species in sampled wards.

- b) Frequency distribution:** Based on the field data, histogram (frequency distribution) of tree canopy were computed and wards were grouped i) wards with > 500 trees and ii) < 500 trees. Based on the tree distribution in each of these categories of sampled wards, number of trees in each ward is computed.
- c) Computation of metrics:** Metrics such as population density, tree density and number of trees per person in each ward was computed. Population for 2013 was estimated under each ward based on the decadal growth using equation 1.

$$P_{2013}(i) = P_{2011}(i) * (1 + n * r(i)) \quad \dots 1$$

Where $P_{2013}(i)$ - Population of ward i for the year 2013

$P_{2011}(i)$ - Population of ward i for the year 2011

n - Number of decades = 0.2

$r(i)$ – Incremental rate of ward i .

The ratio of number of trees in each ward to population is computed using equation 2.

$$TpP(i) = \frac{Tree(i)}{P_{2013}(i)} \quad \dots 2$$

Trees per person for Bangalore is computed by aggregating for all wards as in equation 3

$$TpP(B) = \frac{\sum_{i=1}^{198} Tree(i)}{\sum_{i=1}^{198} P_{2013}(i)} \quad \dots 3$$

Where $TpP(i)$ - Tree per person in ward i

$Tree(i)$ - Number of trees in ward i.

$TpP(B)$ - Tree per person in Bangalore

- d) Validation:** Trees extracted from remote sensing data (for each ward) was compared with the field data using equation 4. Frequency distribution of canopy (based on size) was also compared with the field data. Census of trees in Indian institute of Science campus (178 hectares spatial extent) was done using GPS. Data collected from field include spatial location of a tree, size of its canopy, habit (tree/shrub/ climber/herb). Canopy of these trees were also digitized using virtual data (Google Earth). Frequency distribution of trees based on the canopy data was done. Canopy mapping for the campus was done using fused remote sensing data (with spatial resolution of 2.7 m. Canopy were grouped based on size and histogram was generated.

$$Accuracy = 100 - (abs((Class_{Tree} - GPS_{Tree})/GPS_{Tree}) * 100) \quad \dots 4$$

Where $Class_{Tree}$ - Tree count based on classified data

GPS_{Tree} - Tree count based on field census using GPS

6.0 Results and Discussion

Image Fusion: Fusion of multispectral data (Resourcesat 2) and Cartosat (2.7 m) data was done using algorithms - Hyperspectral Color Space resolution (HCS) merge, High Pass Filter (HPF) fusion, Modified Intensity Hue Saturation (MHIS) fusion, Wavelet Fusion. Quality and accuracy of fused data was assessed using UIQI value. All fusion techniques (except wavelets) were heavy intensive process which consumed 12 cores and 36 hrs of times on cloud computing networked systems. The results is given in Figure 9, visually HCS provided better results.

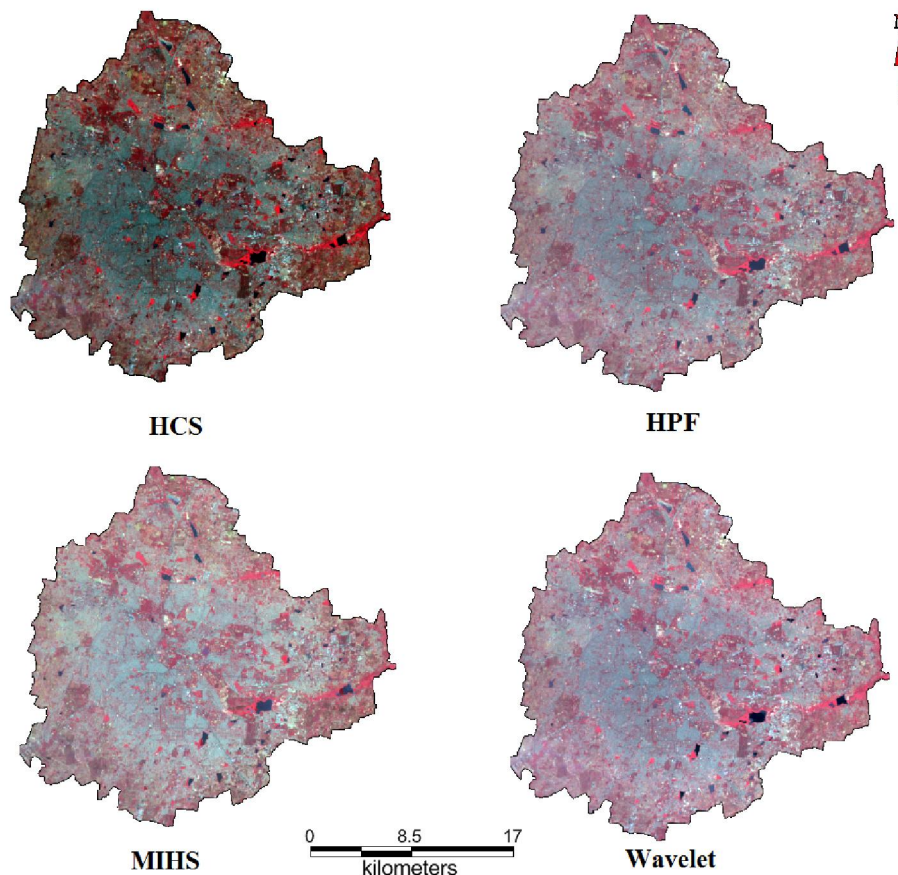


Figure 9: Landscape of Bangalore based on fused remote sensing data

The land use analysis was carried out using HPF fused remote sensing data using the supervised classifier based on Gaussian Maximum Likelihood Classifier (MLC). Categories include two classes - vegetation and non-vegetation (built-up, water bodies, open area, etc.) and is depicted in figure 10. Accuracy assessment show the overall accuracy of 91.5% the kappa of 0.86

indicating higher agreement of the classified data and field data. Results highlight that spatial extent of tree vegetation is 100.02 Hectares (14.08%).

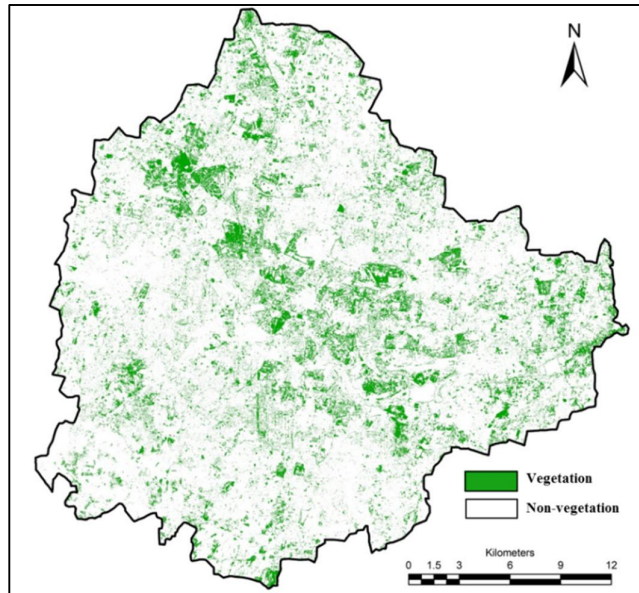


Figure 10: Spatial distribution of vegetation in Bangalore

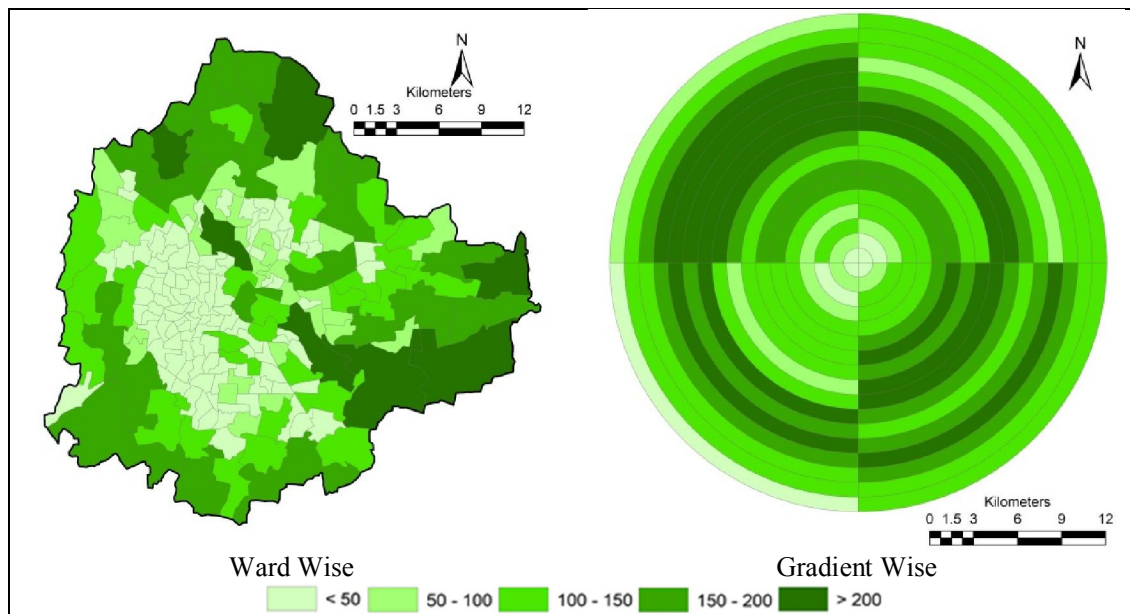


Figure 11: Ward wise spatial extent of vegetation (Hectares)

Tree distribution in wards: Vector layer of wards is overlaid on Figure 10, to extract the vegetation information for each ward. Figure 11 shows the ward wise distribution of vegetation and wardwise tree statistics is included in Annexure II. Spatial extent of vegetation is minimum

(less than 1 hectare) in wards such as Chickpete, Shivajinagara, Kempapura agrahara, Padarayanapura, while wards such as Varthur, Bellandur, Agaram have higher vegetation cover (> 300 hectares).

Bangalore was divided into 1km incrementing radii circles (with respect to the central business district) to assess the vegetation gradient. Figure 12 depicts vegetation density in each concentric regions in 1973 and 2013. Figure 12 illustrates the erosion of vegetation during the last 4 decades. Presence of Lalbhag, Cuban park etc. in the core area show higher vegetation density in the respective gradients. Figure 13 illustrates ward wise vegetation density for 2013. The wards such as Hudi, Aramane nagara and Vasantha pura have higher vegetation density of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower density with less than 0.015. Bangalore has an average vegetation density of 0.14.

i.e., Area of Bruhat Bangalore: 741 sq.km
 Area under vegetation: 100.20 sq.km
 Vegetation Density: $100.02 / 741 = 0.14$

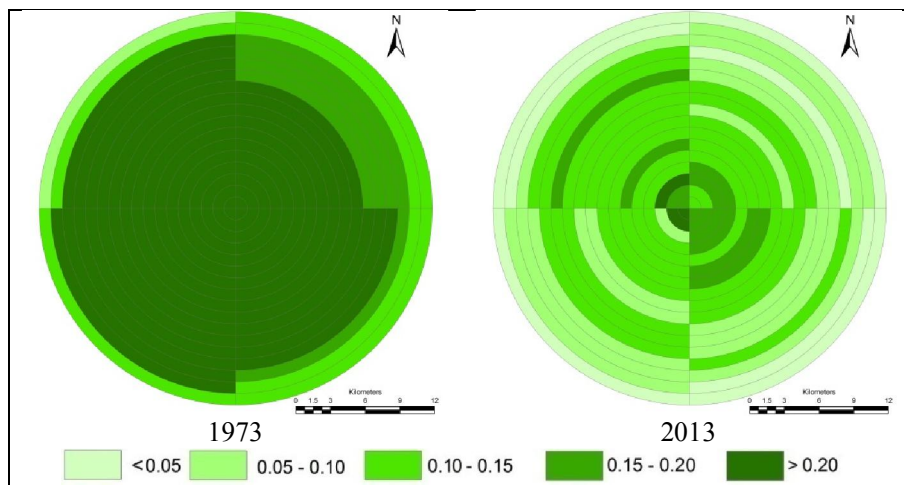


Figure 12: Gradient wise Vegetation density

Field data was collected using GPS in select wards, which include tree census with the canopy dimensions. Canopy was also delineated using online Google Earth. This helped in quantifying number of trees based on delineation of canopy from remote sensing data. Figure 15 gives the frequency distribution based on the canopy size for wards i) < 500 trees and ii) > 500 trees.

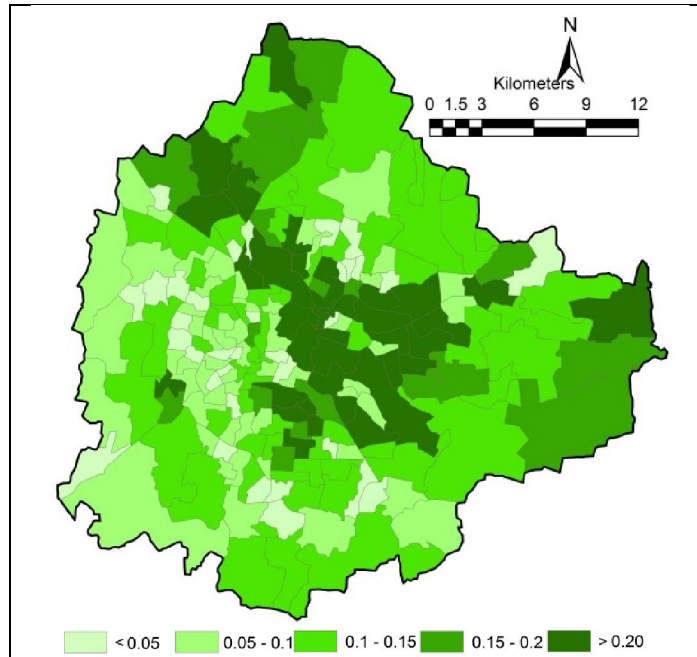


Figure 14: Ward wise vegetation density (2013)

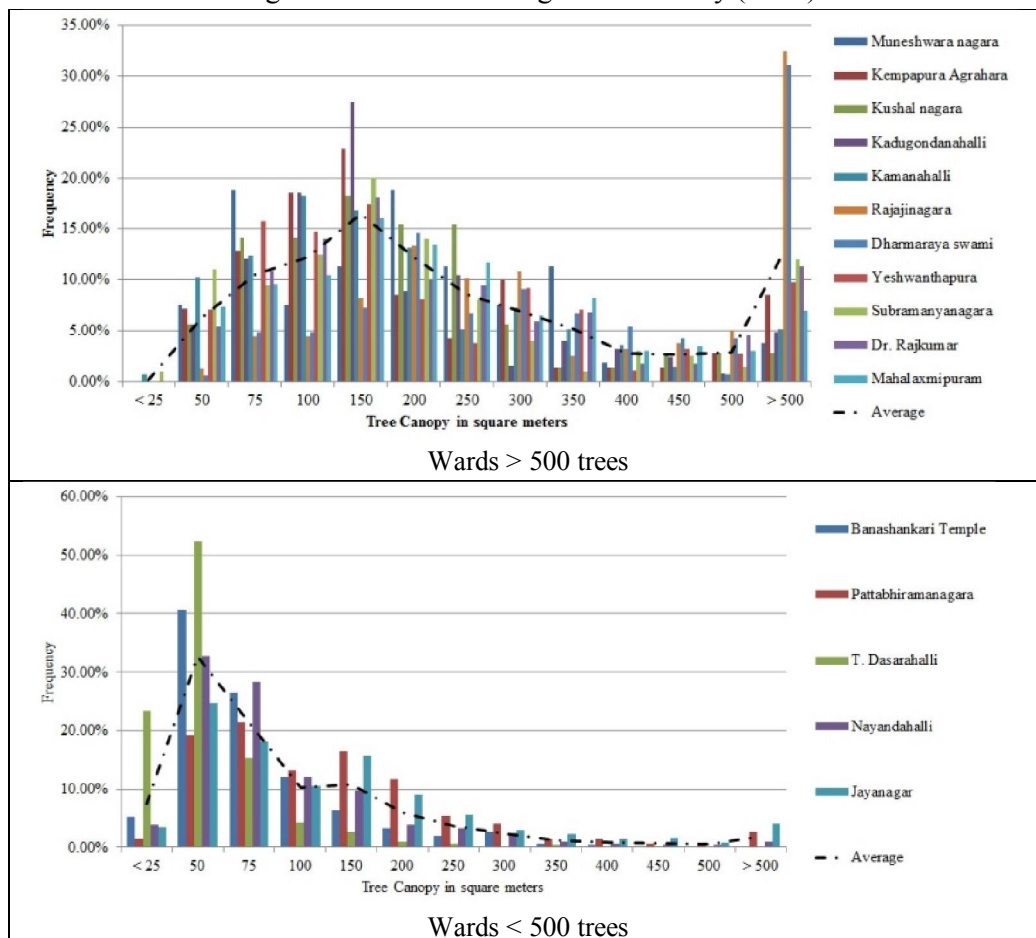


Figure 15: Histogram based on canopy size

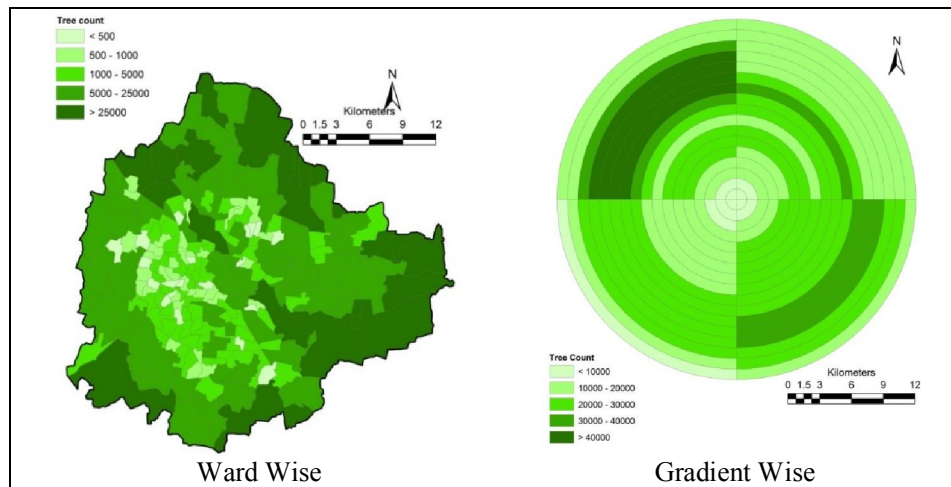


Figure 16: Tree distribution

Based on these, number of trees in each ward are computed. Figure 16 gives the ward wise and gradient wise number of trees. This highlights that wards such as Vathuru, Bellanduru, Agaram, Aramane nagara have the trees greater than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards have trees less than 100 trees. Based on these, total number of trees in Bangalore is about 14,78,412 trees. Annexure III provides details of prominent trees in Bangalore. Annexure IV is the list of trees compiled from various published literatures.

Validation of tree quantification was done in select wards of Bangalore. Figure 17a gives the tree distribution based on field census and Figure 17b gives the canopy distribution based pattern classifier. Total number of trees as per the census is 22201 and figure 18 gives the frequency distribution of canopy classes. Based on the remote sensing data, IISc campus has canopy cover of 107.85 hectares and number of trees as 22616. This means the accuracy of tree estimation based on canopy delineation using fused remote sensing data of 2.7 m spatial resolution is 97%.

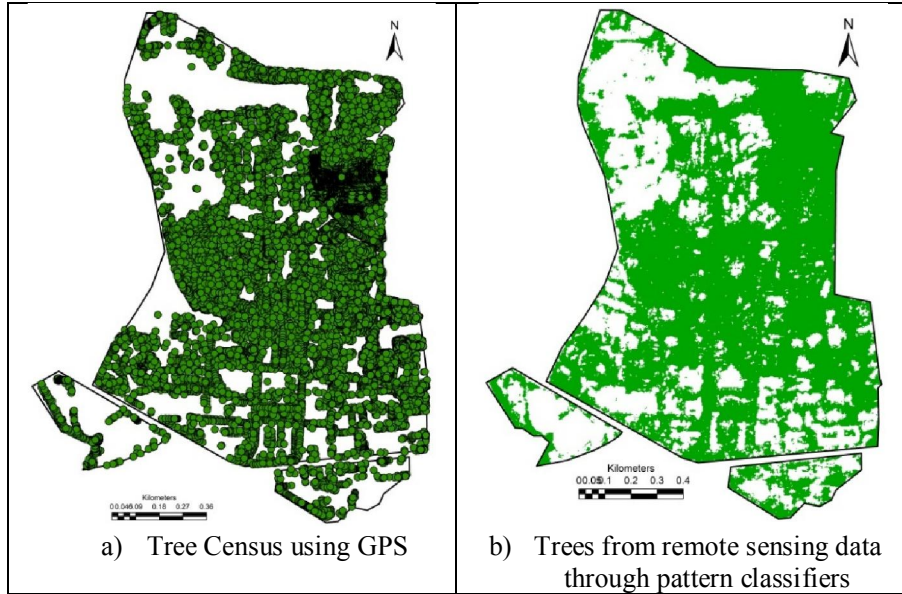


Figure 17: Tree Distribution in Indian Institute of Science campus

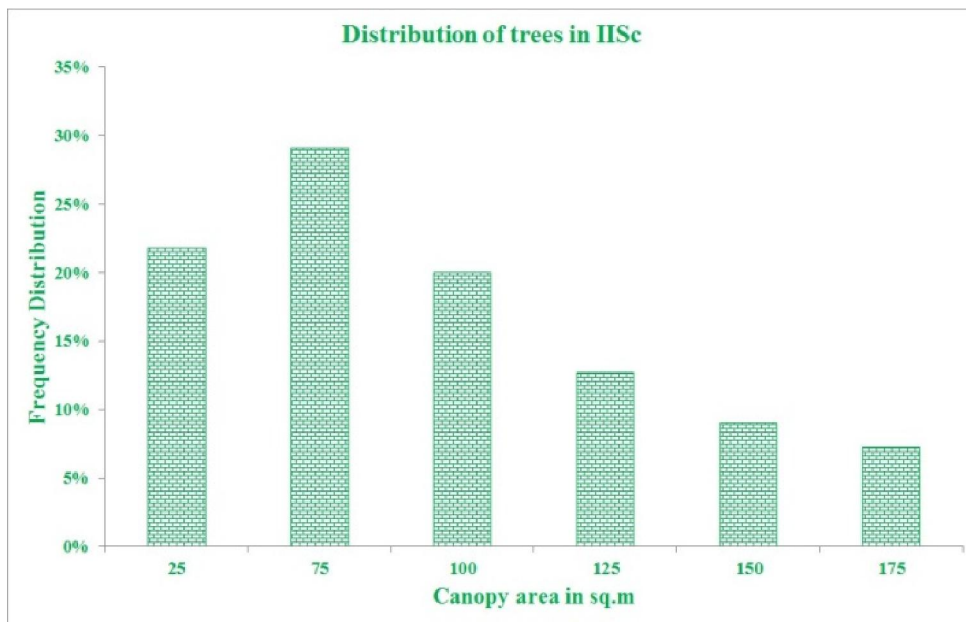


Figure 18: Frequency Distribution based on field measurement

Figure 19 gives ward wise population during 2013 computed considering the growth rate based on the population of 2001 and 2011. This shows wards in the core area of the city have population more than 40000 persons, whereas the wards towards the periphery have population less than 30000.

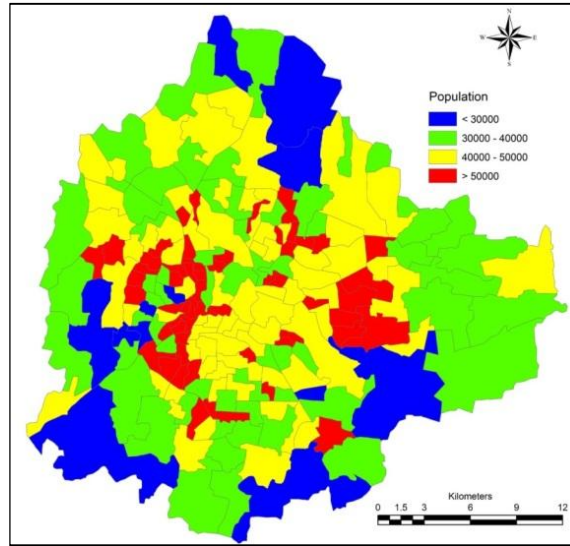


Figure 19: Ward wise population during 2013

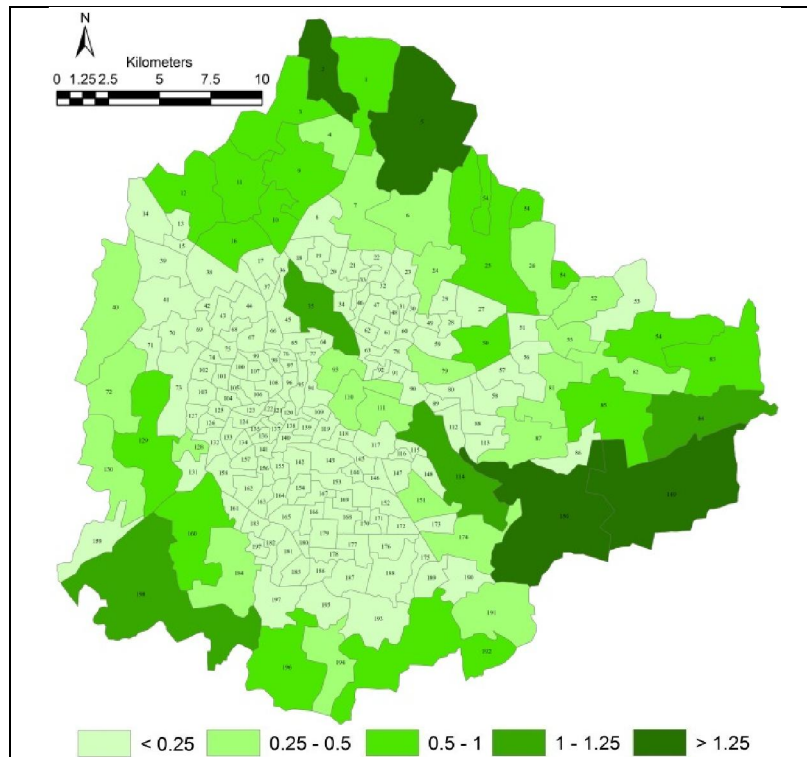


Figure 20: Ward wise tree per person

Figure 20 depicts ward wise trees per person computed considering number of trees and population for the respective ward. This analysis shows that Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara wards have very less number of trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people.

Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, Aramane nagara have trees more than one per person indicating the presence of one tree for every person.

This shows that Gandhinagar (Gujarat), Nashik(Maharashtra) has more than 1 tree per person, while most of other cities are less than one tree per person. Major cities such as Gandhinagar, Bangalore, Ahmedabad, Brihan Mumbai are with spatial extent greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people followed by Bangalore with 17 trees, Brihan Mumbai with 15 trees and Ahmedabad with 11 trees. Table 4 lists city wise number of trees and trees per person based on published literatures

Table 4: Comparative assessment of trees across different cities

State	Location	Population	Area (Ha)	Number of Trees	Tree / person	Tree / Hectare	Reference
Gujarat	<i>Ahmedabad</i>	5570590	46985	617090	0.111	13.13	21
	Surat	4462000	39549	333970	0.075	8.44	21
	Vadodara	1666700	16264	747190	0.448	45.94	21
	<i>Gandhinagar</i>	208300	57000	866670	4.161	15.20	21
	Rajkot	1287000	10400	139520	0.108	13.42	21
	Bhavnagar	593770	5320	485950	0.818	91.34	21
	Junagadh	320250	5670	76690	0.239	13.53	21
	Jamnagar	529310	3434	45880	0.087	13.36	21
Maharashtra	Nagpur	2405421	21717	2143838	0.891	98.72	22
	Nashik	1486973	25900	2055523	1.382	79.36	22
	<i>Brihan Mumbai</i>	12478447	43771	1917844	0.154	43.82	22
	Kalyan*	472208	5198	212795	0.451	40.94	22
	Thane	1818872	12700	45262	0.025	3.56	22
	Navi Mumbai	1119477	16205	478120	0.427	29.50	22
	Nanded	550564	4906	101310	0.184	20.65	22
	Mira and Bhayandar	814655	7904	150000	0.184	18.98	22
Karnataka	<i>Bangalore</i>	8907175	74100	1478412	0.166	19.95	calculated

* Kalyan and Dombivali, combined together has population of 1,246,381 and area of 137.15 sq.km, proportion of area was used to calculate population of Kalyan city

7.0 Conclusions

Land use analysis based on the fusion of resourcesat 2 MSS data with cartosat 2 show that the spatial extent of tree vegetation in Bangalore is 100.02 Hectares (14.08%). Spatial extent of vegetation is minimum (less than 1 hectare) in wards such as Chickpete, Shivajinagara, Kempapura agrahara, Padarayanapura, while wards such as Varthur, Bellandur, Agaram have higher vegetation cover (> 300 hectares). The wards such as Hudi, Aramane nagara and

Vasanthapura have higher vegetation density (spatial extent of area under vegetation to the geographical area of a ward) of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower density with less than 0.015. Bangalore has an average vegetation density of 0.14. Mapping of trees based on canopy delineation coupled with field data show that wards such as Vathuru, Bellanduru, Agaram, Aramane nagara have the trees greater than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards have trees less than 100 trees. Based on these, total number of trees in Bangalore is about 14,78,412 trees. Computation of trees per person show that Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara wards have very less number of trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people. Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, Aramane nagara have trees more than one per person indicating the presence of one tree for every person. Intra city analysis show that major cities such as Gandhinagar, Bangalore, Ahmedabad, Brihan Mumbai are with spatial extent greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people followed by Bangalore with 17 trees, Brihan Mumbai with 15 trees and Ahmedabad with 11 trees.

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Annexure I

Annexure I: Benefits of trees

Sl. No	Benefits	References
1	Reduce the atmospheric temperature and air pollution.	Vailshery et al., 2013
2	Carbon sequestration and reduces the air pollution	Yang et al., 2005
3	Reduces the atmospheric emission and carbon sequestration	McPherson et al., 2013
4	Carbon sequestration	Thomas et al., 2007
5	Reduce consumption of electricity, pollution, ameliorating air borne and water pollution.	Brack 2002
6	Reduce the use energy for cooling and heating.	Simpson 1998
7	Reduces the atmospheric CO2 concentration	Yousif and Tahir 2013
8	Reduces the surface water runoff	Armson et al., 2013
9	Mitigation of Urban heat islands	Sung 2013;
10	Improve air quality	Vos et al., 2013
11	Aesthetic value, reduction of storm water runoff, energy saving,	McPherson et al., 2011
12	Mitigation of urban heat island effect	Zhang et al., 2013
13	Flood control	Sung and Li 2010

Annexure II

Annexure II: Ward wise tree details

Ward Id	Ward Name	Ward Area (Ha)	Vegetation Area (Ha)	Veg Density	Number of Trees	Population	Tree per person
1	Kempegowda ward	1071.6	165.3	0.1543	24412	33683	0.725
2	Chowdeswari	699.2	198.2	0.2834	29259	20897	1.400
3	Atturu	1032.3	134.3	0.1301	19830	37050	0.535
4	Yelahanka satellite town	482.8	85.0	0.1761	12556	43856	0.286
5	Jakkuru	2413.7	255.3	0.1058	37695	29628	1.272
6	Thanisandra	990.9	49.8	0.0502	7356	23836	0.309
7	Byatarayanapura	930.7	133.8	0.1437	19755	47284	0.418
8	Kodigehalli	383.6	48.1	0.1255	7109	38285	0.186
9	Vidyaranyapura	981.9	195.1	0.1987	28812	46061	0.626
10	Dodda Bommasandra	421.6	133.8	0.3173	19757	34213	0.577
11	Kuvempu Nagar	764.1	272.9	0.3572	40296	44501	0.906
12	Shettihalli	912.0	173.1	0.1898	25562	33911	0.754
13	Mallasandra	128.8	6.2	0.0485	928	47010	0.020
14	Bagalakunte	466.3	44.8	0.0961	6619	42661	0.155
15	T.Dasarahalli	89.4	5.0	0.0561	748	38196	0.020
16	Jalahalli	516.0	177.8	0.3445	26255	38073	0.690
17	J.P.Park	214.6	25.8	0.1205	3821	46726	0.082
18	Radhakrishna temple	205.3	35.4	0.1724	5232	30117	0.174
19	Sanjaya nagar	156.3	21.7	0.1387	3207	43546	0.074
20	Ganga nagar	208.9	42.4	0.2029	6261	31734	0.197
21	Hebbala	135.5	12.7	0.0938	1883	43612	0.043
22	Vishwanath Nagenahalli	160.0	4.5	0.0282	672	44041	0.015
23	Nagavara	201.7	6.0	0.0299	895	56746	0.016
24	H B R Layout	486.0	58.0	0.1194	8577	32495	0.264
25	Horamavu	1746.7	209.5	0.1199	30934	46145	0.670
26	Ramamurthy Nagar	790.4	83.7	0.1059	12366	42288	0.292
27	Banasavadi	334.0	40.5	0.1212	5982	49704	0.120
28	Kammanahalli	105.9	2.8	0.0268	262	61883	0.004
29	Kacharkanahalli	164.0	15.6	0.0950	2306	34903	0.066
30	Kadugondanahalli	68.9	1.8	0.0259	169	62304	0.003
31	Kushal nagar	59.8	0.9	0.0151	89	41383	0.002
32	Kaval Bairasandra	153.7	16.4	0.1065	2424	34323	0.071
33	Manorayanapalya	83.1	4.7	0.0566	700	64491	0.011
34	Gangenahalli	107.7	29.2	0.2712	4317	33149	0.130
35	Aramane Nagara	736.5	296.2	0.4022	43743	40379	1.083
36	Mattikere	86.4	3.8	0.0434	562	60014	0.009
37	Yeshwanthpura	74.9	3.2	0.0428	296	57691	0.005
38	HMT ward	492.4	64.7	0.1314	9556	39538	0.242
39	Chokkasandra	394.0	47.7	0.1210	7048	47588	0.148

Ward Id	Ward Name	Ward Area (Ha)	Vegetation Area (Ha)	Veg Density	Number of Trees	Population	Tree per person
40	Dodda Bidarakallu	1298.4	85.8	0.0661	12680	34389	0.369
41	Peenya Industrial Area	557.7	35.4	0.0635	5238	44128	0.119
42	Lakshmi Devi Nagar	148.2	11.7	0.0790	1737	33978	0.051
43	Nandini Layout	145.1	15.1	0.1042	2237	41160	0.054
44	Marappana Playa	215.5	17.5	0.0811	2589	45168	0.057
45	Malleswaram	200.7	47.9	0.2387	7079	48249	0.147
46	Jayachamarajendra Nagar	82.8	8.9	0.1072	1316	43913	0.030
47	Devara Jeevanahalli	142.5	35.7	0.2505	5276	46320	0.114
48	Muneshwara Nagar	48.3	1.2	0.0253	116	55562	0.002
49	Lingarajapura	82.0	5.3	0.0646	788	62207	0.013
50	Benniganahalli	497.9	161.4	0.3241	23829	47446	0.502
51	Vijnanapura	213.3	18.4	0.0863	2721	54181	0.050
52	K R Puram	506.8	88.9	0.1755	13135	35958	0.365
53	Basavanapura	621.6	28.1	0.0452	4153	34641	0.120
54	Hudi	134.7	201.4	1.4955	29745	33016	0.901
55	Devasandra	361.7	76.1	0.2103	11237	31541	0.356
56	A Narayanapura	211.9	13.1	0.0617	1934	47401	0.041
57	C V Raman Nagar	365.7	90.9	0.2486	13432	56495	0.238
58	New Tippasandra	318.3	68.8	0.2160	10159	62891	0.162
59	Maruthi Seva Nagar	246.9	51.2	0.2074	7567	47571	0.159
60	Sagayarapuram	79.2	13.7	0.1728	2028	57499	0.035
61	S K Garden	132.9	39.5	0.2973	5838	41762	0.140
62	Ramaswamy Palya	78.4	11.8	0.1507	1751	48858	0.036
63	Jayamahal	142.2	40.1	0.2821	5927	31969	0.185
64	Rajamahal Guttahalli	76.8	9.4	0.1230	1400	52624	0.027
65	Kadu Malleshwara	139.5	17.5	0.1255	2592	35273	0.073
66	Subramanya Nagar	91.7	4.7	0.0508	694	50422	0.014
67	Nagapura	178.6	19.6	0.1100	2906	47229	0.062
68	Mahalakshampuram	98.7	6.2	0.0633	929	55965	0.017
69	Laggere	166.7	1.8	0.0108	172	48973	0.004
70	Rajagopal Nagar	216.4	4.9	0.0225	725	56113	0.013
71	Hegganahalli	195.9	2.1	0.0109	201	60431	0.003
72	Herohalli	778.2	69.9	0.0899	10332	36966	0.280
73	Kottegapalya	576.2	60.9	0.1057	9000	48032	0.187
74	Shakthi Ganapathi Nagar	74.4	4.5	0.0606	672	62898	0.011
75	Shankar Matt	110.0	5.4	0.0491	804	70165	0.011
76	Gayathri Nagar	61.6	4.2	0.0679	623	60309	0.010
77	Dattatreya Temple	66.7	6.0	0.0895	888	56212	0.016
78	Pulikeshinagar	166.8	33.4	0.2003	4940	37407	0.132
79	Sarvagna Nagar	362.6	125.0	0.3446	18458	46419	0.398

Ward Id	Ward Name	Ward Area (Ha)	Vegetation Area (Ha)	Veg Density	Number of Trees	Population	Tree per person
80	Hoysala Nagar	204.5	44.8	0.2193	6625	47677	0.139
81	Vijnana Nagar	579.4	70.2	0.1212	10376	40288	0.258
82	Garudacharpalya	693.2	97.8	0.1412	14452	35695	0.405
83	Kadugodi	1191.5	267.6	0.2246	39509	41072	0.962
84	Hagadur	1256.1	243.1	0.1935	35895	34733	1.033
85	Dodda Nekkundi	1228.8	162.1	0.1319	23937	31825	0.752
86	Marathahalli	297.8	36.9	0.1238	5447	45844	0.119
87	H A L Airport	682.1	122.5	0.1796	18093	56837	0.318
88	Jeevanbhima Nagar	191.6	45.5	0.2372	6714	68414	0.098
89	Jogupalya	88.8	8.2	0.0920	1212	53063	0.023
90	Haloor	169.9	25.4	0.1492	3749	47678	0.079
91	Bharathi Nagar	73.3	6.3	0.0864	942	50994	0.018
92	Shivaji Nagar	43.0	0.7	0.0164	70	66280	0.001
93	Vasanth Nagar	316.2	78.9	0.2494	11649	34049	0.342
94	Gandhinagar	179.1	17.1	0.0958	2538	46906	0.054
95	Subhash Nagar	135.9	18.7	0.1373	2760	39011	0.071
96	Okalipuram	81.8	12.7	0.1548	1876	55464	0.034
97	Dayananda Nagar	45.5	1.4	0.0304	131	63052	0.002
98	Prakash Nagar	59.5	6.6	0.1117	988	60963	0.016
99	Rajaji Nagar	74.9	7.7	0.1034	1149	51661	0.022
100	Basaveshwara Nagar	83.8	8.5	0.1020	1267	35390	0.036
101	Kamakshipalya	86.7	8.4	0.0970	1249	31806	0.039
102	Vrishabhavathi Nagar	100.0	2.2	0.0222	208	50003	0.004
103	Kaveripura	150.0	5.8	0.0386	861	57774	0.015
104	Govindaraja Nagar	82.3	9.0	0.1096	1340	33141	0.040
105	Agrahara Dasarahalli	79.9	6.5	0.0817	969	36241	0.027
106	Dr. Raj Kumar Ward	96.2	5.6	0.0585	838	26833	0.031
107	Shivanagara	78.3	6.0	0.0770	896	56732	0.016
108	Sriramamandir	116.1	10.0	0.0865	1488	40804	0.036
109	Chickpete	75.9	0.2	0.0023	25	52688	0.000
110	Sampangiram Nagar	446.4	144.7	0.3240	21362	43997	0.486
111	Shantala Nagar	409.6	92.3	0.2253	13629	40151	0.339
112	Domlur	182.0	36.4	0.2002	5386	46100	0.117
113	Konena Agrahara	206.7	33.7	0.1631	4984	56050	0.089
114	Agaram	1139.9	338.2	0.2967	49930	47334	1.055
115	Vannarpet	75.7	5.8	0.0772	870	56093	0.016
116	Nilasandra	51.7	2.9	0.0561	268	64298	0.004
117	Shanthi Nagar	255.8	53.8	0.2102	7946	48388	0.164
118	Sudham Nagar	103.9	6.2	0.0599	925	40949	0.023
119	Dharmaraya Swamy Temple Ward	110.6	4.6	0.0420	692	41323	0.017

Ward Id	Ward Name	Area (Ha)	Vegetation Area (Ha)	Veg Density	Number of Trees	Population	Tree per person
120	Cottonpete	75.3	9.1	0.1210	1351	58936	0.023
121	Binnipete	73.2	6.6	0.0907	988	53722	0.018
122	Kempapura Agrahara	36.3	0.6	0.0174	62	63853	0.001
123	Vijayanagar	73.6	2.4	0.0323	222	58345	0.004
124	Hosahalli	88.6	8.3	0.0940	1237	45248	0.027
125	Marenahalli	77.4	3.3	0.0427	306	22215	0.014
126	Maruthi Mandir Ward	80.3	5.9	0.0730	872	30684	0.028
127	Mudalapalya	101.0	5.1	0.0508	762	48189	0.016
128	Nagarabhavi	159.5	33.0	0.2066	4871	18334	0.266
129	Jnana Bharathi Ward	1216.9	165.7	0.1362	24474	28473	0.860
130	Ullal	895.3	71.0	0.0793	10486	34946	0.300
131	Nayandahalli	208.1	39.7	0.1908	5868	38691	0.152
132	Attiguppe	136.2	9.3	0.0685	1385	29247	0.047
133	Hampi Nagar	112.1	10.0	0.0889	1479	35358	0.042
134	Bapuji Nagar	67.4	1.6	0.0244	156	60446	0.003
135	Padarayanapura	34.3	0.2	0.0061	26	67623	0.000
136	Jagajivanaramanagar	54.0	5.3	0.0984	791	58800	0.013
137	Rayapuram	60.3	8.2	0.1355	1213	55201	0.022
138	Chalavadipalya	42.8	6.3	0.1466	934	43419	0.022
139	K R Market	78.6	6.3	0.0801	937	40309	0.023
140	Chamarajapet	97.4	11.1	0.1143	1652	45530	0.036
141	Azad Nagar	66.4	4.6	0.0693	685	59620	0.011
142	Sunkenahalli	156.4	24.2	0.1545	3575	48032	0.074
143	Vishveshwara Puram	242.1	56.3	0.2325	8317	47946	0.173
144	Siddapura	64.0	14.0	0.2188	2078	52305	0.040
145	Hombegowda Nagara	141.6	21.3	0.1507	3156	48427	0.065
146	Lakkasandra	125.8	22.9	0.1822	3391	37597	0.090
147	Adugodi	165.7	43.1	0.2603	6375	39779	0.160
148	Ejipura	160.3	14.9	0.0927	2203	35093	0.063
149	Varthur	2723.1	488.1	0.1792	72069	30430	2.368
150	Bellanduru	2655.1	368.2	0.1387	54366	25614	2.123
151	Koramangala	368.1	95.4	0.2593	14095	46971	0.300
152	Suddagunte Palya	175.0	23.8	0.1360	3518	47703	0.074
153	Jayanagar	251.8	60.4	0.2400	8928	47774	0.187
154	Basavanagudi	119.4	11.9	0.0994	1757	42077	0.042
155	Hanumanth Nagar	96.2	10.2	0.1062	1515	49847	0.030
156	Srinagar	84.1	3.7	0.0444	343	55903	0.006
157	Gali Anjenaya Templw Ward	111.0	9.1	0.0822	1354	37896	0.036
158	Deepanjali Nagar	214.3	14.6	0.0683	2170	63287	0.034
159	Kengeri	484.1	11.1	0.0230	1653	46698	0.035

Ward Id	Ward Name	Ward Area (Ha)	Vegetation Area (Ha)	Veg Density	Number of Trees	Population	Tree per person
160	Rajarajeshwari Nagar	1149.9	151.6	0.1318	22386	38401	0.583
161	Hosakerehalli	126.5	9.5	0.0751	1409	42577	0.033
162	Girinagar	173.4	19.1	0.1099	2820	63715	0.044
163	Katriguppe	108.0	7.1	0.0657	1055	66776	0.016
164	Vidyapeeta Ward	121.6	10.7	0.0880	1585	65600	0.024
165	Ganesh Mandir Ward	161.9	21.9	0.1355	3245	30688	0.106
166	Karisandra	112.9	13.7	0.1214	2032	40962	0.050
167	Yediyur	123.1	16.9	0.1371	2497	45951	0.054
168	Pattabhiram Nagar	171.6	37.0	0.2156	5468	41167	0.133
169	Byrasandra	88.3	13.3	0.1509	1974	36875	0.054
170	Jayanagar East	105.8	11.5	0.1089	1708	31162	0.055
171	Gurappanapalya	68.1	1.9	0.0284	181	55283	0.003
172	Madivala	113.4	7.6	0.0666	1121	38074	0.029
173	Jakkasandra	150.0	21.0	0.1398	3103	28062	0.111
174	HSR Layout	685.8	93.7	0.1366	13842	35672	0.388
175	Bommanahalli	200.5	9.9	0.0496	1474	46273	0.032
176	BTM Layout	208.3	26.6	0.1279	3937	45745	0.086
177	J P Nagar	181.3	24.1	0.1330	3568	33253	0.107
178	Sarakki	128.6	14.0	0.1092	2079	53803	0.039
179	Shakambari Nagar	182.0	35.1	0.1928	5186	30871	0.168
180	Banashankari Temple Ward	65.1	6.3	0.0969	938	65724	0.014
181	Kumaraswamy Layout	189.0	22.1	0.1169	3269	54606	0.060
182	Padmanabha Nagar	169.2	11.2	0.0663	1664	34171	0.049
183	Chikkalsandra	105.8	3.9	0.0365	576	48164	0.012
184	Uttarahalli	907.0	91.0	0.1004	13445	37677	0.357
185	Yelchenalli	153.9	5.4	0.0354	811	47703	0.017
186	Jaraganahalli	128.5	4.5	0.0354	677	39772	0.017
187	Puttenahalli	288.1	42.3	0.1469	6256	39414	0.159
188	Bilekhal	412.9	56.0	0.1357	8276	38574	0.215
189	Hongasandra	223.1	3.2	0.0143	293	47976	0.006
190	Mangammanapalya	352.7	21.6	0.0612	3195	57126	0.056
191	Singasandra	947.3	70.1	0.0740	10350	36232	0.286
192	Begur	1924.3	194.1	0.1008	28657	29205	0.981
193	Arakere	651.2	58.3	0.0895	8613	46060	0.187
194	Gottigere	642.5	65.8	0.1024	9715	36986	0.263



Annexure IV



Prominent trees of Bangalore

	<p><i>Acacia auriculiformis</i> Cnn. Ex Benth. Common name: Australian wattle Family: Fabaceae Description: A medium size evergreen tree. Leaves alternate, simple, reduced to phyllodes, blade-like and slightly curved. Flowers are minute, loose, yellow-orange elongated inflorescence. Fruit a flat, oblong pod, twisted at maturity. Flowering: July- October Native: Australia Location: Anajana Nagar, Yeshwanthpur, Vijay Nagar and outskirts of city.</p>
<p><i>Bauhinia purpurea</i> L. Common name: Butterfly tree Family: Fabaceae Description: A medium-sized tree up to 6.5 m high. Leaves alternate, simple, broadly ovate-orbicular, cleft to middle, lobes rounded. Inflorescence a raceme. Flowers are in a panicle, rose to pink. Fruit a pod, flat, pubescent. Flowering and fruits: October and May Native: India, Burma, Vietnam Location: Malleshwaram, Mahalakshmpuram, Yeshwanthpura, Jaynagar East, Jayanagar, Rajarajeshwari nagar, Sadashiva Nagar. Cultivated as avenue tree.</p>	



Bombax malabaricum DC.

Common name: Red silk-cotton tree

Family: Bombacaceae

Description: A tall native with straight trunk that is covered with hard, sharp, conical prickles. Leaves are large with 3-7 lanceolate to oval leaflets having pointed apex. Flowers are large clustered at the end of branches. Fruit ovoid in shape with five partitions. Seeds are covered with silky white hairs.

Native: India

Flowering and fruits: February – March

Location: Malleshwaram, M.G Road, Sadashiva Nagar.

Cassia spectabilis DC.

Common name: Popcorn bush cedar

Family: Fabaceae

Description: A medium sized tree with dense canopy. Leaves are pinnately compound. Flowers yellow in terminal corymbose panicles. Fruit is a long compressed and dehiscent pod.

Flowering and Fruits: March –October

Native: Tropical Southeast Asia

Location: Malleshwaram, Sanjay Nagar, Sankey Road, M.G Road, Yeshwanthpur, Rajaji Nagar. Dr Rajkumar ward.



Cocos nucifera L.

Common name: Coconut palm

Family: Arecaceae

Description: A monoecious palm with regular leaf scars. Leaves are pinnately compound. Flowers are in a branched spadix, male flowers are small and many. Fruit is a drupe. Endocarp is lined with hallow endosperm, which is edible.

Flowering and Fruits: Throughout the year

Native: Indo-Pacific

Location: Rajaji Nagar, Mahalakshmi layout, Rajajeshwari Nagar, Basveshwara Nagar, Jayanagar, Yeshwanthpur, Yelahanka, Armane Nagar. Commonly occur in residential area.

Delonix regia (Bojer ex Hook.) Raf.

Common name: Gulmohur

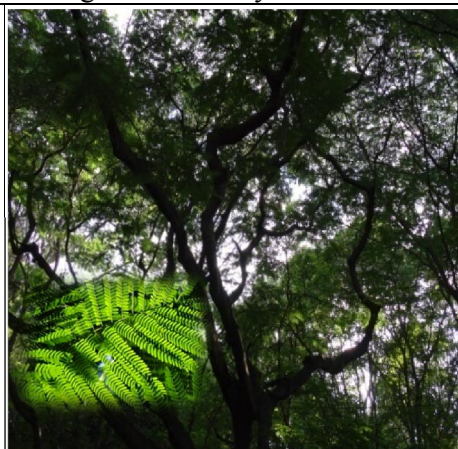
Family: Fabaceae




Description: Moderate sized tree upto 9 m high. Leaves alternate, bipinnate, upto 40 cm long. Inflorescence a corymb. Fruit a pod, long, black, when dry, upto 50 cm long, septate within.

Flowering and fruits: April - June

Native: Madagascar

Location: Rajajeshwari Nagar, Malleshwaram, Rajaji Nagar, Shankar Mutt, Seshadripuram, Yelahanka. Cultivated as avenue tree.



	<p><i>Polyalthia longifolia</i> (Sonn.) Thwaites Common name: Mast tree Family: Annonaceae Description: Tree up to 4 m high. Leaves alternate, simple, shortly-petioled undulate, acute, shining, membranous when young. Inflorescence a panicle, sometimes in a short-peduncled umbel. Fruits a berry, ovoid, reddish black. Flowering and Fruits: March –April; April –May Native: South India Location: Yeshwanthpur, Rajajinagar, Vijaynagar, Malleshwaram, Mahalakshmpuram. Cultivated as avenue tree.</p>
<p><i>Spathodea campanulata</i> P. Beauv. Common name: African tulip tree Family: Bignoniaceae Description: Glabrescent evergreen tree, upto 20 m high. Leaves opposite, imparipinnate, ovate-lanceolate, entire. Flowers in terminal racemes or panicles. Capsule linear-lanceolate, acuminate at both ends. Flowering: December –March Fruits: April-July Native: Tropical Africa Location: Malleshwaram, Rajajinagar, M.G Road, Sanjay Nagar, Sadashiva nagar, Raj Rajeshwari Nagar, Vijay nagar, Hebbal. Cultivated as avenue tree.</p>	
	<p><i>Millingtonia hortensis</i> L.f. Common name: Indian cork tree Family: Bignoniaceae Description: Tree with drooping upto 16 m high. Leaves opposite, simple, 2-3-pinnate upto 30 cm. inflorescence a terminal corymbose panicle. Fruit an elongated capsule, flattened, dehiscent, leathery. Flowering and Fruits: April –May Native: Myanmar Location: Dr. Rajkumar ward, Malleshwaram, Yeshwanthpur, Jaynagar, Sadashiva nagar, Aramane Nagar. Cultivated as avenue tree.</p>
<p><i>Pongamia pinnata</i> Common name: Indian elm Family: Fabaceae Description: Moderate sized tree upto 7 m high. Leaves alternate, pinnate, stipules small, oblong, caducous. Inflorescence a paniced raceme, axillary and terminal. Fruit a pod, oblong-obovoid, compressed, woody. Seeds solitary, reniform, brown at both ends. Flowering and Fruits: March – April Native: India Location: Malleshwaram, Mahalakshmpuram, Basaveshwara Nagar, Yelahanka. It is drought-resistant and has high tolerance level to air pollution.</p>	



Bauhinia variegata L.

Common name: Mountain ebony

Family: Fabaceae

Description: A Moderate sized tree. Leaves alternate, simple, coriaceous, cordate, cleft to the middle. Inflorescence a corymbose racemose. Fruit a pod, flat, glabrous, prominently veined when dry dehiscent.

Native: India, China

Flowering and Fruits: February-March & May.

Location: Malleshwaram, Rajajinagar, Yeshwanthpur, Yelahanka, Jayanagar, Hebbal. It is drought-resistant.

Albizia lebbek (L.) Benth

Common name: East Indian walnut

Family: Fabaceae

Description: A large deciduous tree upto 12 m high. Leaves alternate, pinnate, with glands at base, leaflets upto 10 pairs. Flowers are white globose. Fruit a pod, flat upto 20 cm long, straw coloured.

Flowering: March - December

Native: Asia

Location: Malleshwaram, Rajajinagar, Vijayanagar, Yeshwanthpur, Banashankari.



Peltophorum pterocarpum (DC.)

Common name: Copper pod

Family: Fabaceae

Description: A large deciduous tree, upto 20 m high. Leaves are bipinnately compound and pubescent. Flowers are in a terminal panicle, golden yellow with brownish stripes. Fruit is a pod 5-10 cm long, copper coloured.

Flowering: Summer months

Native: Sri Lanka, Southeast Asia

Location: Malleshwaram, Rajajinagar, Yeshwanthpur, Armane Nagar.

Roystonea regia (H.B.K) O.F.Cook

Common name: Cuban royal palm

Family: Arecaceae

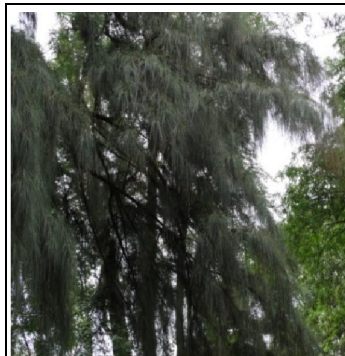
Description: A tall palm up to 20-30 m high, thickened at about the middle. Leaves are innately compound, pinnae are in 2 rows, strap-like, strongly several-nerved. Inflorescence found beneath the crown shaft and emerges from narrow. Flowers are borne on a branched panicle. Fruit is an oblong or globose drupe, deep purple when ripe.

Flowering: July-August

Native: Cuba

Location: It is cultivated as Ornamental palm. It is occur in Offices, Institutes.





Casuarina equisetifolia L.
Common name: She- oak
Family: Casuarinaceae
Description: Dioecious tree, up to 15 m high. Stem cylindrical, woody. Bark grey-brown, smooth, branch drooping. Leaves whorled, scale-like, linear and sometimes sheathing at base. Inflorescence a spike or globose. Flowers unisexual. Fruit a winged nutlet, seeds winged.
Flowering and Fruits: Dec. – Feb.
Native: Malaysia, S. Asia, Australia
Location: Yelahanka, Ramanagaram, Malleshwaram.




Tectona grandis L.f
Common name: Teak
Family: Verbenaceae
Description: Deciduous stellate-tomentose tree, upto 9 m high. Leaves opposite, simple, entire. Flowers in terminal panicles. Fruit a drupe enclosed by the enlarged calyx.
Flowering and Fruits: Jun. –Oct.
Native: Southeast Asia
Location: Malleshwaram, Anajana Nagar.



Grevillea robusta Cunn. Ex R. Br.
Common name: Silver oak
Family: Proteaceae
Description: A fast-growing evergreen tree. Leaves are dark green dented bipinnatifid long with grayish white or rusty undersides. Flowers are golden-orange in one-sided racemes. Fruit is a boat-shaped, dark brown leathery dehiscent follicle.
Flowering and Fruits: Mar. -May
Native: Australia
Location: M.G Road, Hebbal, Yeshwanthpur.

Swietenia macrophylla King
Common name: Honduras mahogany
Family: Meliaceae
Description: A large deciduous tree. Leaves are compound and opposite. Flowers are in axillary panicles, small and cream-coloured, pentamerous. Fruit is a globose woody dehiscent capsule shape like an inverted club. Seeds are many and winged.
Flowering: March-May
Native: Tropical America, Mexico, Brazil
Location: Magadi Road, Banashankari, Raj Rajeshwari Nagar.



	<p><i>Cassia fistula</i> Common name: Indian laburnum Family: Fabaceae Description: Tree up to 5 m high. Leaves alternate, pinnate, leaflets up to 8 pairs, ovate-oblong, inflorescence a lax raceme, and drooping up to 50 cm long. Fruit a pod, pendulous, black, cylindrical. Flowering and Fruits: Mar. – May; Sep. Native: India, China, Southeast Asia Location: Malleshwaram, Jayanagar East, Sanjay Nagar, Yeshwanthpur, Rajajeshwari Nagar, Sadashiva Nagar, Seshadripuram, Yelahanka, Mahalakshmi Layout.</p>
<p><i>Milletia ovalifolia</i> Common name: Moulmein Rose Wood Family: Fabaceae Description: A small deciduous tree. Leaves imparipinnately compound, elliptical, obtuse. Flowers solitary or fascicled. Fruit linear, glabrous to subglabrous. Flowering and Fruits: January – February Native: Burma Location: Lalbagh, Vidhana Soudha, Cubbon park, Malleshwaram.</p>	
	<p><i>Michelia champaca</i> L. Common name: Orange champak Family: Magnoliaceae Description: Erect tree, up to 10 m high. Leaves alternate, simple, petiolate, ovate-lanceolate, coriaceous and glabrous. Flowers solitary, fragrant, Fruit a capsule, brown, dehiscent. Flowering and Fruits: March- May. Native: India, Malaysia Location: Lalbagh, Mahalakshmi layout, Rajajeshwari Nagar.</p>

Samanea saman (Jacq.) Merr.

Common name: Rain tree

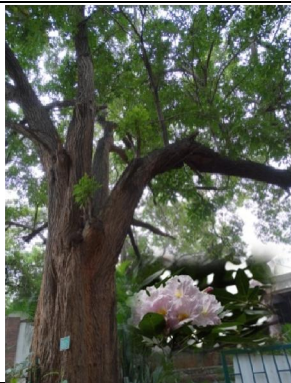
Family: Fabaceae

Description: A large tree upto 15 m high. Leaves alternate, bipinnate upto 30 cm long, stipules early caduceous. Inflorescence a corymbose spike, bracts spatulate. Fruit pod with sugary pulp, brownish-black, upto 20 cm long. Seeds ovoid.

Flowering: March- May

Native: Tropical America, West Indies

Location: Banashankari, Jeevanbhima Nagar, Magadi Road.



Tabebuia rosea (Bertol) DC.

Common name: Rosy trumpet

Family: Bignoniaceae

Description: A deciduous tree grows up to 30 m. Leaves are compound, digitate and each leaf has 5 leaflets. Flowers appear in dense terminal panicles. Fruit capsule is a horn-shaped capsule.

Flowering: Summer

Native: Tropical South America

Location: Basavangudi, Jayanagar 4th Block, National College, Cubbon park, Lalbagh, Malleshwaram

Murraya koenigii

Common name: Curry leaf tree

Family: Rutaceae

Description: An evergreen small tree. Leaves are compound. Inflorescence is a bunch of small flowers which are mildly fragrant. Fruit is globose to oblong and deep purple or black and shiny when ripe.

Flowering and Fruits: Summer months

Native: India, Sri Lanka, China, Laos, Myanmar

Location: Trees are particularly occurring in the backyards of Residential area.



Psidium guajava L.

Common name: Guava

Family: Myrtaceae

Description: A small-sized tree. Leaves are opposite, decussate and elliptic-lanceolate. Flowers are solitary or in pairs at the axils. Petals are white. stamens are many and exerted. Fruit is an edible berry.

Flowering and Fruits: March - May

Native: Tropical America

Location: It is found in almost all residential area

Mangifera indica

Common name: Mango

Family: Anacardiaceae

Description: Moderate sized tree, up to 8 m high. Leaves alternate or sub-opposite, simple, exstipulate, lanceolate, undulate, acute or acuminate. Inflorescence a terminal panicle. Flowers polygamous. Fruit a fleshy drupe, orange yellow, heart-shaped.

Flowering and Fruits: Feb. – May.

Native: India

Location: Yeshwanthpur, Hebbal, Malleshwaram, Rajaji Nagar, Mahalakshmi Layout. It is cultivated in almost all residential areas.



Jacaranda mimosifolia D. Don

Common name: Blue Jacaranda

Family: Bignoniaceae

Description: Deciduous tree, upto 10 m high. Leaves opposite, bipinnate, pulvinate. Inflorescence a terminal panicle. Fruit a capsule, flat, woody, orbicular, black. Seeds compressed samaroid.

Native: South America

Location: Jeevanbhima Nagar, Malleshwaram, Rajajinagar.

Saraca asoca (Roxb.) de Wilde

Common name: Flowering ashoka

Family: Fabaceae

Description: Trees, upto 3.5 m high. Leaves alternate, pinnate, upto 20 cm long, rachis glabrous. Inflorescence a corymb, axillary. Fruit a pod, linear-oblong, black, narrow at both filaments slender.

Native: India, Sri Lanka

Location: It is cultivated for ornamental tree.





Thespesia populnea (L.) Sol. Ex Corr. Serr.
 Common name: Portia tree
 Family: Malvaceae
 Description: Tree upto 8 m high. Leaves alternate. Flowers axillary, solitary, bracteoles caducous. Fruit a capsule, subglobose, covered with peltate scales, yellow latex present. Seeds ovoid, channelled along the back, pubescent.
 Native: India, Africa, Pacific Isles
 Location: Sarjapur Road,

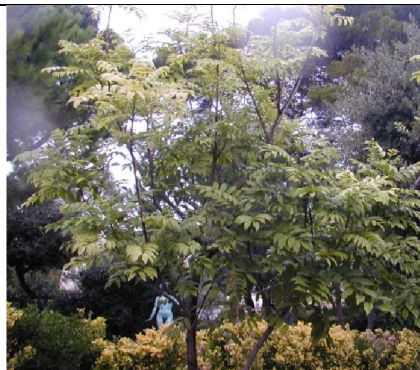
Solanum grandiflorum
 Common name: Potato Tree
 Family: Solanaceae
 Description: Small tree upto 15 feet. Leaves are deeply indented. Flowers are dark purple and found in clusters.
 Native: South America
 Location: Malleshwaram,



Parkia biglandulosa
 Common name: Badminton Ball Tree
 Family: Fabaceae
 Description: A large tree with many branches. Leaves are feathery. Inflorescence is similar to a badminton ball hanging at a long thick stalk.
 Flowering: October - December
 Native: Malaya
 Location: J.P Nagar, Cubbon Park, Sarjapur Road, Rajajinagar.

Lagerstroemia speciosa (L.) Pers.
 Common name: Pride of India
 Family: Lythraceae
 Description: Evergreen tree upto 6 m high. Leaves opposite, simple, elliptic-lanceolate, entire, acute, glabrous, base rounded. Inflorescence a terminal panicle. Fruit a capsule, woody, dehiscent. Seeds flat, winged at apex.
 Flowering: May
 Native: India
 Location: Lalbagh, Vidhana Soudha, M.G. Road, Malleshwaram.





Castanospermum australe Cunn. & Fraser

Common name: Australian chestnut

Family: Fabaceae

Description: evergreen tree planted as an ornamental in warm regions. Leaves pinnately compound, large and leathery. Flowers large, yellow to orange or reddish in racemes. Fruit is a woody pod with shining surface, cylindrical with tapering ends on both sides.

Flowering: January - March

Native: Australia

Location: Lalbagh, Cubbon Park,

Butea monosperma

Common name: Flame of the Forest

Family: Fabaceae

Description: A medium-sized native tree which is highly ornamental. Leavea are pinnately 3-foliolate with large leaflets. Flowers are bright red or orange-red in color. Pod is broad, oblong follicle.

Flowering: February - March

Native: India

Location: Yeshwanthpur, Mahalakshmi Layout, Jayanagar.



Enterolobium cyclocarpum

Common name: Elephant ear tree

Family: Fabaceae

Description: medium-sized tree upto 25-35 m tall. Leaves are bipinnate compound. Globular inflorescences. Fruit large glossy dark brown indehiscent and spirally-organized pods.

Flowering: February to April

Native: America, Central Mexico

Location: Malleshwaram, J P Nagar.

Tabebuia impetiginosa (Mart. Ex DC.) Standl.

Common name: Pink trumpet tree

Family: Bignoniaceae

Description: A small tree with light canopy of spreading branches. Leaves compound of five board leaflets. Flowers vary from pale pink to purple. Fruit is a pale-brown capsule.

Flowering: February – March

Native: South America

Location: M.G Road, Lalbagh, Cubbon park, Hudson circle.





Tabebuia aurea (Manso) benth. & Hook.f. ex S. Moore
 Common name: Caribbean trumpet tree
 Family: Bignoniaceae
 Description: A small deciduous tree. Leaves are palmately compound of five thick leaflets with long stalks. Flowers trumpet-shaped and appear in dense clusters at the ends of branches. Fruit is a pale-brown, hard capsule with winged seeds.
 Flowering: January- March
 Native: South America
 Location: Malleshwaram, Mahlakshmi layout.

Dolichandrone platycalyx
 Common name: Nile Tulip tree
 Family: Bignoniaceae
 Description: Tree grows tall with not branching very much. Flowers are tubular yellow found in clusters. Pods are brown, twisted.
 Flowering: Most of the year.
 Native: East Africa
 Location: Cultivated as avenue tree.



Eucalyptus tereticornis
 Common name: Forest red gum
 Family: Myrtaceae
 Description: A tall evergreen tree with mottled grey bark and a smooth creamy bark. Leaves are long, narrow and curved. Flowers are in stalked cclusters with conical 'pixie-cap'. Fruit is woody, dehiscent with protruding teeth.
 Flowering: October- January
 Native: Australia
 Location: M.G Road, Malleshwaram, Mysore Road and Outskirts of City.

Callistemon viminalis (Soland. Ex Gaertn.) G. Don
 Common name: Drooping bottle-brush
 Family: Myrtaceae
 Description: A graceful willow-like medium-sized evergreen tree with drooping. Leaves are simple and narrow. Flowers are small with several long attractive stamens. Inflorescence elongated axis giving a bottle-brush appearance.
 Flowering: July-October
 Native: Australia
 Location: occur in institutions,








Azadirachta indica Juss. Mem. Mus. Par.
Common Name: **Neem tree**
Family: Meliaceae
Description: Moderate sized tree upto 10 m high. Leaves alternate, pinnate, subopposite, obliquely lanceolate, dentate, acute. Inflorescence an axillary panicle, fruit a drupe, oblong, yellow.



Native: India
Flowers: March; **Fruits:** April-May
Location: It is usually found near temples.



Michelia champaca L.
Common name: **Orange champak**
Family: Magnoliaceae
Description: Erect tree, up to 10 m high. Leaves alternate, simple, petiolate, ovate-lanceolate, coriaceous, glabrous. Flowers solitary, fragrant, Fruit a capsule, brown, dehiscent.

Flowering and Fruits: March- May.
Native: India, Malaysia
Location: Lalbagh, Mahalakshmi layout, Rajajeshwari Nagar, Malleśwaram.



Yellamma Koil Street

Native: India
Flowers and Fruits : February
Location: Malleshwaram, Rajrajeshwari nagar.




Artocarpus heterophyllus Lam.
Common name: Jack Fruit
Family: Moraceae
Description: Moderate sized tree up to 6m high. Leaves alternate, oblong-obovate, entire, obtuse, acute at base, dark-green above. Inflorescence oblong heads, axillary and an old trunk. Flowers unisexual. Fruit multiple, seeds large, oblong.

Halasuru



@Google






Mangifera indica
Common name: Mango
Family: Anacardiaceae
Description: Moderate sized tree, up to 8 m high. Leaves alternate or sub-opposite, simple, exstipulate, lanceolate, undulate, acute or acuminate. Inflorescence a terminal panicle. Flowers polygamous.. fruit a fleshy drupe, orange yellow. Heart-shaped.

Mavallipura

Flowering and Fruits: Feb. – May.
Native: India
Location: Yeshwanthpur, Hebbal, Malleshwaram, Rajaji Nagar, Mahalakshmi Layout

50 m



Delonix regia (Bojer ex Hook.) Raf.

Common name: Gulmohur

Family: Fabaceae

Description: Moderate sized tree upto 9 m high. Leaves alternate, bipinnate, upto 40 cm long. Inflorescence a corymb. Fruit a pod, long, black, when dry, upto 50 cm long, septate within.

Flowering and fruits: April - June

Native: Madagascar

Location: Rajajeshwari Nagar, Malleshwaram, Rajaji Nagar, Shankar Mutt, Seshadripuram, Yelahanka. Cultivated as avenue tree.



Swietenia mahagoni

Common name: West Indian

Mahogany

Family: Meliaceae

Description: A large deciduous tree with spreading branches. Leaves are long, pinnately compound with 2-5 pairs of leaflets. Leaves are deciduous to semi-evergreen. Flowers are inconspicuous, unisexual, greenish-yellow in branched clusters.



Flowering and Fruits: March- May.

Native: Tropical America, Mexico, Brazil

Location: Raj rajeshwari Nagar, Malleshwaram, Rajaji Nagar, Mahalakshmi Layout



Grevillea robusta Cunn. Ex R. Br.

Common name: Silver oak

Family: Proteaceae

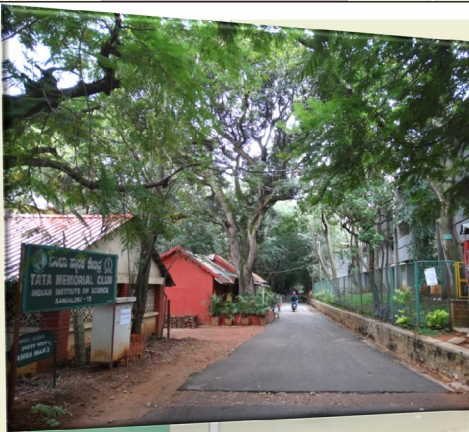
Description: A fast-growing evergreen tree. Leaves are dark green dented bipinnatifid long with grayish white or rusty undersides. Flowers are golden-orange in one-sided racemes. Fruit is a boat-shaped, dark brown leathery dehiscent follicle.



Flowering and Fruits: March -May

Native: Australia

Location: M.G Road, Hebbal, Yeshwanthpur.



Mangifera indica

Common name: Mango

Family: Anacardiaceae

Description: Moderate sized tree, up to 8 m high. Leaves alternate or sub-opposite, simple, exstipulate, lanceolate, undulate, acute or acuminate. Inflorescence a terminal panicle. Flowers polygamous.. fruit a fleshy drupe, orange yellow. Heart-shaped.



Amra marg



Flowering and Fruits: Feb. – May.

Native: India

Location: Yeshwanthpur, Hebbal, Malleshwaram, Rajaji Nagar, Mahalakshmi Layout

INSDOC

Terminalia arjuna
Common name: Arjun
Family: Combretaceae
Description: A large handsome nearly evergreen tree with often buttressed trunk and drooping branchlets. Leaves are simple, oblong, crenulate and leathery in texture. Flowers are small, white, catkin inflorescence. Fruit is ovoid winged.
Flowering and Fruits: Summer months
Native: India

Eucalyptus tereticornis
Common name: Forest red gum
Family: Myrtaceae
Description: A tall evergreen tree with mottled grey bark and a smooth creamy bark. Leaves are long, narrow and curved. Flowers are in stalked cclusters with conical 'pixie-cap'. Fruit is woody, dehiscent with protruding teeth.
Flowering: October- January
Native: Australia



Insights to urban dynamics through landscape spatial pattern analysis

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ABSTRACT

Urbanisation is a dynamic complex phenomenon involving large scale changes in the land uses at local levels. Analyses of changes in land uses in urban environments provide a historical perspective of land use and give an opportunity to assess the spatial patterns, correlation, trends, rate and impacts of the change, which would help in better regional planning and good governance of the region. Main objective of this research is to quantify the urban dynamics using temporal remote sensing data with the help of well-established landscape metrics. Bangalore being one of the rapidly urbanising landscapes in India has been chosen for this investigation. Complex process of urban sprawl was modelled using spatio temporal analysis. Land use analyses show 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. The Study area was divided into four zones and each zone is further divided into 17 concentric circles of 1 km incrementing radius to understand the patterns and extent of the urbanisation at local levels. The urban density gradient illustrates radial pattern of urbanisation for the period 1973–2010. Bangalore grew radially from 1973 to 2010 indicating that the urbanisation is intensifying from the central core and has reached the periphery of the Greater Bangalore. Shannon's entropy, alpha and beta population densities were computed to understand the level of urbanisation at local levels. Shannon's entropy values of recent time confirms dispersed haphazard urban growth in the city, particularly in the outskirts of the city. This also illustrates the extent of influence of drivers of urbanisation in various directions. Landscape metrics provided in depth knowledge about the sprawl. Principal component analysis helped in prioritizing the metrics for detailed analyses. The results clearly indicates that whole landscape is aggregating to a large patch in 2010 as compared to earlier years which was dominated by several small patches. The large scale conversion of small patches to large single patch can be seen from 2006 to 2010. In the year 2010 patches are maximally aggregated indicating that the city is becoming more compact and more urbanised in recent years. Bangalore was the most sought after destination for its climatic condition and the availability of various facilities (land availability, economy, political factors) compared to other cities. The growth into a single urban patch can be attributed to rapid urbanisation coupled with the industrialisation. Monitoring of growth through landscape metrics helps to maintain and manage the natural resources.

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1. Introduction

Urbanisation and Urban Sprawl: Urbanisation is a dynamic process involving changes in vast expanse of land cover with

the progressive concentration of human population. The process entails switch from spread out pattern of human settlements to compact growth in urban centres. Rapidly urbanising landscapes attains inordinately large population size leading to gradual collapse in the urban services evident from the basic problems in housing, slum, lack of treated water supply, inadequate infrastructure, higher pollution levels, poor quality of life, etc. Urbanisation is a product of demographic explosion and poverty induced rural-urban migration. Globalisation, liberalization, privatization are the agents fuelling urbanisation in most parts of India. However, unplanned urbanisation coupled with the lack of holistic approaches, is leading to lack of infrastructure and basic amenities.

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E-mail addresses: cestvr@ces.iisc.ernet.in, energy@ces.iisc.ernet.in (R. TV).

URL: <http://ces.iisc.ernet.in/energy> (R. TV).

Hence proper urban planning with operational, developmental and restorative strategies is required to ensure the sustainable management of natural resources.

Urban dynamics involving large scale changes in the land use depend on (i) nature of land use and (ii) the level of spatial accumulation. Nature of land use depends on the activities that are taking place in the region while the level of spatial accumulation depends on the intensity and concentration. Central areas have a high level of spatial accumulation of urban land use (as in the CBD: Central Business District), while peripheral areas have lower levels of accumulation. Most economic, social or cultural activities imply a multitude of functions, such as production, consumption and distribution. These functions take place at specific locations depending on the nature of activities – industries, institutions, etc.

Unplanned growth would involve radical land use conversion of forests, surface water bodies, etc. with the irretrievable loss of ground prospects (Pathan et al., 1989, 1991, 1993, 2004). The process of urbanisation could be either in the form of townships or unplanned or organic. Many organic towns in India are now influencing large-scale infrastructure development, etc. Due to the impetus from the National government through development schemes such as JNNURM (Jawaharlal Nehru National Urban Renewal Mission), etc. The focus is on the fast track development through an efficient infrastructure and delivery mechanisms, community participation, etc.

The urban population in India is growing at about 2.3% per annum with the global urban population increasing from 13% (220 million in 1900) to 49% (3.2 billion, in 2005) and is projected to escalate to 60% (4.9 billion) by 2030 (Ramachandra and Kumar, 2008; World Urbanisation Prospects, 2005). The increase in urban population in response to the growth in urban areas is mainly due to migration. There are 48 urban agglomerations/cities having a population of more than one million in India (in 2011).

Urbanisation often leads to the dispersed haphazard development in the outskirts, which is often referred as sprawl. Thus urban sprawl is a consequence of social and economic development of a certain region under certain circumstances. This phenomenon is also defined as an uncontrolled, scattered suburban development that depletes local resources due to large scale land use changes involving the conversion of open spaces (water bodies, parks, etc.) while increasing carbon footprint through the spurt in anthropogenic activities and congestion in the city (Peiser, 2001;

Ramachandra and Kumar, 2009). Urban sprawl increasingly has become a major issue facing many metropolitan areas. Due to lack of visualization of sprawl a priori, these regions are devoid of any infrastructure and basic amenities (like supply of treated water, electricity, sanitation facilities). Also these regions are normally left out in all government surveys (even in national population census), as this cannot be grouped under either urban or rural area. Understanding this kind of growth is very crucial in order to provide basic amenities and more importantly the sustainable management of local natural resources through decentralized regional planning.

Urban sprawl has been captured indirectly through socio-economic indicators such as population growth, employment opportunity, number of commercial establishments, etc. (Brueckner, 2000; Lucy and Philips, 2001). However, these techniques cannot effectively identify the impacts of urban sprawl in a spatial context. In this context, availability of spatial data at regular interval through space-borne remote sensors are helpful in effectively detecting and monitoring rapid land use changes (e.g., Chen et al., 2000; Epstein et al., 2002; Ji et al., 2001; Lo and Yang, 2002; Dietzel et al., 2005). Urban sprawl is characterised based on various indicators such as growth, social, aesthetic, decentralisation, accessibility, density, open space, dynamics, costs, benefits, etc. (Bhatta, 2009a,b, 2010). Further, Galster et al. (2001), has identified parameters such as density, continuity, concentration, clustering, centrality, nuclearity, proximity and mixed uses for quantifying sprawl. Urbanisation and sprawl analysis would help the regional planners and decision makers to visualize growth patterns and plan to facilitate various infrastructure facilities. In the context of rapid urban growth, development should be planned and properly monitored to maintain internal equilibrium through sustainable management of natural resources. Internal equilibrium refers to the urban system and its dynamics evolving harmony and thus internally limiting impacts on the natural environment consequent to various economic activities with the enhanced growth of population, infra-structure, services, pollution, waste, etc. (Barredo and Demicheli, 2003). Due to globalisation process, the cities and towns in India are experiencing rapid urbanisation consequently lacking appropriate infrastructure and basic amenities. Thus understanding the urban dynamics considering social and economic changes is a major challenge. The social and economic dynamics trigger the change processes in urban places of different sizes ranging from large metropolises, cities and small towns. In this context, the

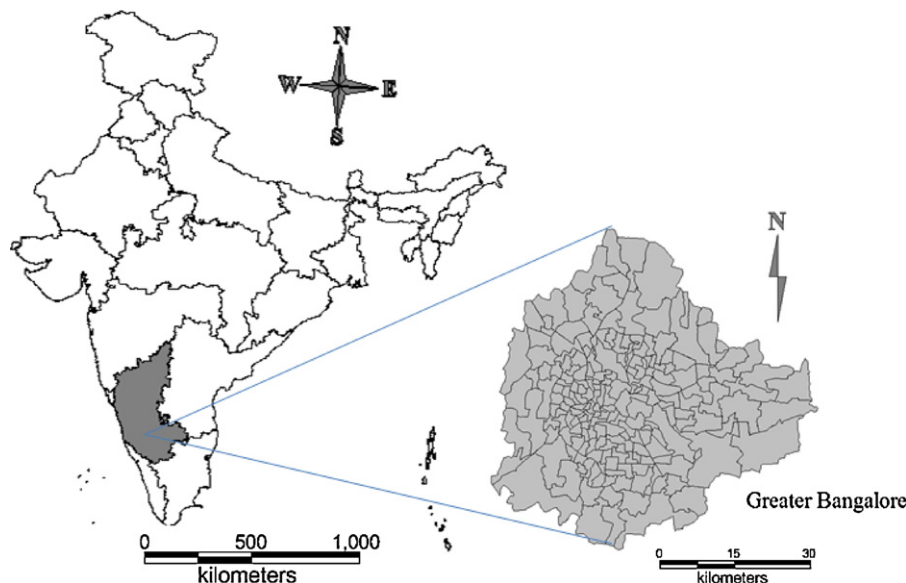


Fig. 1. Study area: Greater Bangalore.

Table 1
Materials used in the analysis.

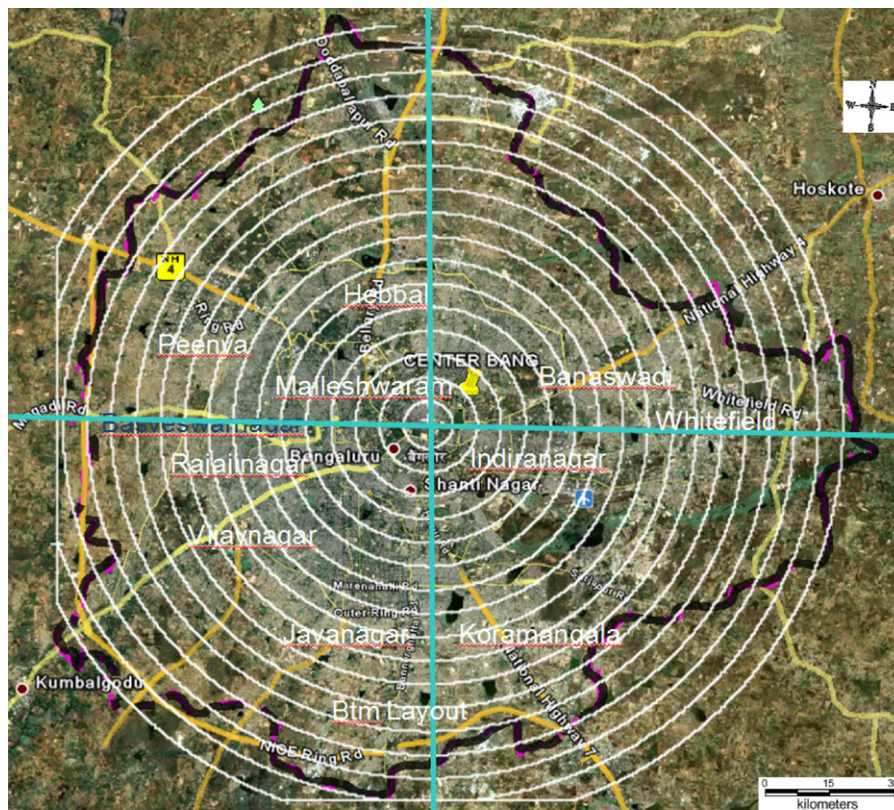
Data	Year	Purpose
Landsat Series Multispectral sensor (57.5 m)	1973	Land use analysis
Landsat Series Thematic mapper (28.5 m) and enhanced thematic mapper sensors	1992, 1999, 2002, 2006, 2010	Land use analysis
Survey of India (SOI) toposheets of 1:50,000 and 1:250,000 scales		Boundary and base layers
Census data	2001	Population density ward-wise

analysis of urban dynamics entails capturing and analyzing the process of changes spatially and temporally (Sudhira et al., 2004; Tian et al., 2005; Yu and Ng, 2007).

Land use Analysis and Gradient approach: The basic information about the current and historical land cover and land use plays a major role in urban planning and management (Zhang et al., 2002). Land-cover essentially indicates the feature present on the land surface (Janssen, 2000; Lillesand and Kiefer, 2002; Sudhira et al., 2004). Land use relates to human activity/economic activity on piece of land under consideration (Janssen, 2000; Lillesand and Kiefer, 2002; Sudhira et al., 2004). This analysis provides various uses of land as urban, agriculture, forest, plantation, etc., specified as per USGS classification system (<http://landcover.usgs.gov/pdf/anderson.pdf>) and National Remote Sensing Centre, India (<http://www.nrsc.gov.in>). Mapping landscapes on temporal scale provide an opportunity to monitor the changes, which is important for natural resource management and sustainable planning activities. In this regard, “Density Gradient metrics” with the time series spatial data analysis are potentially useful in measuring urbanisation and sprawl (Torrens and Alberti, 2000). Density gradient metrics include sprawl density gradient, Shannon’s entropy, alpha and beta population densities, etc. This paper presents temporal land use analysis for rapidly urbanising Bangalore and density gradient metrics have been computed to

evaluate and monitor urban dynamics. Landscape dynamics have been unraveled from temporally discrete data (remote sensing data) through spatial metrics (Crews-Meyer, 2002). Landscape metrics (longitudinal data) integrated with the conventional change detection techniques would help in monitoring land use changes (Rainis, 2003). This has been demonstrated through the application in many regions (Kienast, 1993; Luque et al., 1994; Simpson et al., 1994; Thibault and Zipperer, 1994; Hulshoff, 1995; Medley et al., 1995; Zheng et al., 1997; Palang et al., 1998; Sachs et al., 1998; Pan et al., 1999; Lausch and Herzog, 1999).

Further, landscape metrics were computed to quantify the patterns of urban dynamics, which helps in quantifying spatial patterns of various land cover features in the region (McGarigal and Marks, 1995) and has been used effectively to capture urban dynamics similar to the applications in landscape ecology (Gustafson, 1998; Turner et al., 2001) for describing ecological relationships such as connectivity and adjacency of habitat reservoirs (Geri et al., 2010; Jim and Chen, 2009). Herold et al. (2002, 2003) quantifies urban land use dynamics using remote sensing data and landscape metrics in conjunction with the spatial modelling of urban growth. Angel et al. (2007) have considered five metrics for measuring the sprawl and five attributes for characterizing the type of sprawl. Spatial metrics were used for effective characterisation of the sprawl by quantifying landscape attributes (shape, complexity,



Source: Google earth

Fig. 2. Division of the study area into concentric circles of incrementing radius of 1 km.

Table 2
Prioritised landscape metrics.

Indicators	Type of metrics and formula	Range	Significance/description
1 Number of urban patches	Patch metrics $NPU = n$ NP equals the number of patches in the landscape	$NPU > 0$, without limit	Higher the value more the fragmentation
2 Perimeter Area Weighted Mean Ratio. PARA_AM	Edge metrics $PARA_AM = P_{ij}/A_{ij}$ P_{ij} = perimeter of patch ij A_{ij} = area weighted mean of patch ij $AM = \sum_{j=1}^n x_{ij} \left[\left(\frac{a_{ij}}{\sum_{j=1}^n a_{ij}} \right) \right]$	≥ 0 , without limit	PARA AM is a measure of the amount of 'edge' for a landscape or class. PARA AM value increases with increasing patch shape complexity
3 Landscape Shape Index (LSI)	Shape Metrics $LSI = \frac{e_i}{\min e_i}$ e_i = total length of edge (or perimeter) of class i in terms of number of cell surfaces; includes all landscape boundary and background edge segments involving class i . $\min e_i$ = minimum total length of edge (or perimeter) of class i in terms of number of cell surfaces (see below)	$LSI > 1$, without limit	$LSI = 1$ when the landscape is a single square or maximally compact patch; LSI increases without limit as the patch type becomes more disaggregated
4 Clumpiness	Compactness/contagion/dispersion metrics $CLUMPY = \begin{cases} \frac{G_i - P_i}{P_i - P_i} & \text{for } G_i < P_i \& P_i < 5, \text{ else} \\ \frac{G_i - P_i}{1 - P_i} \end{cases}$ $G_i = \left(\frac{g_{ii}}{\sum_{k=1}^m g_{ii}} - \min e_i \right)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the <i>double-count</i> method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the <i>double-count</i> method. $\min - e_i$ = minimum perimeter (in number of cell surfaces) of patch type (class) i for a maximally clumped class. P_i = proportion of the landscape occupied by patch type (class) i	$-1 \leq CLUMPY \leq 1$	It equals 0 when the patches are distributed randomly, and approaches 1 when the patch type is maximally aggregated
5 Aggregation index	Compactness/contagion/dispersion metrics $AI = \left[\sum_{i=1}^m \left(\frac{g_{ii}}{\max - g_{ii}} \right) P_i \right] \times 100$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) i based on the single count method. $\max - g_{ii}$ = maximum number of like adjacencies (joins) between pixels of patch type class i based on single count method. P_i = proportion of landscape comprised of patch type (class) i .	$1 \leq AI \leq 100$	AI equals 1 when the patches are maximally disaggregated and equals 100 when the patches are maximally aggregated into a single compact patch.
6 Interspersion and Juxtaposition	Compactness/contagion/dispersion metrics $IJI = \frac{-\sum_{i=1}^m \sum_{k=i+1}^m \frac{[(e_{ik}/E) \ln(e_{ik}/E)]}{\ln(0.5[m(m-1)])}}{\ln(0.5[m(m-1)])} \times 100$ e_{ik} = total length (m) of edge in landscape between patch types (classes) i and k . E = total length (m) of edge in landscape, excluding background m = number of patch types (classes) present in the landscape, including the landscape border, if present.	$0 \leq IJI \leq 100$	IJI is used to measure patch adjacency. IJI approach 0 when distribution of adjacencies among unique patch types becomes increasingly uneven; is equal to 100 when all patch types are equally adjacent to all other patch types

etc.). Jiang et al. (2007) used 13 geospatial indices for measuring the sprawl in Beijing and proposed an urban Sprawl Index combining all indices. This approach reduces computation and interpretation time and effort. However, this approach requires extensive data such as population, GDP, land-use maps, floor-area ratio, maps of roadways/highways, urban city center spatial maps, etc. This confirms that landscape metrics aid as important mathematical tool for characterising urban sprawl efficiently. Population data along with geospatial indices help to characterise the sprawl (Ji et al., 2006) as population is one of the causal factor driving land use changes. These studies confirm that spatio-temporal data along with landscape metrics, population metrics and urban modelling would help in understanding and evaluating the spatio temporal patterns of urban dynamics.

2. Objective

The objective of this study is to understand the urbanisation and urban sprawl process in a rapidly urbanising landscape, through

spatial techniques involving temporal remote sensing data, geographic information system with spatial metrics. This involved (i) temporal analysis of land use pattern, (ii) exploring interconnection and effectiveness of population indices, Shannon's entropy for quantifying and understanding urbanisation and (iii) understanding the spatial patterns of urbanisation at landscape level through metrics.

3. Study area

The study has been carried out for a rapidly urbanising region in India. Greater Bangalore is the administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka, India with an area of 741 sqkm and lies between the latitude $12^{\circ}39'00''$ to $13^{\circ}13'00''$ N and longitude $77^{\circ}22'00''$ to $77^{\circ}52'00''$ E. Bangalore city administrative jurisdiction was redefined in the year 2006 by merging the existing area of Bangalore city spatial limits with 8 neighbouring Urban Local Bodies (ULBs) and 111 Villages of Bangalore Urban District. Bangalore has grown spatially more

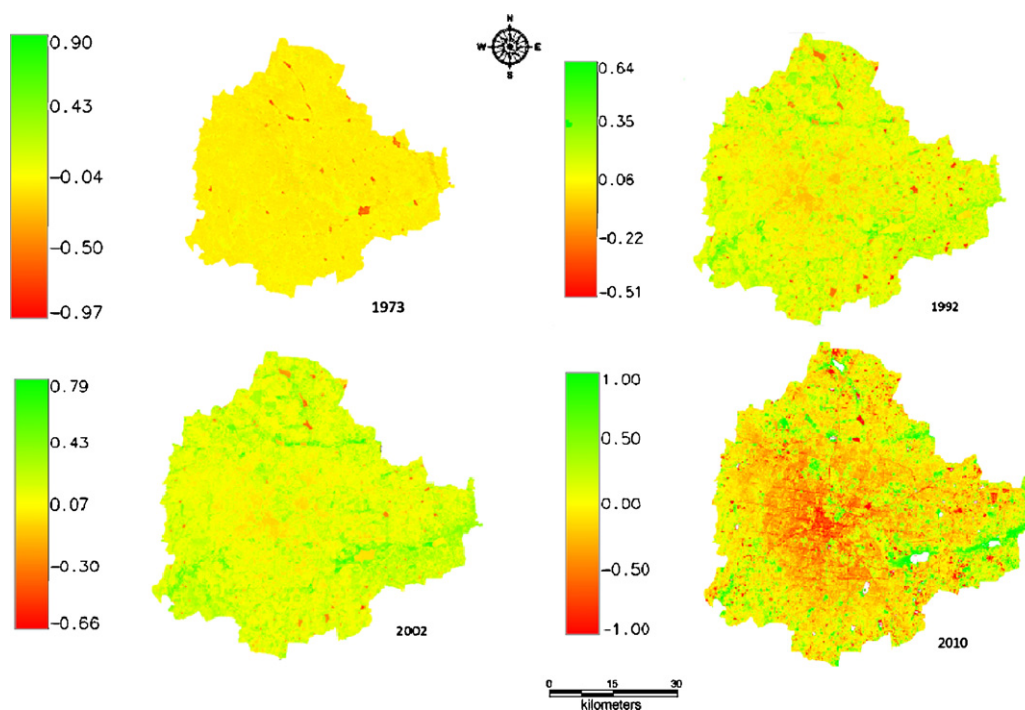


Fig. 3. Land cover changes from 1973 to 2010.

than ten times since 1949 (~69–716 square kilometres) and is the fifth largest metropolis in India currently with a population of about 7 million (Ramachandra and Kumar, 2008, 2010; Sudhira et al., 2007). Bangalore city population has increased enormously from 6,537,124 (in 2001) to 9,588,910 (in 2011), accounting for 46.68% growth in a decade. Population density has increased from as 10,732 (in 2001) to 13,392 (in 2011) persons per sq. km. The per capita GDP of Bangalore is about \$2066, which is considerably low with limited expansion to balance both environmental and economic needs (Fig. 1).

4. Material and methods

Urban dynamics was analysed using temporal remote sensing data of the period 1973–2010. The time series spatial data acquired from Landsat Series Multispectral sensor (57.5 m), Thematic mapper and enhanced thematic mapper plus (28.5 m) sensors for the period 1973–2010 were downloaded from public domain (<http://glcf.umiacs.umd.edu/data>). Survey of India (SOI) topographic maps of 1:50,000 and 1:250,000 scales were used to generate base layers of city boundary, etc. City map with ward boundaries were digitized from the BBMP (Bruhat Bangalore Mahanagara Palike) map. Population data was collected from the Directorate of Census Operations, Bangalore region (<http://censuskarnataka.gov.in>). Table 1 lists the data used in the current analysis. Ground control points to register and geo-correct remote sensing data were

collected using handheld pre-calibrated GPS (Global Positioning System), Survey of India Toposheet, Google earth, Bhuvan (<http://earth.google.com>, <http://bhuvan.nrsc.gov.in>).

5. Data analysis involved

5.1. Pre-processing

The remote sensing data obtained were geo-referenced, rectified and cropped pertaining to the study area. Geo-registration of remote sensing data (Landsat data) has been done using ground control points collected from the field using pre calibrated GPS (Global Positioning System) and also from known points (such as road intersections, etc.) collected from geo-referenced topographic maps published by the Survey of India. The Landsat satellite 1973 images have a spatial resolution of 57.5 m × 57.5 m (nominal resolution) were resampled to 28.5 m comparable to the 1989–2010 data which are 28.5 m × 28.5 m (nominal resolution). Landsat ETM+ bands of 2010 were corrected for the SLC-off by using image enhancement techniques, followed by nearest-neighbour interpolation.

5.2. Vegetation cover analysis

Normalised Difference Vegetation Index (NDVI) was computed to understand the changes in the vegetation cover during the study

Table 3
Temporal land use dynamics.

Class→ Year ↓	Urban		Vegetation		Water		Others	
	Ha	%	Ha	%	Ha	%	Ha	%
1973	5448	7.97	46639	68.27	2324	3.40	13903	20.35
1992	18650	27.30	31579	46.22	1790	2.60	16303	23.86
1999	24163	35.37	31272	45.77	1542	2.26	11346	16.61
2002	25782	37.75	26453	38.72	1263	1.84	14825	21.69
2006	29535	43.23	19696	28.83	1073	1.57	18017	26.37
2010	37266	54.42	16031	23.41	617	0.90	14565	21.27

period. NDVI is the most common measurement used for measuring vegetation cover. It ranges from values -1 to $+1$. Very low values of NDVI (-0.1 and below) correspond to soil or barren areas of rock, sand, or urban builtup. Zero indicates the water cover. Moderate values represent low-density vegetation ($0.1-0.3$), while high values indicate thick canopy vegetation ($0.6-0.8$).

5.3. Land use analysis

The method involves (i) generation of False Colour Composite (FCC) of remote sensing data (bands–green, red and NIR). This helped in locating heterogeneous patches in the landscape, (ii) selection of training polygons (these correspond to heterogeneous patches in FCC) covering 15% of the study area and uniformly distributed over the entire study area, (iii) loading these training polygons co-ordinates into pre-calibrated GPS, (vi) collection of the corresponding attribute data (land use types) for these polygons from the field. GPS helped in locating respective training polygons in the field, (iv) supplementing this information with Google Earth and (v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment.

Land use analysis was carried out using supervised pattern classifier – Gaussian maximum likelihood algorithm. This has been proved superior classifier as it uses various classification decisions using probability and cost functions (Duda et al., 2000). Mean and covariance matrix are computed using estimate of maximum likelihood estimator. Accuracy assessment to evaluate the performance of classifiers (Mitrakis et al., 2008; Ngigi et al., 2008; Gao and Liu, 2008), was done with the help of field data by testing the statistical significance of a difference, computation of kappa coefficients (Congalton et al., 1983; Sha et al., 2008) and proportion of correctly allocated cases (Gao and Liu, 2008). Recent remote sensing data (2010) was classified using the collected training samples. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies. For earlier time data, training polygon along with attribute details were compiled from the historical published topographic maps, vegetation maps, revenue maps, etc.

Table 4
Kappa values and overall accuracy.

Year	Kappa coefficient	Overall accuracy (%)
1973	0.88	72
1992	0.63	77
1999	0.82	76
2002	0.77	80
2006	0.89	75
2010	0.74	78

Table 5
Shannon entropy.

	NE	NW	SE	SW
1973	0.173	0.217	0.126	0.179
1992	0.433	0.509	0.399	0.498
1999	0.504	0.658	0.435	0.607
2002	0.546	0.637	0.447	0.636
2006	0.65	0.649	0.610	0.695
2010	0.771	0.812	0.640	0.778

Application of maximum likelihood classification method resulted in accuracy of 76% in all the datasets. Land use was computed using the temporal data through open source program GRASS – Geographic Resource Analysis Support System (<http://grass.fbk.eu/>). Land use categories include (i) area under vegetation (parks, botanical gardens, grass lands such as golf field), (ii) built up (buildings, roads or any paved surface), (iii) water bodies (lakes/tanks, sewage treatment tanks), and (iv) others (open area such as play grounds, quarry regions, etc.).

5.4. Density gradient analysis

Urbanisation pattern has not been uniform in all directions. To understand the pattern of growth *vis-a-vis* agents, the region has been divided into 4 zones based on directions – Northwest (NW), Northeast (NE), Southwest (SW) and Southeast (SE), respectively (Fig. 2) based on the Central pixel (Central Business district). The growth of the urban areas in respective zones was monitored through the computation of urban density for different periods.

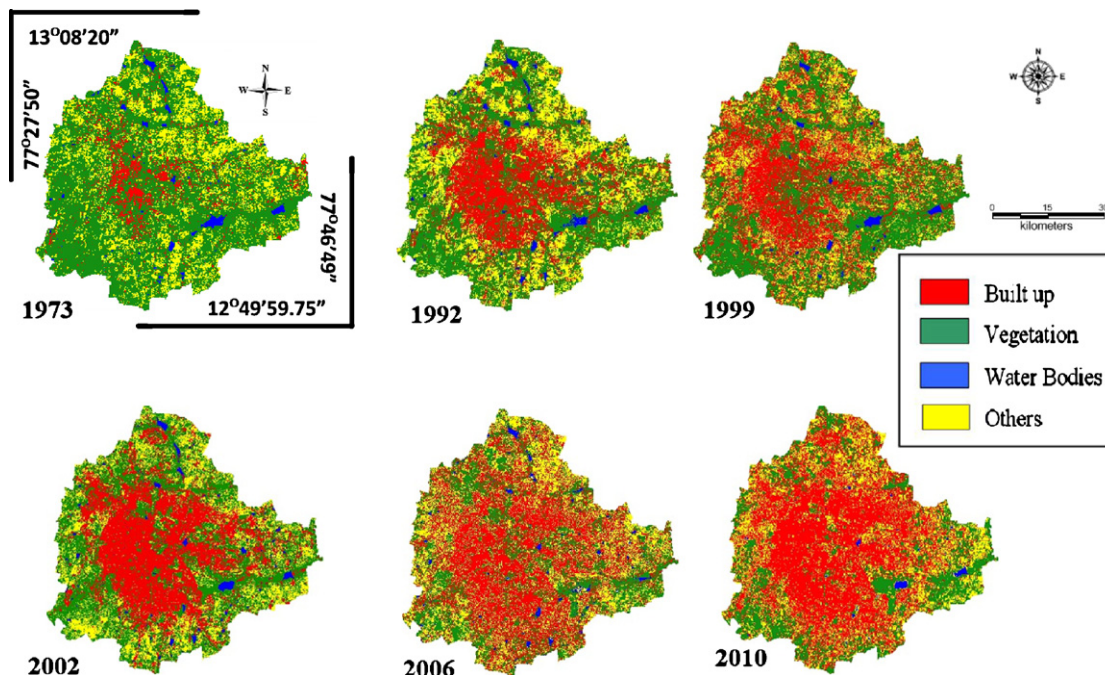
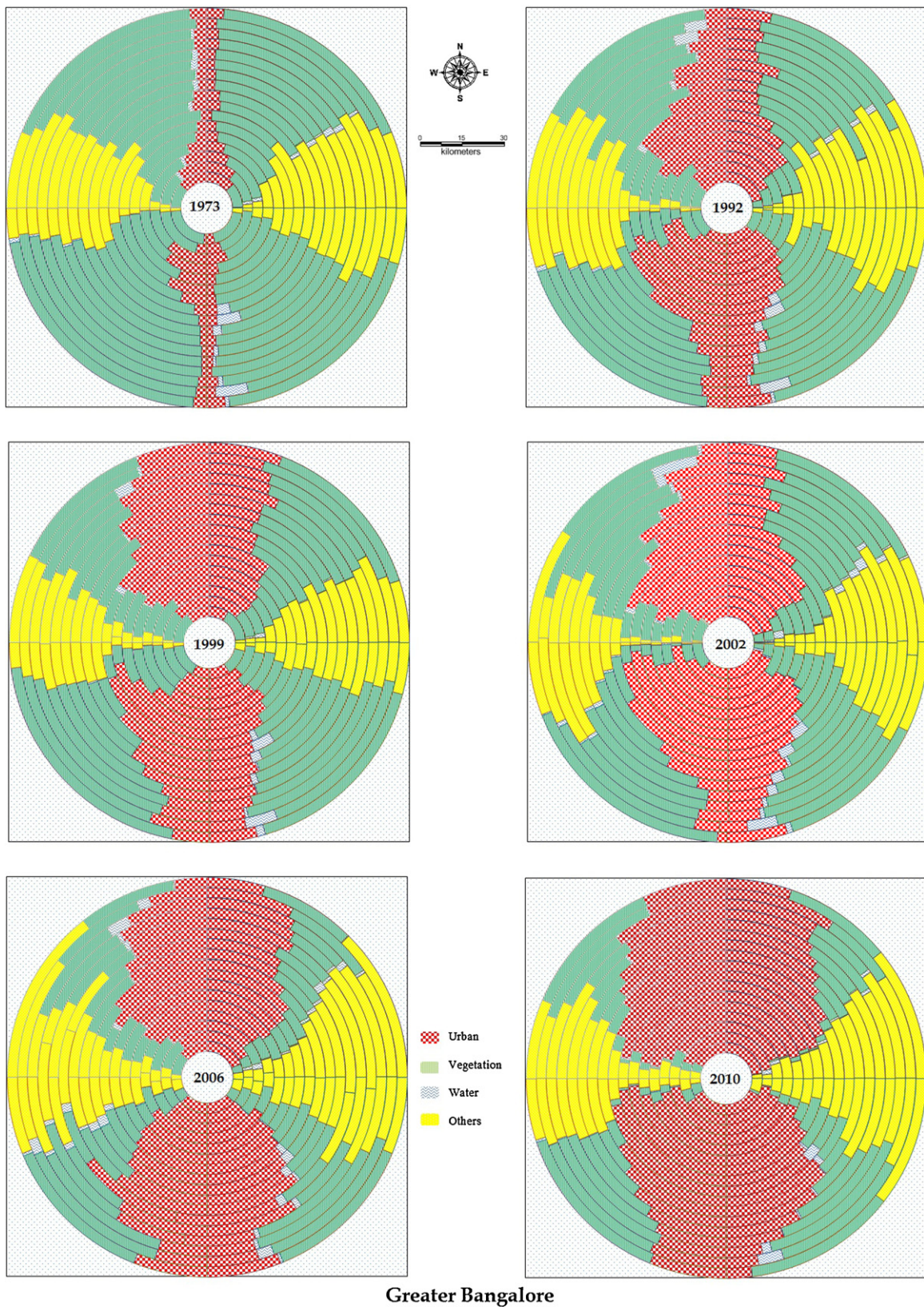


Fig. 4. Land use changes in Greater Bangalore.



Greater Bangalore

Fig. 5. Zone-wise and Gradient-wise temporal land use.

5.5. Division of these zones to concentric circles and computation of metrics

Further each zone was divided into concentric circle of increasing radius of 1 km from the centre of the city (Fig. 2), that

would help in visualizing and understanding the agents responsible for changes at local level. These regions are comparable to the administrative wards ranging from 67 to 1935 hectares. This helps in identifying the causal factors and locations experiencing various levels (sprawl, compact growth, etc.) of urbanisation in response to

the economic, social and political forces. This approach (zones, concentric circles) also helps in visualizing the forms of urban sprawl (low density, ribbon, leaf-frog development). The built up density in each circle is monitored overtime using time series analysis.

5.6. Computation of Shannon's entropy

To determine whether the growth of urban areas was compact or divergent the Shannon's entropy (Yeh and Liu, 2001; Li and Yeh, 2004; Lata et al., 2001; Sudhira et al., 2004; Pathan et al., 2004) was computed for each zones. Shannon's entropy (H_n) given in Eq. (1), provides the degree of spatial concentration or dispersion of geographical variables among 'n' concentric circles across Zones.

$$H_n = - \sum_{i=1}^n P_i \log(P_i) \tag{1}$$

where P_i is the proportion of the built-up in the i th concentric circle. As per Shannon's entropy, if the distribution is maximally concentrated in one circle the lowest value zero will be obtained. Conversely, if it is an even distribution among the concentric circles will be given maximum of $\log n$.

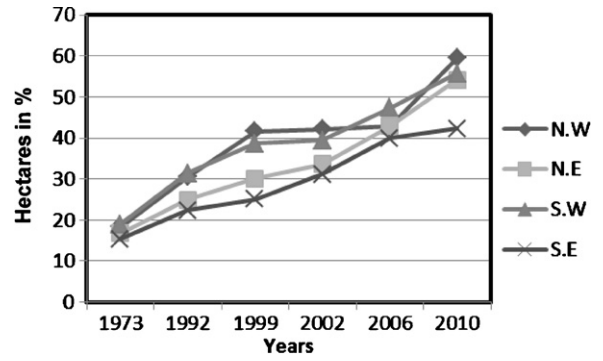


Fig. 6. Built up density across years from 1973 to 2010.

5.7. Computation of alpha and beta population density

Alpha and beta population densities were calculated for each circle with respect to zones. Alpha population density is the ratio of total population in a region to the total builtup area, while Beta population density is the ratio of total population to the total

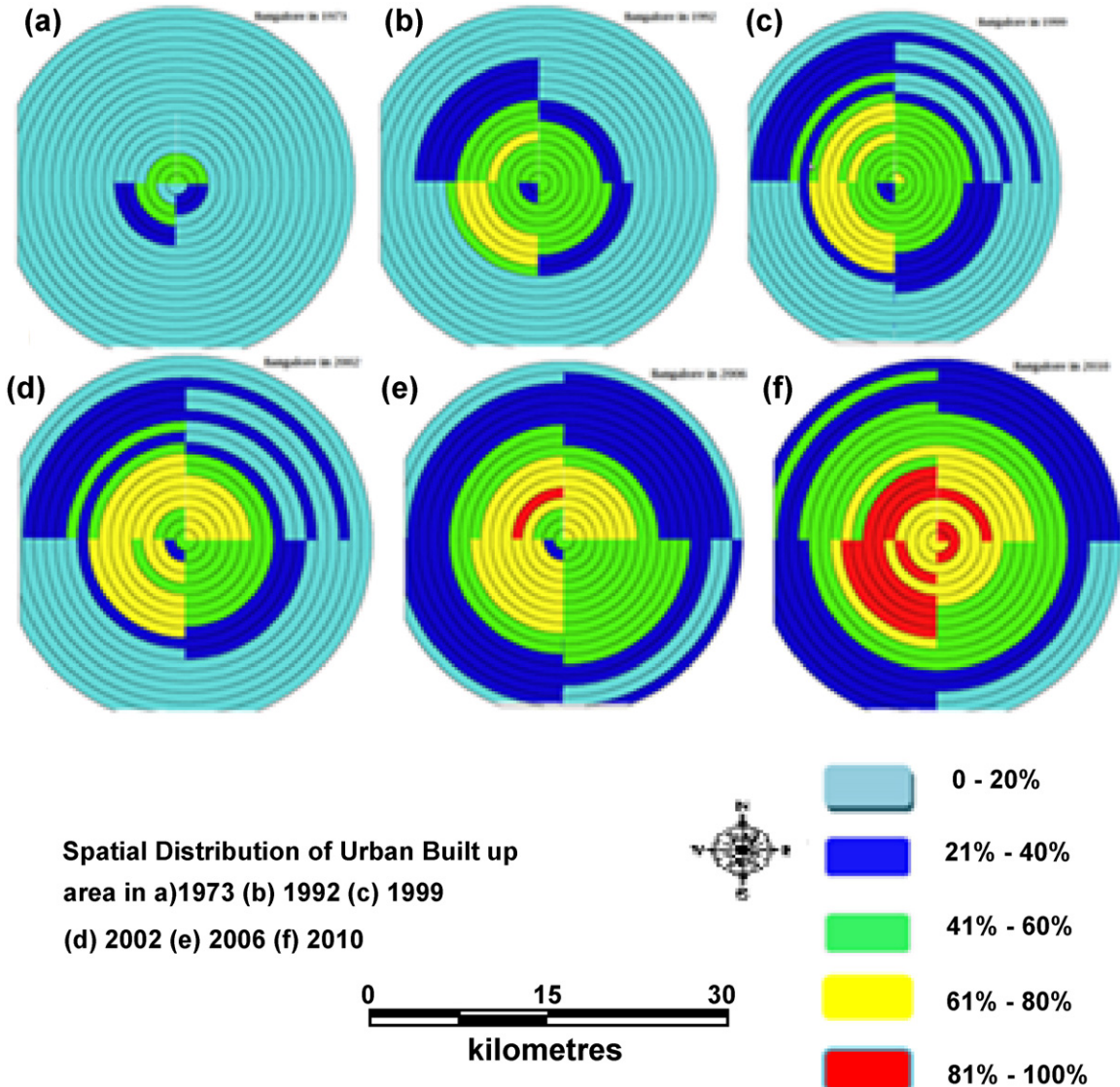


Fig. 7. Gradient analysis of Greater Bangalore- Builtup density circlewise and zonewise.

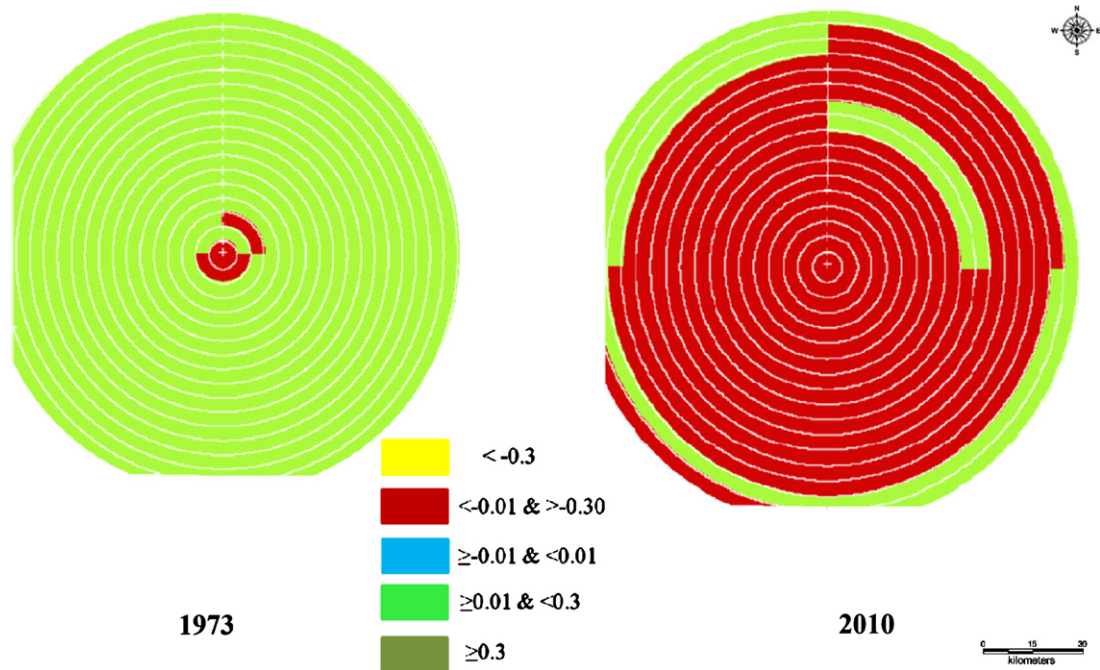


Fig. 8. NDVI gradients – circlewise and zone wise.

geographical area. These metrics have been often used as the indicators of urbanisation and urban sprawl and are given by:

$$\alpha \text{ density} = \frac{\text{total population}}{\text{total built up}} \quad (2)$$

$$\beta \text{ density} = \frac{\text{total population}}{\text{total geographic area}} \quad (3)$$

5.8. Gradient analysis of NDVI images of 1973 and 2010

The NDVI gradient was generated to visualize the vegetation cover changes in the specific pockets of the study area.

5.9. Calculation of landscape metrics

Landscape metrics provide quantitative description of the composition and configuration of urban landscape. 21 spatial metrics chosen based on complexity, centrality and density criteria (Huang et al., 2007) to characterize urban dynamics, were computed zone-wise for each circle using classified land use data at the landscape level with the help of FRAGSTATS (McGarigal and Marks, 1995). The metrics include the patch area (built up (total land area), Percentage of Landscape (PLAND), Largest Patch Index (percentage of landscape), number of urban patches, patch density, perimeter-area fractal dimension (PAFRAC), Landscape Division Index (DIVISION)), edge/border (edge density, area weighted mean patch fractal dimension (AWMPFD), perimeter area weighted mean ratio (PARA_AM), mean patch fractal dimension (MPFD), total edge (TE), shape (NLSI – Normalized Landscape Shape Index), Landscape Shape Index (LSI)), epoch/contagion/dispersion (Clumpiness, percentage of like adjacencies (PLADJ)), total core area (TCA), ENND coefficient of variation, Aggregation Index, interspersed and juxtaposition). These metrics were computed for each region and principal component analysis was done to prioritise metrics for further detailed analysis.

5.10. Principal component analysis

Principal component analysis (PCA) is a multivariate statistical analysis that aids in identifying the patterns of the data while reducing multiple dimensions. PCA through Eigen analysis transforms a number of (possibly) correlated variables into a (smaller) number of uncorrelated variables called principal components. The first principal component accounts for as much of the variability in the data as possible, and each succeeding component accounts for as much of the remaining variability as possible (Wang, 2009). PCA helped in prioritizing six landscape metrics based on the relative contributions of each metrics in the principal components with maximum variability (Table 2).

6. Results and discussion

Vegetation cover of the study area was analysed through NDVI. Fig. 3 illustrates that area under vegetation has declined from 72% (488 sq. km in 1973) to 21% (145 sq. km in 2010).

6.1. Land use analysis

- Land use analysis for the period 1973 to 2010 has been done using Gaussian maximum likelihood classifier and the temporal land use details are given in Table 3. Fig. 4 provides the land use in the region during the study period. Overall accuracy of the classification was 72% (1973), 77% (1992), 76% (1999), 80% (2002), 75% (2006) and 78% (2010) respectively. There has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Analyses of the temporal data reveals an increase in urban built up area of 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. Fig. 5 illustrates the zone-wise temporal land use changes at local levels. Table 4 lists kappa statistics and overall accuracy.
- Urban density is computed for the period 1973–2010 and is depicted in Fig. 6, which illustrates that there has been a linear

Table 6
Alpha and beta density in each region – zone wise, circle wise.

Radius	North east		North west		South east		South west	
	Alpha	Beta	Alpha	Beta	Alpha	Beta	Alpha	Beta
1	1526.57	1385.38	704.71	496.05	3390.82	2437.32	3218.51	2196.83
2	333.99	288.58	371.00	280.41	983.51	857.04	851.23	555.33
3	527.99	399.83	612.02	353.50	904.02	701.47	469.19	369.67
4	446.99	343.51	360.72	286.39	602.14	441.66	308.47	262.52
5	152.43	122.74	255.11	226.72	323.07	243.02	236.56	188.26
6	123.16	94.91	370.22	324.12	306.48	203.54	58.57	51.12
7	73.65	57.96	254.49	207.29	54.77	32.64	77.07	73.09
8	38.16	27.80	71.54	62.38	57.22	30.52	61.85	57.29
9	44.99	29.54	92.73	69.97	51.74	26.00	37.60	31.90
10	48.43	25.22	93.51	55.75	33.31	17.44	25.99	16.61
11	50.32	23.77	100.55	56.56	22.69	11.63	35.90	18.75
12	42.34	17.92	67.36	34.36	27.12	11.29	25.52	10.86
13	59.87	22.20	40.87	17.71	30.66	9.44	35.59	11.92
14	54.10	18.38	24.51	9.91	24.16	5.35	19.77	5.49
15	60.81	20.73	21.48	8.98	19.52	3.50	26.41	6.56
16	62.17	23.79	46.81	12.83	16.92	2.96	66.19	17.35
17	16.54	24.76	53.30	14.58	16.45	2.02	41.40	10.36

growth in almost all directions (except NW direction, which show stagnation during 1999–2006). Developments in various fronts with the consequent increasing demand for housing have urbanised these regions evident from the drastic increase in the urban density during the last two decades. In order to understand the level of urbanisation and quantification at local level, each zone is further divided into concentric circles.

6.2. Density gradient analysis

Study area was divided into concentric incrementing circles of 1 km radius (with respect to centroid or central business district). The urban density gradient given in Fig. 7 for the period 1973–2010, illustrates radial pattern of urbanisation and concentrated closer to the central business district and the growth was minimal in 1973. Bangalore grew intensely in the NW and SW zones in 1992 due to the policy of industrialization consequent to the globalisation. The industrial layouts came up in NW and housing colonies in SW and urban sprawl was noticed in others parts of the Bangalore. This phenomenon intensified due to impetus to IT and BT sectors in

SE and NE during post 2000. Subsequent to this, relaxation of FAR (floor area ratio) in mid-2005, lead to the spurt in residential sectors, paved way for large-scale conversion of land leading to intense urbanisation in many localities. This also led to the compact growth at central core areas of Bangalore and sprawl at outskirts which are deprived of basic amenities. The analysis showed that Bangalore grew radially from 1973 to 2010 indicating that the urbanisation has intensified from the city centre and reached the periphery of Greater Bangalore. Gradients of NDVI given in Fig. 8 further corroborate this trend. Shannon entropy, alpha and beta population densities were computed to understand the level of urbanisation at local levels.

6.3. Calculation of Shannon's entropy, alpha and beta densities

Shannon entropy was calculated for the years 1973, 1992, 1999, 2002, 2006, 2010 listed in Table 5. The value of entropy ranges from zero to log(*n*). Lower entropy values indicate aggregated or compact development. Higher the value or closer to log(*n*) indicates the sprawl or dispersed or sparse development. Grater

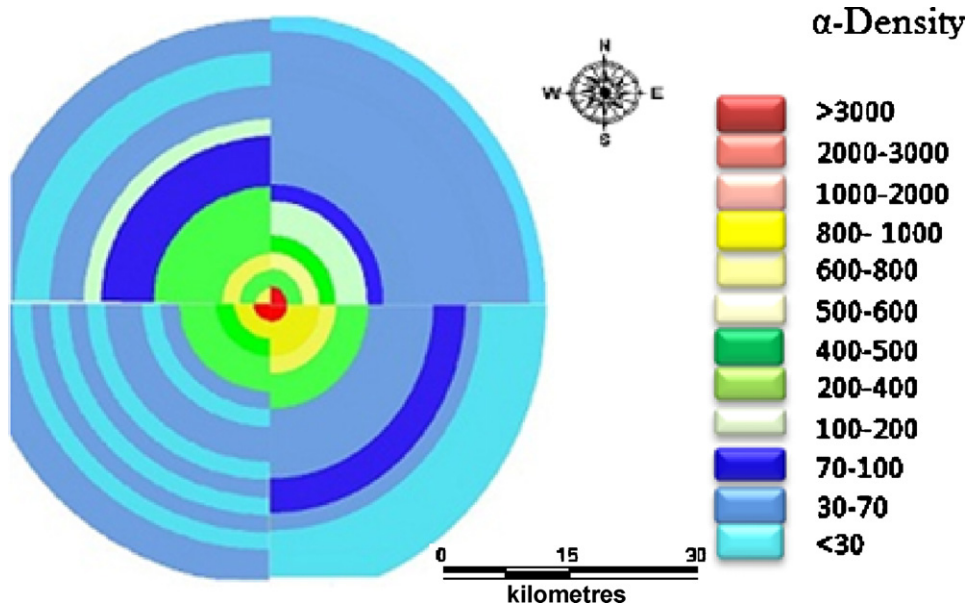


Fig. 9. Alpha density– zonewise for each local regions.

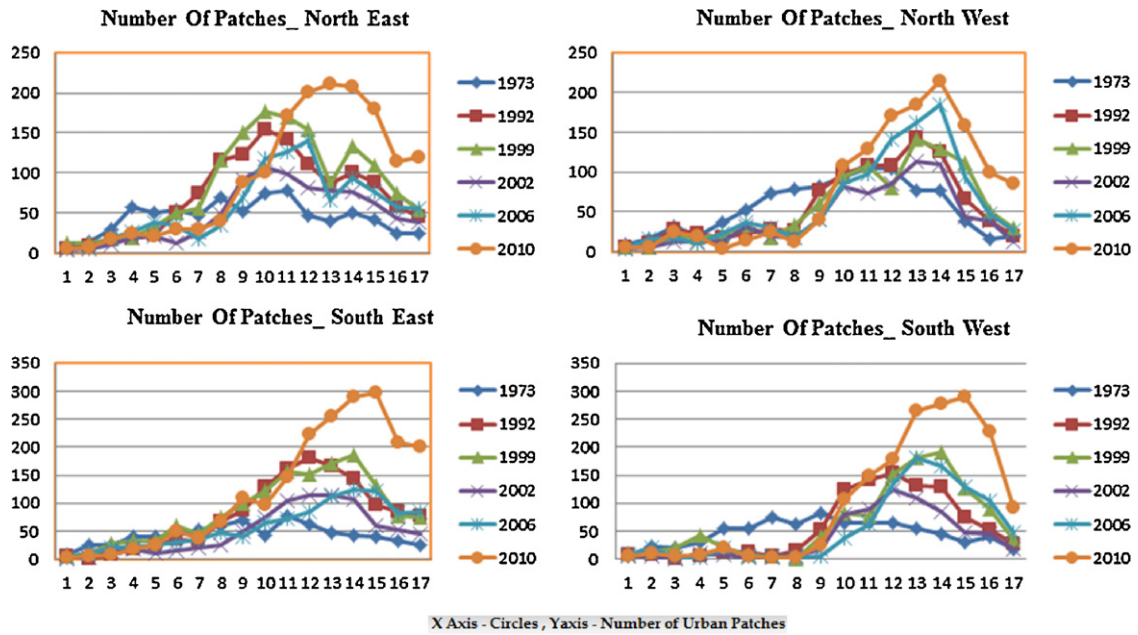


Fig. 10. Number of patches – direction-wise/circle-wise.

Bangalore grew and has almost reached the threshold of growth ($\log(n) = \log(17) = 1.23$) in all directions. Lower entropy values of 0.126 (SE), 0.173 (NE), 0.170 (SW) and 0.217 (NW) during 1970s show aggregated growth. However, the dispersed growth is noticed at outskirts in 1990s and post 2000s (0.64 (SE), 0.771 (NE), 0.812 (NW) and 0.778 (SW)).

Shannon’s entropy values of recent time confirm dispersed haphazard urban growth in the city, particularly in city outskirts. This also illustrates the extent of influence of drivers of urbanisation in various directions. In order to understand this phenomenon, alpha and beta population densities were computed.

Table 6 lists alpha and beta densities zone-wise for each circle. These indices (both alpha and beta densities) indicate that there has been intense growth in the centre of the city and SE, SW and NE core central area has reached the threshold of urbanisation.

Gradients of alpha and beta densities is given in Fig. 9, illustrates urban intensification in the urban centre and sprawl is also evident NW and SW regions.

6.4. Landscape metrics

Landscape metrics were computed circle-wise for each zones. Percentage of Landscape (PLAND) indicates that the Greater Bangalore is increasingly urbanised as we move from the centre of the city towards the periphery. This parameter showed similar trends in all directions. It varied from 0.043 to 0.084 in NE during 1973. This has changed in 2010, and varies from 7.16 to 75.93. NW also shows a maximum value of 87.77 in 2010. Largest patch index indicate that the city landscape is fragmented in all direction during 1973 due to heterogeneous landscapes. However, this has aggregated

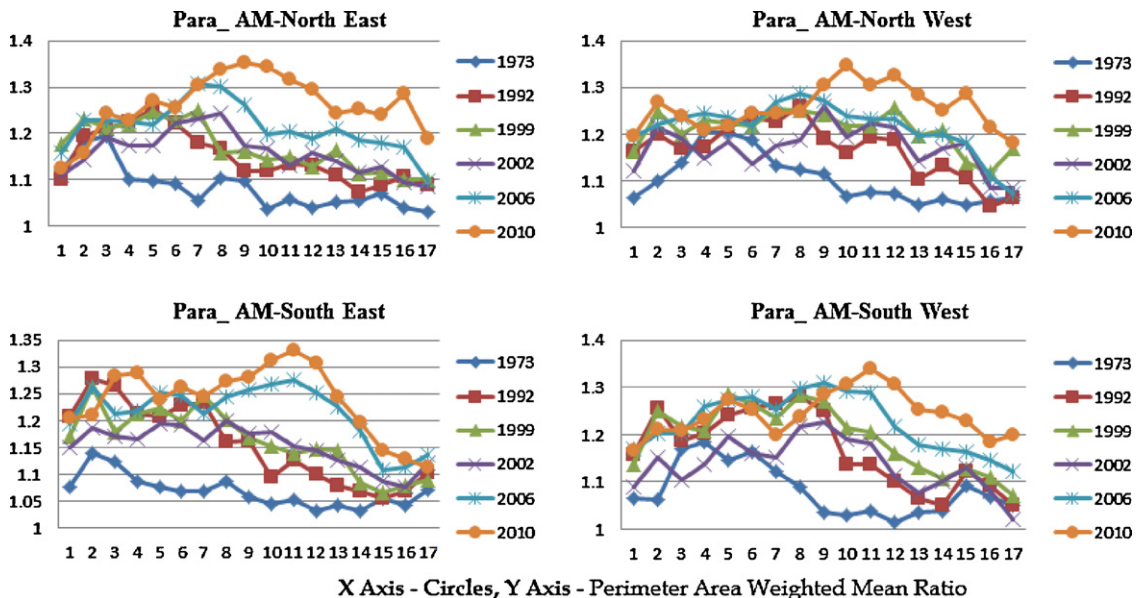


Fig. 11. PARA_AM – direction-wise/circle-wise.

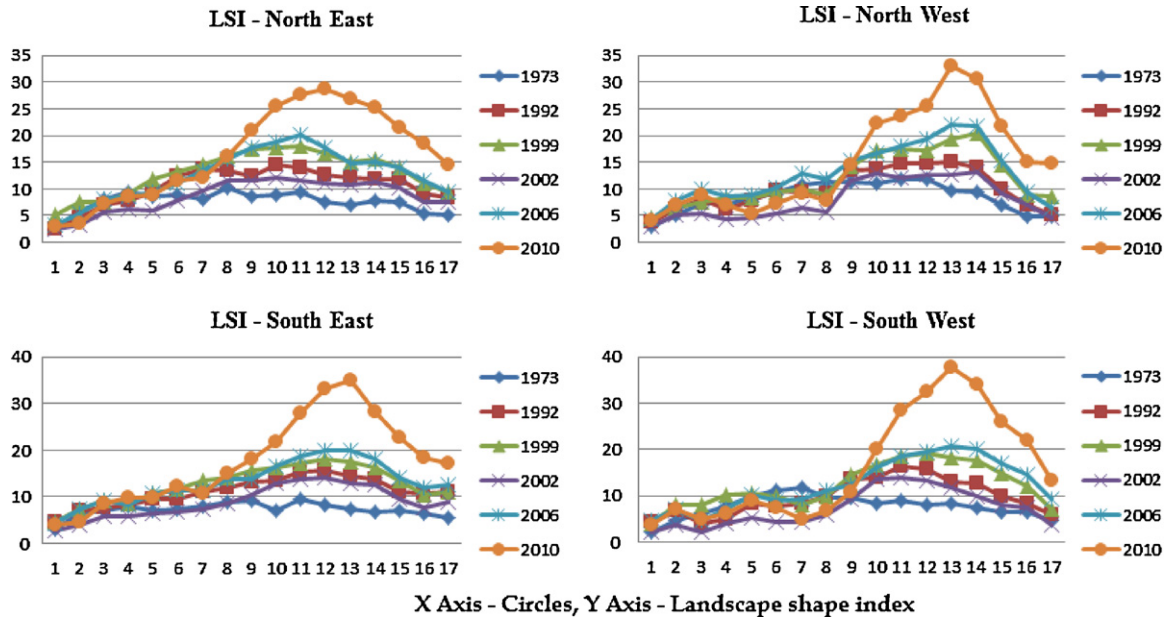


Fig. 12. LSI - direction-wise/circle-wise.

to a single patch in 2010, indicating homogenisation of landscape. The patch sizes were relatively small in all directions till 2002 with higher values in SW and NE. In 2006 and 2010, patches reached threshold in all directions except NW which showed a slower trend. Largest patches are in SW and NE direction (2010). The patch density was higher in 1973 in all directions due to heterogeneous land uses, which increased in 2002 and subsequently reduced in 2010, indicating the sprawl in early 2000s and aggregation in 2010. PAFRAC had lower values (1.383) in 1973 and maximum of 1.684 (2010) which demonstrates circular patterns in the growth evident from the gradient. Lower edge density was in 1973, increased drastically to relatively higher value 2.5 (in 2010). Clumpiness index,

Aggregation index, Interspersion and Juxtaposition Index highlights that the centre of the city is more compact in 2010 with more clumpiness in NW and SW directions. Area weighted Euclidean mean nearest neighbour distance is measure of patch context to quantify patch isolation. Higher v values in 1973 gradually decrease by 2002 in all directions and circles. This is similar to patch density dynamics and can be attributed to industrialization and consequent increase in the housing sector. Analyses confirm that the development of industrial zones and housing blocks in NW and SW in post 1990s, in NE and SE during post 2000 are mainly due to policy decision of either setting up industries or boost to IT and BT sectors and consequent housing, infrastructure and transportation

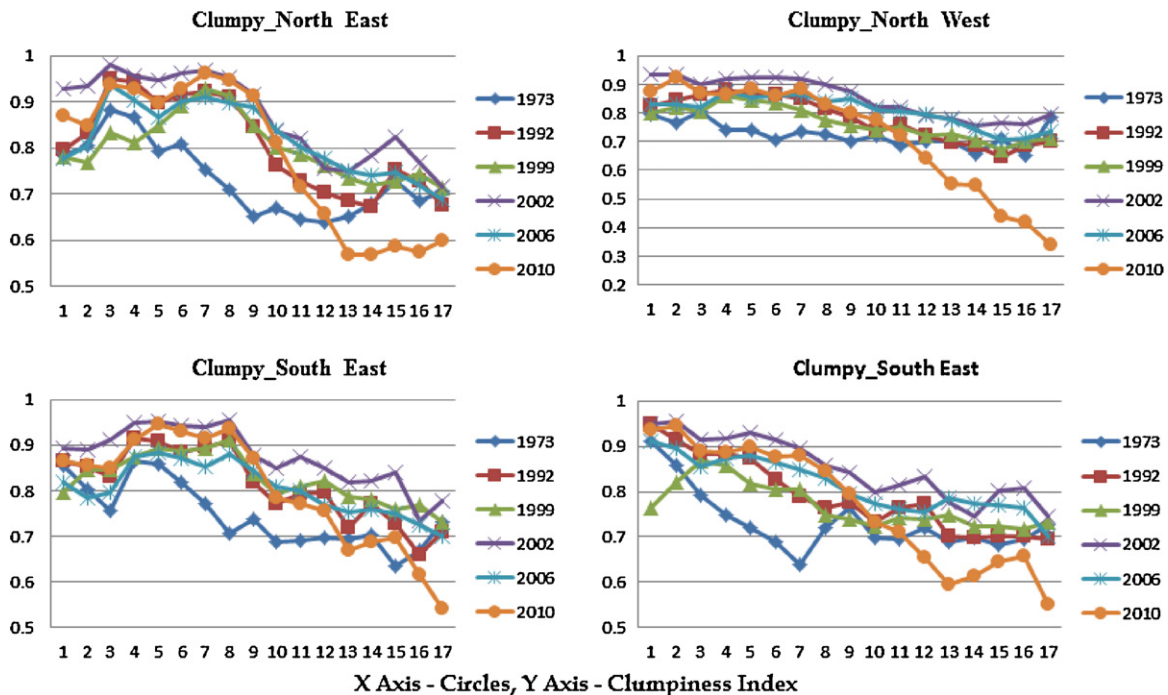


Fig. 13. Clumpiness Index - direction-wise/circle-wise.

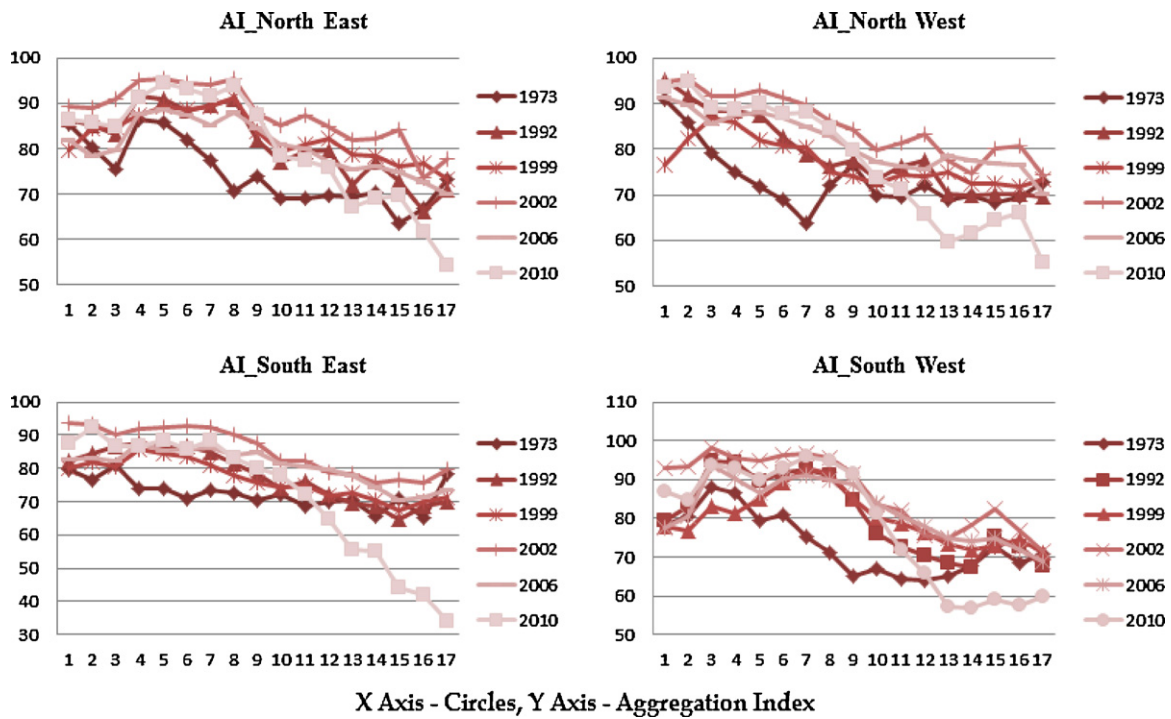


Fig. 14. Aggregation Index – direction-wise/circle-wise.

facilities. PCA was performed with 21 metrics computed zonewise for each circle. This helped in prioritising the metrics (Table 2) while removing redundant metrics for understanding the urbanisation, which are discussed next.

- i. Number of urban patches has steadily decreased in the inner core circles from 1973 to 2010, which indicates aggregation. A sharp increase in the urban patches in the periphery (outer rings) from 25 to 120 indicates of numerous small urban patches pointing to the urban sprawl. Urban sprawl is thus effectively visualized by this index, evident with SW, SE and NE zones in

Fig. 10. The outer circle having on an average 120 urban patches compared to 5 in inner circles.

- ii. Perimeter area weighted mean ratio (PAWMR) reflects the patch shape complexity and is given in Fig. 11. The values closer to zero in the inner circles indicate the simple shape, whereas the outer circles show the increasing trends in all directions. This highlights an enhanced rate of anthropogenic interventions and hence the process of Sprawl.
- iii. Landscape shape index indicates the complexity of shape, close to zero indicates maximally compact (at city centre) and higher values in outer circles indicate disaggregated growth in 2010

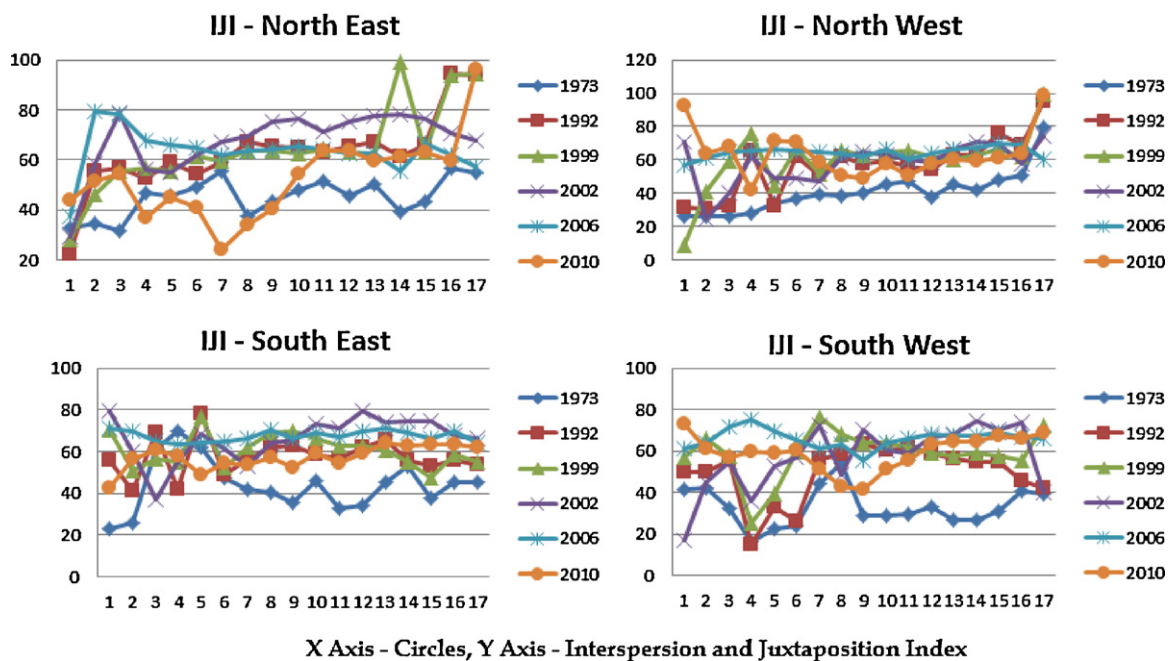


Fig. 15. Interspersion and Juxtaposition – direction-wise/circle-wise.

(Fig. 12). The trend of sprawl at city outskirts as well as at the centre was noticed till 1980s. However, post 1980s values indicate of compactness at city centre, while outer rings show disaggregated growth.

- iv. Clumpiness index represents the similar trend of compact growth at the center of the city which gradually decreases towards outer rings indicating the urban agglomeration at centre and phenomena of sprawl at the outskirts in 2010 (Fig. 13). This phenomenon is very prominent in Northeast and South-west direction.
- v. Aggregation Index indicated that the patches are maximally aggregated in 2010 while it was more dispersed in 1973, indicating that city is getting more and more compact (Fig. 14).
- vi. Interspersion and Juxtaposition Index was very high as high as 94 in all directions which indicate that the urban area is becoming a single patch and a compact growth towards 2010 (Fig. 15). All these metrics point towards compact growth in the region, due to intense urbanisation. Concentrated growth in a region has telling influences on natural resources (disappearance of open spaces – parks and water bodies), traffic congestion, enhanced pollution levels and also changes in local climate (Ramachandra and Kumar, 2009, 2010)

The discussion highlights that the development during 1992–2002 was phenomenal in NW, SW due to Industrial development (Rajajinagar Industrial estate, Peenya industrial estate, etc.) and consequent spurt in housing colonies in the nearby localities. The urban growth picked up in NE and SE (Whitefield, Electronic city, etc.) during post 2000 due to State's encouraging policy to information technology and biotechnology sectors and also setting up International airport.

7. Conclusion

Urban dynamics of rapidly urbanising landscape – Bangalore has been analysed to understand historical perspective of land use changes, spatial patterns and impacts of the changes. The analysis of changes in the vegetation cover shows a decline from 72% (488 sq. km in 1973) to 21% (145 sq. km in 2010) during the last four decades in Bangalore.

Land use analyses show that there has been a 584% growth in built-up area during the last four decades with the decline of vegetation by 66% and water bodies by 74%. Temporal analyses of greater Bangalore reveals an increase in urban built up area by 342.83% (during 1973–1992), 129.56% (during 1992–1999), 106.7% (1999–2002), 114.51% (2002–2006) and 126.19% from 2006 to 2010. Urban growth pattern of Greater Bangalore has been done in four directions through landscape metrics and gradient analysis across six time periods. The urban density gradient illustrates radial pattern of urbanisation during 1973–2010 indicating of intense urbanisation at central core and sprawl at outskirts, which conform with Shanon's entropy, alpha and beta population densities. Landscape metrics further highlight of compact growth in the region.

Gradients of alpha and beta densities illustrate urban intensification in the center and sprawl in NW and SW regions. Landscape metrics point towards compact growth in the region, due to intense urbanisation in 2000. The analysis confirms that the nature of land use depended on the activities while the level of spatial accumulation depended on the intensity and concentration of urban builtup. Central areas have a high level of spatial accumulation and corresponding land uses, such as in the CBD, while peripheral areas have lower levels of accumulation. Unplanned concentrated growth or intensified developmental activities in a region has telling influences on natural resources (disappearance of open spaces – parks

and water bodies), traffic congestion, enhanced pollution levels and also changes in the local climate.

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Modelling Urban Revolution in Greater Bangalore, India

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Abstract- Land-use change is a main driving force for the development of the human and his surrounding environment and effects largely on local ecology, hydrology and environment and also globally. This has necessitated understanding changing land use spatial pattern for an effective planning. Remote sensing data enables the synoptic monitoring and visualization of urban growth patterns and dynamics. This study addresses the issue of urban sprawl through the perspective of simulation modeling over an urbanising landscape with a buffer of 10km. Bangalore, Silicon Valley of India is facing numerous challenges and problems of loss of green space, mobility constraints, etc. This study essentially brings out comparison of effective modelling algorithm considering three prime methods.

Land Change Modeler (LCM), Markov Cellular Automata and Geomod were used to predict likely land use in 2020 with the knowledge of land use changes during 2006-2012 with the constraint of no-change in land use of water category. The results showed a drastic change in the land use, which were converted to urban. Thus necessitating the land use managers and city planners to understand future growth and plan the further developments.

I. INTRODUCTION

Large scale land-use land-cover (LULC) dynamics is leading to the drastic change in global climate changes and alteration of biogeochemical cycles. Human induced environmental changes and consequences are not uniformly distributed over the earth. Large scale industrialization during 90's era paved way for major LULC changes, caused by migration of people from different parts of the country, also from other parts of the globe and country for the employment opportunities. These led to intense urbanisation of major cities that in turn led to unplanned urbanisation. Unplanned urbanisation is characterised by drastic landscape and local ecology changes that leads to conversion of ecological land use (such as vegetation. Open area, cultivable lands, water) into impervious layers on the earth surface. Increasing unplanned urbanisation is an important cause for depletion of natural resources [1, 2]. The unplanned urbanisation has various underlying effects such as sprawl that effect largely the natural resource and leading to depletion.

Urban Sprawl refers to an unplanned and scattered growth of paved land [2, 3], the sprawl occurs basically in the periphery and the outskirts and regions devoid of basic amenities.

Megacities or the metropolitan continue to evolve and grow [4] with leads to further environmental degradation [5]. This phenomenon is most prevalent in developing countries [3] such as India [6, 7]. Demographic and the degradation of the surrounding natural ecology at longer timescales has a large impact on land use in a region. Hence there is a need for better planning and administration. For better land use planning changes in current land use patterns temporally is essential [8]. This necessitates the analysis of land use changes and the prediction of likely changes in the future.

Availability of spatio-temporal data and the advancement of remote sensing [9] has enabled unbiased land use analysis. Analysis of land use dynamics has attained research attention both at global and Indian contexts focusing on dynamically evolving cities [10]. Several studies have assessed urban growth in various megacities around the world [1, 8, 11, 12, 13]. These studies though mapped and focused on temporally evolved current land use across various cities, have not addressed the likely growth required for the regional planning. Prediction of future growth are essential to control the uncontrolled development and plan for sustainable cities. Predictive models become very significant as they foresee spatial changes based on the historical land uses, which helps the decision makers in planning the growth including sprawl across the city periphery.

CA with markov considering spatial context based on neighbourhood configuration generates transition potential maps [14, 15]. However, for models to be effective there is a need for incorporating the agents such as social factors, economic factors, geography of an area which have decisive role in the urban process of a region. This has been demonstrated through incorporation of socioeconomic data into CA-Markov to predict land use changes [16]. Geomod which is also determined using structure of CA markov is also proved as one of the main methods in modeling urban pattern this highlights the need for research, which still remains a research challenge. This communication analyses three different algorithms such as Geomod, CA Markov and land use change modeler, for

modelling rapidly urbanising landscape, which will help the decision makers and city planners in planning further developments.

II. STUDY AREA:

Bangalore the IT hub of India is located in the southern part of the country of Karnataka state. With the spurt in IT industries in the region during late 1990's, the city was termed "Silicon Valley". This policy interventions created job opportunities to different category of people. The city has grown spatially during the last year by 10 times and the current spatial extent is about 741 km². Geographically Bangalore is located in the Deccan plateau, toward the south east of Karnataka state extending from 12°49'5"N to 13°8'32" N and 77°27'29" E to 77°47'2"E. To account for developments in the peri urban regions, the study area includes ten km buffer (from the administrative boundary) with a gross area of over 2250 km² as shown in Fig. 1. Bangalore has spatially increased from 69 sq.km (1901) to 741 sq.km (2006). The decadal (2001 to 2011) increase in population for urban areas of India is 31.8% and in Karnataka is 31.5%, but Bangalore has a decadal increase of 44% very large compared to that of the state and country.

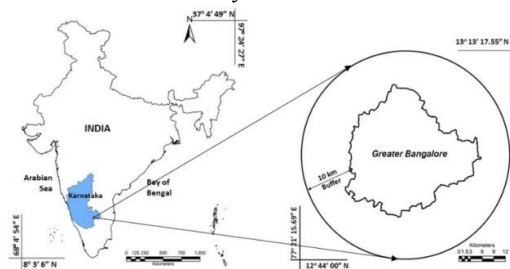


Fig.1. Study Area- greater Bangalore with 10 km buffer

III. DATA USED

Temporal remote sensing data of Landsat 7 TM AND ETM+ sensors for the year 2008, 2010 and 2012 with resolution of 30 m were downloaded from public domain (<http://glcf.umiacs.umd.edu/data>). Ground control points to register and geo-correct remote sensing data were collected using hand held pre-calibrated GPS (Global Positioning System), Survey of India topo-sheet (1:50000 and 1:250000), Google earth (<http://earth.google.com>) and Bhuvan (<http://bhuvan.nrsc.gov.in>).

IV. METHOD

The process of urbanisation and sprawl in Bangalore (study area) have been assessed which includes (i) Land use analysis, (ii) Modeling and prediction. Land use data was used from the previous analysis (Bharath S et al., 2012). This data was reclassified into Urban and non-urban for Geomod analysis. But other modelling techniques such as CA Markov and LCM

same data with 4 classes as described in table 1 was considered.

Modeling and Prediction: CA MARKOV: The land use pattern is evolving dynamically and follows the Markovian random process properties with various constraints that include average transfer state of land use structure stable and different land use classes may transform to other land use class given certain condition (Such as non-transition of urban class to water or vice versa). Thus Markov was used for deriving the land use change probability map for the study region and was applied using Markov module of IDRISI. The probability distribution map was developed through Markov process. A first-order Markov model based on probability distribution over next state of the current cell that is assumed to only depend on current state. CA was used to obtain a spatial context and distribution map. CA's transition rules use its current neighborhood of pixels to judge land use type in the future. State of each cell is affected by the states of its neighboring cells in the filter considered. Besides using CA transition rule and land use transition is governed by maximum probability transition and will follow the constraint of cell transition that happens only once to a particular land use, which will never be changed further during simulation. CA coupled with Markov chain was then used to predict urban land use state in 2020

Land use class	Land use included in class
Urban	Residential Area, Industrial Area, Paved surfaces, mixed pixels with built-up area
Water	Tanks, Lakes, Reservoirs, Drainages
Vegetation	Forest, Plantations
Others	Rocks, quarry pits, open ground at building sites, unpaved roads, Croplands, Nurseries, bare land

Table 1. Land use categories

Land use Change Modeller (LCM): an ecological modeller module in IDRISI Taiga was used for modelling the land use scenario based on the data of 2008, 2010 and 2012. LCM module provides quantitative assessment of category-wise land use changes in terms of gains and losses with respect to each land use class. This can also be observed and analysed by net change module in LCM (IDRISI manual). The Change analysis was performed between the images of 2008 and 2010, 2010 and 2012, to understand the transitions of land use classes during the years. Threshold of greater than 0.1 ha. Were considered for transitions. CROSSTAB module of IDRISI was used between two images to generate a cross tabulation table in order to see the consistency of images and distribution of image cells between the land use categories. Multi-Layer perceptron neural

network was used to calibrate the module and relate the effects of agents considered and obtain transition potential sub models. Further markov module was used to generate transition probabilities, which were used as input in cellular automata for prediction of future transitions. This has been analysed with an inbuilt module of LCM or using the CA_Markov in IDRISI.

GEOMOD: GEOMOD was used for modeling the spatial patterns of urbanisation and predict likely land use changes. GEOMOD simulates the spatial pattern of land use changes [56], or change between two land categories (Binary images of urban and non-urban). GEOMOD selects the location of the grid cells based on the following decision rules:

- [1] Persistence: simulates one way change.
- [2] Regional stratification: simulate land use changes within a series of regions called strata.
- [3] Neighborhood constraint: It is based on a nearest neighbor principle, whereby restricting land change within any one time step to cells that are on the edge between landscape A and landscape B
- [4] Suitability map considering drivers.

If there is a net increase in the Class A category as the simulation proceeds from a beginning time to the ending time, then GEOMOD will search among the Class B grid cells in order to select the cells that are most likely to be converted to become Class A during the time interval and vice versa [56][57][58].

Suitability map is created using GEOMOD Module in IDRISI TAIGA (<http://clarklabs.org>) considering drivers. Each driver is considered as real number (%), obtained by comparing the driver map to the beginning time land-cover map. Site suitability of each cell is calculated using the equation (1) below, based on each reclassified attribute,

$$R(i) = \sum_{a=1}^A \{W_a * P_a(i)\} / \sum_{a=1}^A W_a \quad ..(1)$$

Where: R(i) = suitability value in cell(i), a = particular driver map, A = the number of driver maps, W_a = the weight of driver map a , and $P_a(i)$ = percent-developed in category a_k of attribute map a , where cell (i) is a member of category a_k . Predictions were done considering three population growth rates of 5% (current average population growth of Karnataka)

V. RESULTS

Land use analysis: Land use analysis was done using Maximum Likelihood classifier (MLC) considering training data collected from field. Land use analysis show an increase in urban area from 49915.42 (2008) to 59103 hectares (2012) which constitute about 30%. Fig. 2 illustrates the increase in urban area and the same is listed in table 2. Overall accuracy and Kappa was calculated using the module r.kappa in GRASS

and results shows an accuracy of 85% and 0.9 kappa was obtained on average.

Validation: Predicted land uses of 2010 and 2012 were compared with actual land uses of 2010 and 2012 classified based on remote sensing data with field data. The weights for each scenario was then obtained based on validation per pixel basis so that the developed semantics match the original land use. Validation of predicted land use was done using the actual land uses as reference and accuracy assessment was done with Kappa values which are given in table 5. Results reveal that predicted and actual land uses are in conformity to an extent of 87 to 91%. The prediction exercise is repeated for 2020 keeping 2012 as base year.

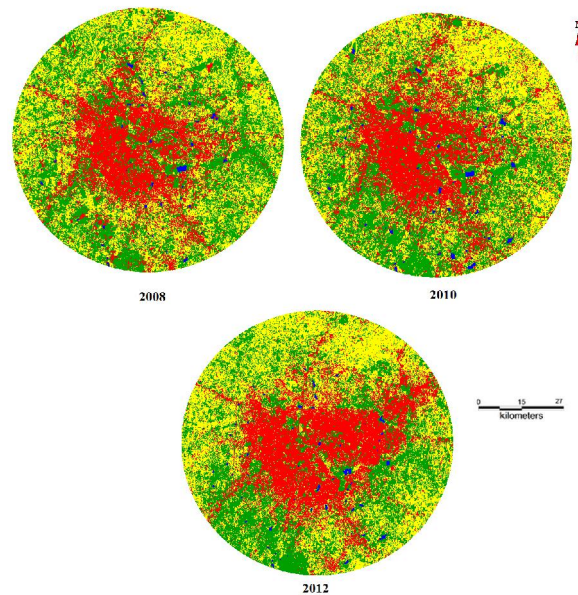


Fig. 2. Land use transitions during 2008 to 2012

Class Year	Built-up Area		Water	
	Ha	%	Ha	%
2008	49915.42	24.85	1068.94	0.53
2010	57208.40	28.48	1571.41	0.78
2012	59103.90	29.33	1169.82	0.58
Class Year	Vegetation		Others	
	Ha	%	Ha	%
2008	77036.96	38.35	72851.95	36.27
2010	73460.57	36.57	68,656.40	34.17
2012	67883.85	33.68	73385.73	36.41

Table 2: Land use during 2008, 2010 and 2012

Modelling: Using *cellatom* module of IDRISI the results of CA_MARKOV were obtained as illustrated in Figure 5. The likely land use is indicated in Table 3. The land use change modeler of IDRISI was used to obtain the prediction, results of which are as shown in Figure 6 and tabulated in table 4. Geomod analysis

required the land use derived data to reclassified into two classes: Urban and non-urban. Results of this analysis is as shown in Figure 7 and tabulated in table 5.

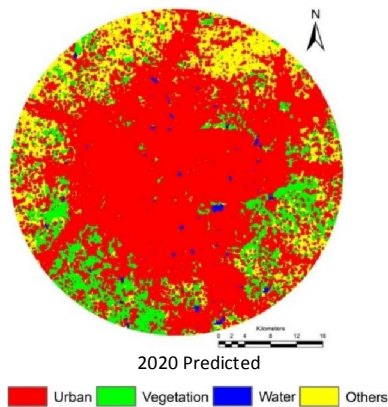


Fig.5. Predicted land use map for 2020

Year	2020 - Predicted
Land use	%
Urban	70.64
Vegetation	13.55
Water	0.74
Others	15.07

Table 3: Land use 2020

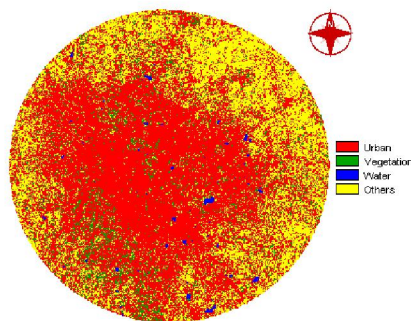


Fig. 6: Predicted growth of Bangalore by 2020 using LCM

Year	2020 - Predicted
Land use	%
Urban	61.27
Vegetation	7.00
Water	0.55
Others	31.18

Table 4. Land use statistics of Bangalore for 2020.

VI. Discussion

Three modelling techniques considered show relatively good accuracy with validation dataset. But Geomod gives a conclusive output considering the better validation results and proposed city development plan. But Geomod has a capability of using only two land use classes. Comparatively

using 4 land use classes LCM provides better visual interpretation since it uses agents to derive the growth. CA-Markov is dependent on neighborhood and rules and shows an exaggerated output of further aggregation of already urbanised city.

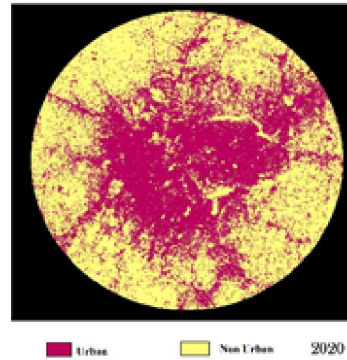


Fig. 7: Predicted growth of Bangalore by 2020 using Geomod

Year	Non-Urban	Urban
2020	49.62%	50.38%

Table 5: Land use 2020 using Geomod

The predicted land use reveals of similar patterns of urbanisation of last decade. The main concentration will be mainly in the vicinity of arterial roads and proposed outer ring roads. Predicted land use also indicate of densification of urban utilities near the Bangalore international airport limited (BIAL) and surroundings. Further an exuberant increase in the urban paved surface growth due to IT Hubs in south east and north east. The results also indicated the growth of suburban towns such as Yelahanka, Hesaragatta, Hoskote and Attibele with urban intensification at the core area in almost all modelling techniques used. The results indicate that the urban area would cover close to 50 to 60 % of the total land use in and surrounding Bangalore. Thus providing insights to relevant information. Further modelling can be improved using nature and bio inspired techniques.

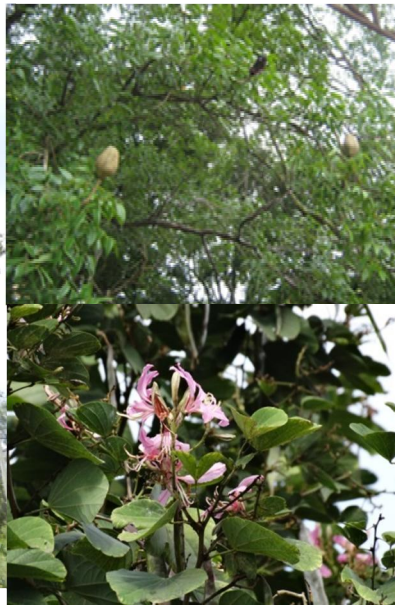
VII. Acknowledgement

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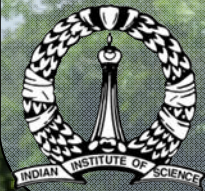
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