TREES OF BENGALURU

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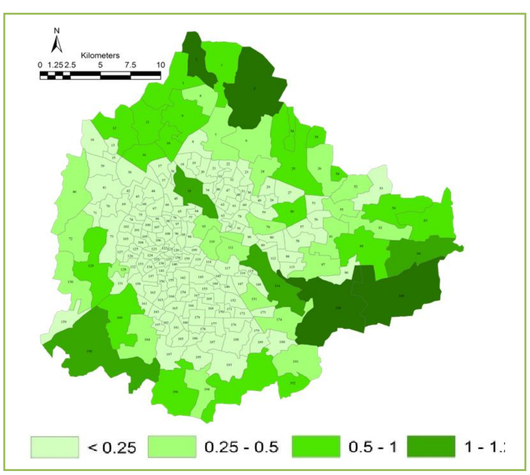

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Summary

Urban vegetation includes trees, shrubs and herbs on public and private lands (parks, streets, backyards), all interspersed within a landscape dominated by paved surfaces. This kind of vegetation plays a vital role in moderating micro climate, sequestering greenhouse gases (CO_2, etc.) and also in aiding the percolation of water. World Health Organization has recommended a minimum green space of 9.5 m^2/person) considering the services (oxygen, moderation of micro climate) and goods of an urban environment. Estimates indicate that about 6 tons of carbon is sequestered by 1 hectare of forests annually and this averages out as the carbon sequestration of 6 kg/tree/year. Per capita respiratory carbon ranges from 192 to 328 kg/year depending on the physiology of humans. Generally, the carbon dissipated through respiration varies from 525 to 900 gm/day/person. This means 32 to 55 trees per person in a region is required to exclusively mitigate respiratory CO_2.

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 Karnataka state. Bangalore city's population has increased enormously from 6,537,124(in 2001) to 9,588,910 (in 2011), amounting to a decadal growth of 46.68%. With this, the 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 had enjoyed salubrious climate throughout the year prior to the industrialization era.

Land use analysis based on the fusion of Resourcesat-2 MSS data with Cartosat 2 shows that the spatial extent of tree vegetation in Bangalore is 100.02 sq.km (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 area of a ward) of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have density lower 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 Vathur, Bellandur, Agaram, Aramane nagara have greater than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards less than 100 trees. Based on these aggregates, the total number of trees in Bangalore rounds up to 14,78,412.

The wards Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara have very few trees per person (< 0.002). This implies that these wards have less than 1 tree for every 500 people. In contrast to these, the wards Bellandur, Jakkuru, Varthuru, Agaram, and Aramane nagara have more than one tree per person. Intra city analysis shows that the major cities Gandhinagar, Bangalore, Ahmedabad, Brhihan Mumbai have spatial extents greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people, which is preceded by Bangalore (with 17 trees per 100 persons), Brihat Mumbai (with 15 trees per 100 persons) and Ahmedabad (with 11 trees per 100 persons). The reduction of vegetation cover and collateral urbanization have serious implications on a city's environmental and ecological health. Bangalore has evidently crossed the threshold of urbanization which can be gauged by the increase of psychological, social and health related issues among its residents. Additionally, there have been higher instances of domestic violence, traffic bottlenecks, road accidents, and incidences of diseases such as obesity and asthma. A need for overall improvements in human well-being and community vitality compel urban planners to sustain at least 33% green cover in cities. In such a case, there would be at least 1.15 trees/person in a 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 a landscape dominated by paved surfaces. Urban vegetation plays a vital role in moderating micro climate and sequestering greenhouse gases (CO_2, etc.). It also aids the percolation of water into earth. Enormous environmental, ecological, economic and social benefits accrue from urban vegetation. These benefits include the removal of air pollutants such as sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon dioxide (CO_2), and particulate matter. These air pollutants are removed by leaf stomata and leaf surfaces especially when they 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). It has also been found that dust from air is removed by the leaves of Mango (*Mangifera indica*), Ashoka (*Polyalthia longifolia*), Pongamia (*Derris indica*) and Umbrella - *Thespesia populnea* (Shetye and Chaphekar, 1980, Ghose et al., 2005). Trees act as barriers of noise pollution by absorbing and blocking urban noise, whereby stress for people living or working with trees around is reduced (Zannin et al., 2006). Furthermore, urban trees function as natural 'air conditioners' which substitute for local energy (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, reducing solar heat gains on windows, walls, roofs through shading, increasing latent cooling by increasing humidity through evapo-transpiration. It also attenuates the long-wave radiation exchange with the sky resulting in the lowered building surface temperatures (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 returns to the atmosphere through evaporation. A significant part of precipitation gets percolated recharging ground water aquifers and vadose regions. Due to microbial interactions with roots, soil layer becomes more porous, permitting infiltration. Thus, vegetation helps in mitigating flooding in the landscape. The extent to which urban vegetation cools the urban climate mainly depends upon the type and composition of vegetation. The leaf temperatures depend upon the anatomical, physical and physiological factors (Monteith and Unsworth, 1990). Studies have substantiated that temperature is moderated by vegetation (Myrup et al., 1993; Shashua-Bar and Hoffman, 2004; Doick and Hutchings 2013). Reports reveal that unshaded suburban areas are approximately 2.5°C warmer when compared to the open rural areas and unshaded suburban sites are warmer by 1°C when compared to the shaded areas.

All the tree species do not have the same cooling effect; they varies in their ability to reduce the air temperature which may be due to the tree size and tree canopy characteristics. World Health Organization recommends a minimum green space of 9.5 m^2/person, considering the services (oxygen production, moderation of micro climate, etc.) and goods in the urban environment (Kuchelmeister, 1998). Trees play a major role in accommodating arboreal species of insects, animals and birds. Trees also carry an aesthetic value as their presence adds beauty to the surroundings by lending color, softening harsh lines of buildings and by contributing to the character of their immediate environment.

Industrialization, coupled with deforestation and other anthropogenic activities have increased the emission of greenhouse gases such as carbon dioxide (CO_2), methane (CH_4), oxides of nitrogen (NOx), and sulphur dioxide (SO_2). About 75% of CO_2 had been emitted due to the burning of fossil fuels during the past 20 years (Schneider, 1989) and the atmospheric carbon dioxide concentration has increased (Trenberth and Kevin 2007) from 280 ppm (before industrialization) to 382 ppm, (in 2006), and has reached 390 ppm (in 2011). This has led to an increase in the atmospheric temperature with the trapping of a certain wavelength of radiation in the atmosphere. Trees and soil in urban areas serve as sinks to capture and store atmospheric carbon dioxide (Negi and Gupta 2013; Nowak and Crane 2002; Secon, 2010). Estimates indicate that about 6 tons of carbon is sequestered by 1 hectare of forests annually and this amounts to about 6 kg/tree/year. The per capita human respiratory carbon ranges from 192 to 328 kg/year, which means 32 to 55 trees per person in a region are required to mitigate respiratory CO_2.

Rapid urbanization is the dominant anthropogenic phenomenon throughout the world (Ramachandra et al., 2012). Unplanned urban development has telling impacts on the environment of developing countries, which has been evident from the higher amounts of pollutants in their air, contamination of water and land (Gairola 2013). Population in India has increased from 63 (in 1950) to 127 million (in 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 ecosystems have been retreating with the expansion of cities (Gairola 2013; Zhou et al., 2011). Urbanization is a global phenomenon involving unprecedented expansion of land cover has invariably led to rapid increase of urban extents and growth of unplanned regions (Ramachandra and Bharath, 2012). Unplanned urbanization and lack of optimal management of natural resources by city officials has led to the gradual decline of urban services such as water quality, air quality, inadequate infrastructure, poor quality of life, etc. (Escobedo et al., 2011; Ramachandra et al., 2012). A trend called urban heat island, in which urban areas are warmer than rural areas, is caused by anthropogenic heat discharges due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities supplemented by decrease in vegetation and water bodies (Ramachandra and Uttam 2010; Song 2013). Table 1 lists the efforts towards quantification of ecological services.

Trees have the potential to moderate air temperature through reduction of surface temperature and evaporative cooling (McPherson et al., 1994). Apart from being inherently biased, the traditional practice of tree counting requires extensive labour. Remote sensing and geographic information system (GIS) makes timely unbiased spatial information accessible. Spatial information refers to the extraction of various land form features (Bhatta, 2009; Ramachandra et al., 2013). Multi resolution remote sensing data aids in capturing these dynamics. Fusion of data from multiple sensors aids in comprehensively delineating objects due to the integration of spatial information present in the high resolution (HR) panchromatic (PAN) images and spectral information present in the low resolution (LR) Multispectral (MS) images. Image fusion techniques integrate both PAN and MSS and the techniques can be performed at pixel, feature and decision levels.

Table 1: Benefits of trees

Benefits	References
Improves urban microclimate and reduces emission of SO4 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 andwater pollution.	Brack 2002
Reduce the use energy for cooling and heating.	Simpson 1998
Reduces the atmospheric CO2 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

To measure the green cover in Greater Bangalore, multi-resolution data analysis was performed and optimized with pattern classifiers. Remote sensing image fusion techniques are useful to integrate a lower spatial resolution MSS (multi spectral sensors) data with a higher spatial resolution PAN (panchromatic) data. Fusion of multi resolution data aided in taking advantage of spectral and spatial resolutions for the identification of features in urban areas. This was done because the characteristic of urban objects are determined not only by their spectra but also by their structure. The main aim of this 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 (geographically located at the south eastern part of Karnataka State at 77°37'19.54''E and 12°59'09.76'' N) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state (Figure 1). The city is subdivided into 8 zones with 198 wards under the jurisdiction of BBMP. Bangalore geographically extends from 12º49'5"N to 13º8'32"N and 77º27'29" E to 77º47'2"E encompassing an area of 741 km^2. Spatial extent of Bangalore has increased over 10 times from 1949 (69km^2) to 2006 (741km^2) (Figure 2). Currently, it 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 6.53 million in 2001(Census, 2001) to about 9.58 million in 2011(Census, 2011). The ward-wise population distribution in the past two decades is depicted in figure 4.The population density in the region (Figure 4) has increased from 10732 people/km^2 (2001) to13392 people/km^2 (2011).

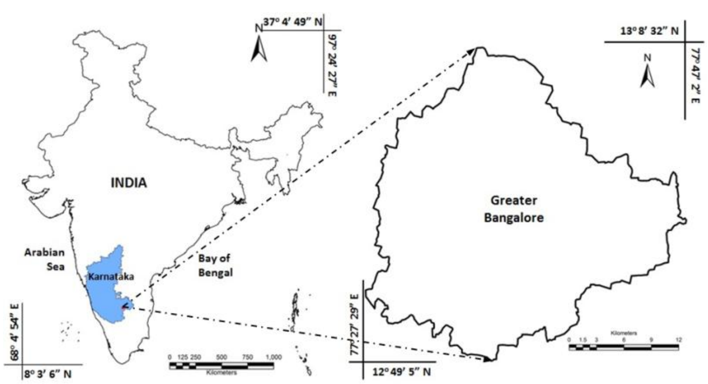


Figure 1: Study area Greater Bangalore / Bengaluru / Bruhat Bengaluru / Bangalore

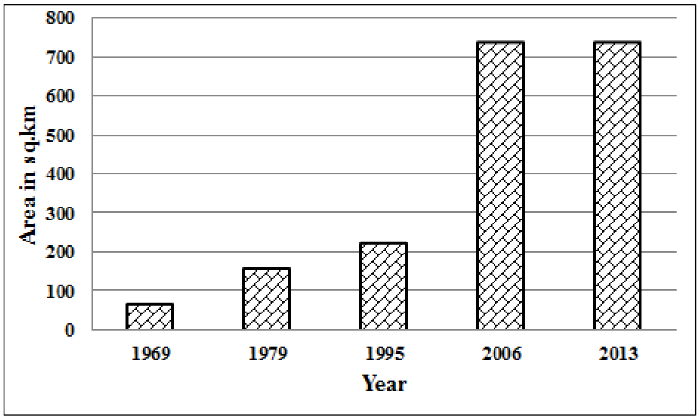


Figure 2: Spatial growth of Bangalore

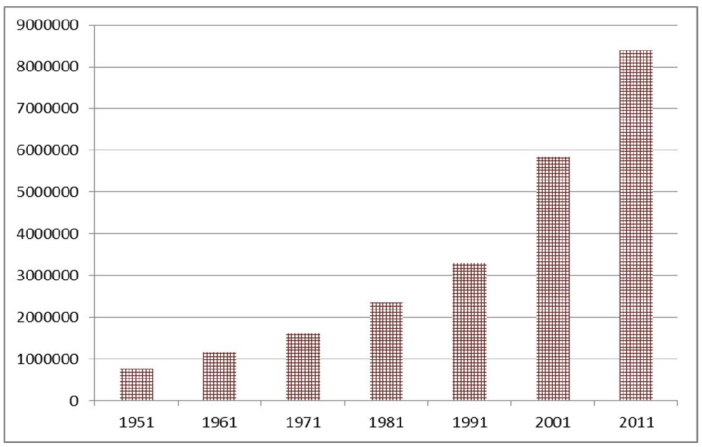


Figure3: Escalating Population of Bangalore

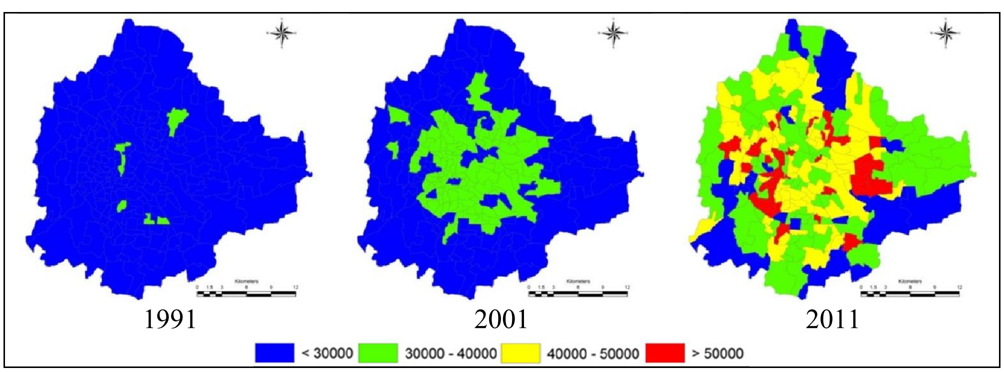


Figure4: Ward wise population distribution

The topography (Figure 5) of Bangalore is undulating and the altitude varies from about 740 m to over 960 m above mean sea level. This is the main reason for occurrence of a large number of drainages and water bodies. These water bodies along with open green spaces are responsible for moderating local climate. Temperatures vary from 22ºC to 38ºC during summers and 14ºC to 27ºC in winters. Bangalore receives an annual average rainfall of about 800 mm.

Bengaluru, the present name of Bangalore has its origin in '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 the 'Garden city of India' due to its vast green cover, fauna and two nationally recognized botanical gardens - Cubbon Park and Lalbagh. Currently, Bangalore is the second fastest growing and fifth largest metropolis in India that has experienced unprecedented expansion of urban area from 69 km^2 in 1949 to 741 km^2 (Ramachandra and Kumar, 2010; Ramachandra et al., 2012). Bangalore city's population has increased enormously from 6,537,124(in 2001) to 9,588,910 (in 2011), amounting to a decadal growth of 46.68%. Its population density has increased from 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 (Champion and Seth, 1968) under the *Terminalia*-*Anogeissus latifolia*-*Tectona* series (Puri et al., 1983). The city had enjoyed a salubrious climate throughout the year till eighties.

In the early 17th century, Bangalore had comprised of natural thorny forests (Kamath 1990). The planting of a wide variety of green vegetation within Bangalore city was initiated by Hyder Ali, a ruler of Mysore city. He had established a private garden for himself called Lalbagh that had an area coverage of 100 hectares. Today, Lalbagh is an open botanical garden for the public. Since the establishment of Lalbagh, Bangalore city had been acknowledged as 'The Garden city'. Also, in 1831, the British created the Cubbon Park in Bangalore, which added even more to its greenery (Issar 1998, Iyer et al., 2012).

During the British occupation, park culture had been introduced in Bangalore which became a new perspective in the usage of social spaces. The park culture gradually integrated amongst Indians through the influence of the elite and educated. For instance, Malleshwaram, which is one of the oldest areas in the city, has readily adopted the park culture and also retained Indian traditional practices. The settlers of Malleswaram had started off with growing vegetables and fruits in their home gardens and they had also planted trees along the roadsides. Some streets in Malleshwaram derived their names from the trees that were grown along its entire stretch, namely, "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 became recognized as an IT hub. Bangalore also houses IT and IT based industries and numerous leading commercial and educational institutions, and specialized industries of textiles, aviation, space, and biotechnology. The immediate consequence of the growth of these 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 lawns. In terms of natural flora, Bangalore city had 979 species in 542 genera, 133 families during early 1970s (Ramaswamy and Razi, 1973). Due to the rapid unplanned urbanization and urban sprawl, the spatial extent of Bangalore increased from 69 sq.km (in 1949) to 741 sq. km (in 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 such as *Alstonia scholaris*, *Artocarpus heterophyllus* (Jack fruit), *Azadirachta indica* (Neem), *Bombax ceiba* (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* (Honne), *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, Polyalthia longifolia* etc. Trees have various important roles to play in the ecosystem, a few of them are as listed in **Annexure I**. In recent years, the increase of vehicular traffic has also increased the amounts of carbon dioxide, nitrogen, sulphur dioxide and suspended particulate matter in the atmosphere. Air pollution and reduction in green vegetation has induced the urban heat island effect which has caused a variation of Bangalore's microclimate.

Bangalore had also been known for its lakes which had, once upon a time, made it a paradise in ecological terms. In 1962, Bangalore had 265 water bodies. Due to rapid urbanization, the water bodies decreased to 98 in 2010. As the city grew in space and time, inner areas got more crowded and congested (Ramachandra et al., 2012). Road networks have increased and the roads are also being widened by axing the numerous roadside trees. Many lakes and tanks were encroached and converted into 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 there has been about 584% growth in built-up area during the last four decades with there being a decline of vegetation by 66% and that of water bodies by 74% (Ramachandra et al., 2012).

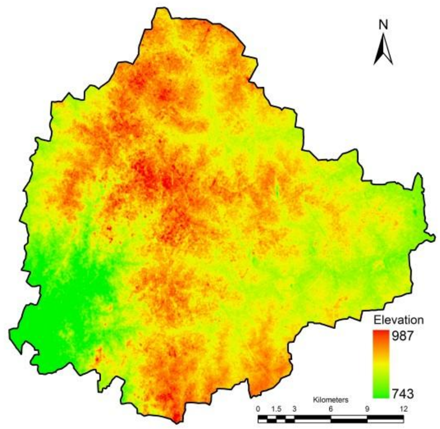


Figure5: Topography

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 flow of Cauvery River 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 a series of tanks formed by embankment of streams along the valley for irrigational purposes. These valleys vary in size bearing small ponds and large lakes. The southern portion of the land consists of hills that are close knit and surrounded by scrub jungles and forests. Geologically, the area consists of Granitic and Gneisses rocks in large scales (Bangalore District Gazetteer, 1981; Sekhar and Mohan, 2009), and other rocks such as dykes, dolerites, and schist. As the city grew in space and time, inner areas got more crowded and congested.

Land use dynamics: Table 1and Fig 6 give an insight to the temporal land use changes in Bangalore. 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 1990s can be attributed to the industrialization of Peenya and Rajajinagar.

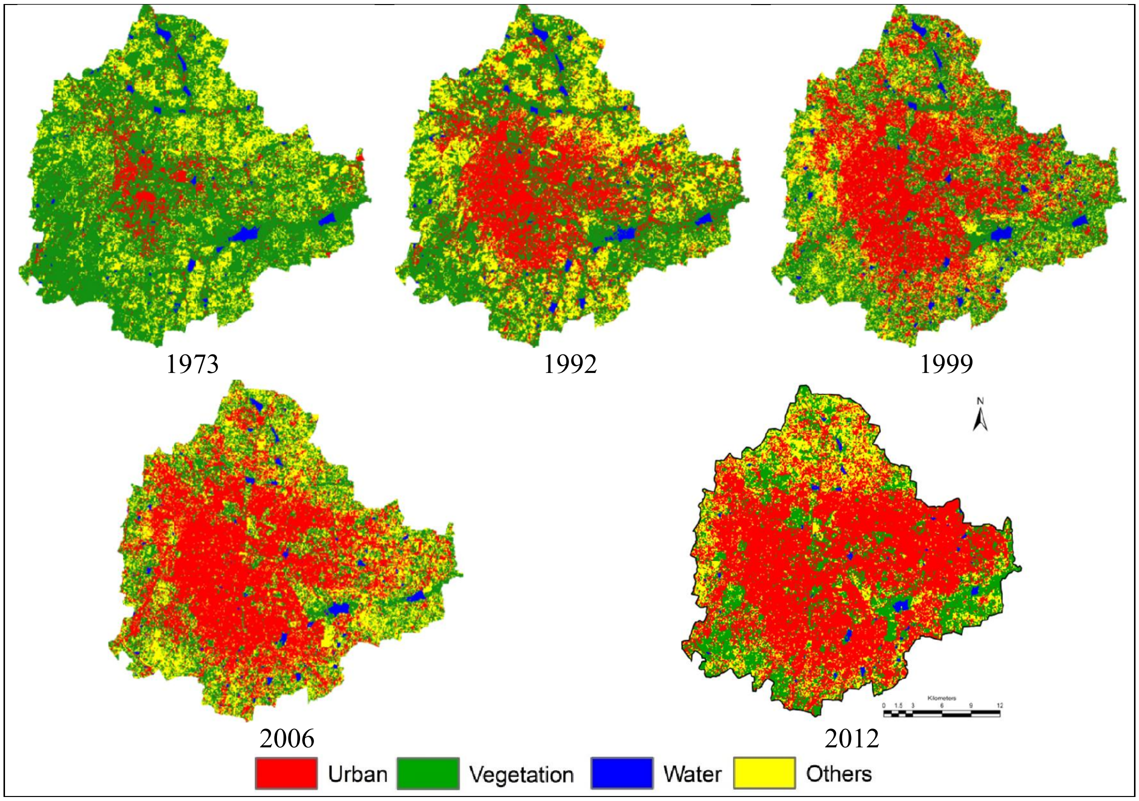


Figure 6:Land use dynamics

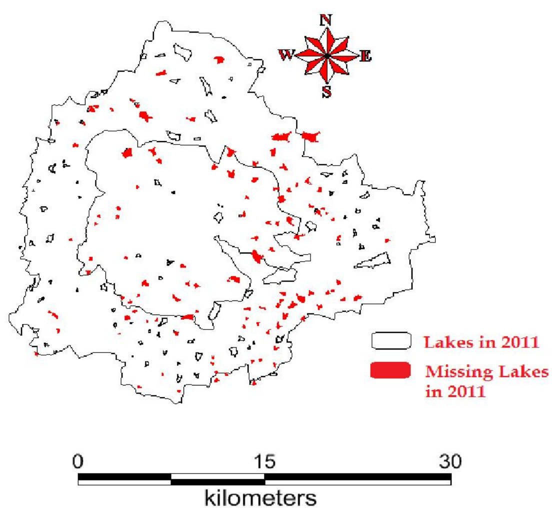


Figure 7: Lakes of Bangalore

Table 1: Temporal Land use dynamics

Class	Urban		Vegetation		Water		Others	
Year	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

Due to the evolution of IT sectors during and after the year 2000, there occurred large scale land use changes with urbanization at White field, Electronic city, Domlur, and Hebbal with the help of private players and development of Special Economic Zones. Bangalore was once branded as the Garden city due to its dense vegetation cover, but the amount of vegetation has declined from 68.27% (in 1973) to less than 25% (in 2012). Bangalore had also been known as a city of lakes once upon a time for the numerous lakes that were present in it. The impact of urbanization has reduced the number of water bodies now (which is 93 lakes as per 2011) (fig 7). Additionally, there has also been a reduction in the number of feeder canals (rajakaluve / storm water drains). The water bodies have reduced from 3.4% (1973) to less than 1% (2012). Other land uses have changed from 20.35% (1973) to 17.49% (2012).

3.0 Objective: The objective of this study is to map trees in Bangalore city (Bruhat Bangalore) and compute 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 this analysis. The remote sensing 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 datasets 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 better online virtual spatial resolution remote sensing data were used for estimating the number of trees per ward. A census of canopied trees 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

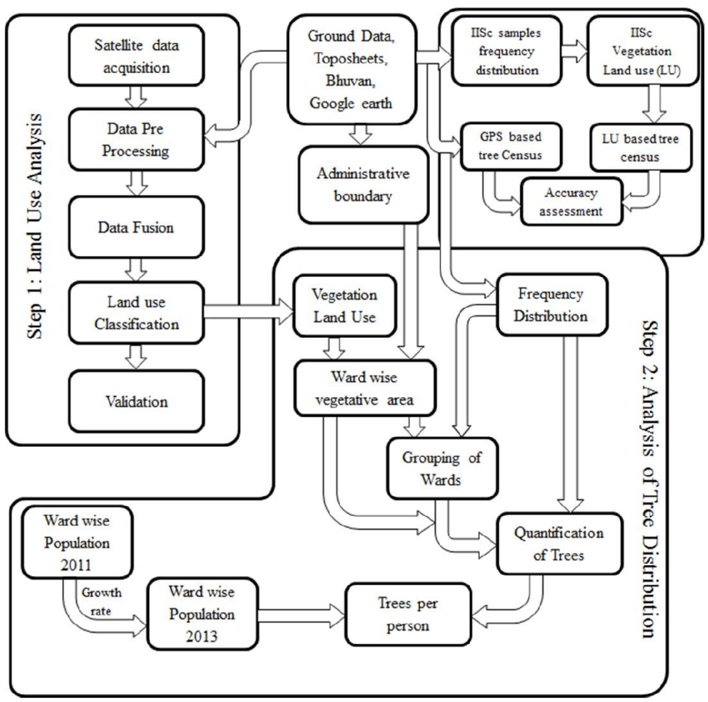


Fig 8: Method used for data analysis

To quantify the number of trees per person in each of the wards in Bangalore, the following steps were followed: i) Land use analysis using remote sensing data, ii) deriving tree canopy from the classified data, iii) assessment of 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 by the following steps: a) data pre-processing b) data fusion c) classification and 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 from GPS recordings. This involved rectification of horizontal shifts.

   Land use analysis: The method involved 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 the 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 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 to be a 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 was done which included computation of kappa (κ) statistics and overall (producers' and users') 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 be classified into 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 (Lilesand 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 the help of training datasets 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 through accuracy assessment and kappa statistics for conforming the classified land use information with a reference land use information 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 the frequency distribution of tree canopy area. The method of assessing the distribution includes: a) Data Collection, b) Frequency distribution, and 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 were delineated using better resolution virtual data (Bhuvan, Google Earth). These provided information about species wise canopy's spatial extent and number of species in sampled wards.

b) **Frequency distribution:** Based on the field data, histograms (frequency distribution) of tree canopy were created and wards were grouped as i) wards with >500 trees and ii) <500 trees. Field data provided canopy size and number of trees for each type. Histogram of canopy size distribution helped in assessing number of trees in each ward.

c) **Extraction of tree canopy using fused remote sensing data:** Tree canopy was derived using fused remote sensing data through pattern classifier. A vector layer of Bangalore with wards were overlaid on tree canopy information to derive ward-wise canopy. Based on the derived tree canopy, number of trees were computed considering frequency distribution of tree canopy categories (based on the field knowledge, explained in the previous step) in the respective ward.

d) **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.

$$P2013(i) = P2011(i)*(1+n*r(i)) \qquad \ldots 1$$

Where P2013(i) - Population of ward i for the year 2013
P2011(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.

$$TpP(i) = \frac{Tree(i)}{P2013(i)} \text{ ------2}$$

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

$$TpP(B) = \frac{\sum_{i=1}^{198} Tree(i)}{\sum_{i=1}^{198} P2013(i)} \qquad \ldots\ldots..3$$

Where TpP(i)- Tree per person in ward i
Tree(i)- Number of trees in ward i.
TpP(B) - Tree per person in Bangalore

e) **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 (Global Positioning System). Data collected from field include spatial location of a tree, size of its canopy, and also its 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 tabulated. Canopy mapping for the campus was performed using fused remote sensing data (with spatial resolution of 2.7 m. Canopy were grouped based on size and a histogram for it was generated.

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

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 heavily intensive processes which consumed 12 cores and 36 hrs of times on cloud computing networked systems. The results are given in Figure 9, visually HCS provided better results.

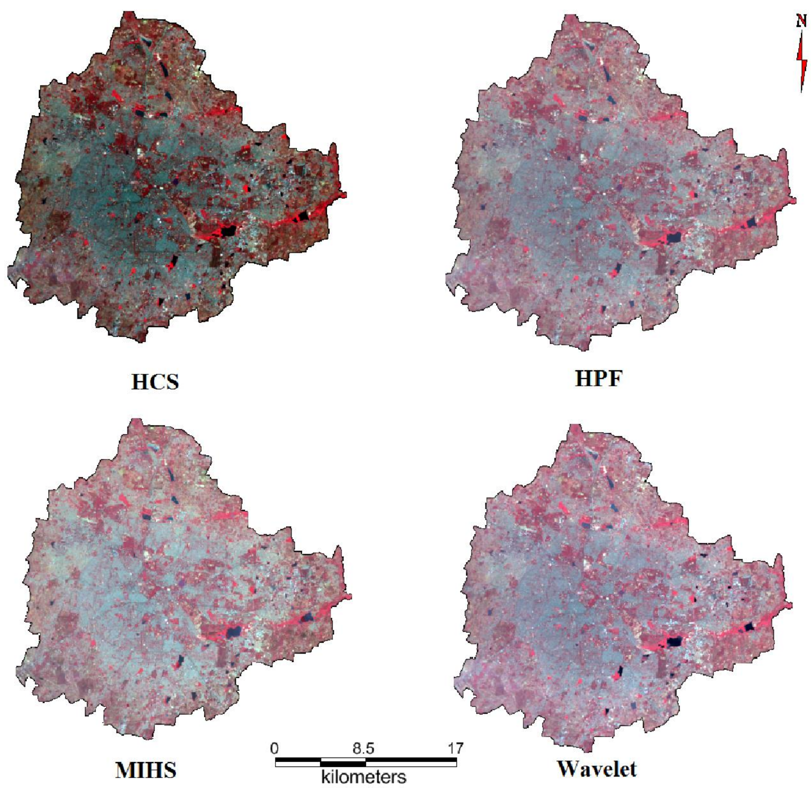


Figure 9: Landscape of Bangalore based on fused remote sensing data

Land use analysis was carried out using HPF fused remote sensing data with supervised algorithm based on Gaussian Maximum Likelihood Classifier (MLC). Categories included two classes - vegetation and non-vegetation (built-up, water bodies, open area, etc.) which are depicted in figure 10. Accuracy assessment shows an overall accuracy of 91.5%. The kappa of 0.86 indicates higher agreement of the classified data with field data. Results highlight that the spatial extent of tree vegetation in Bangalore is 100.02 sq.km. (14.08%).

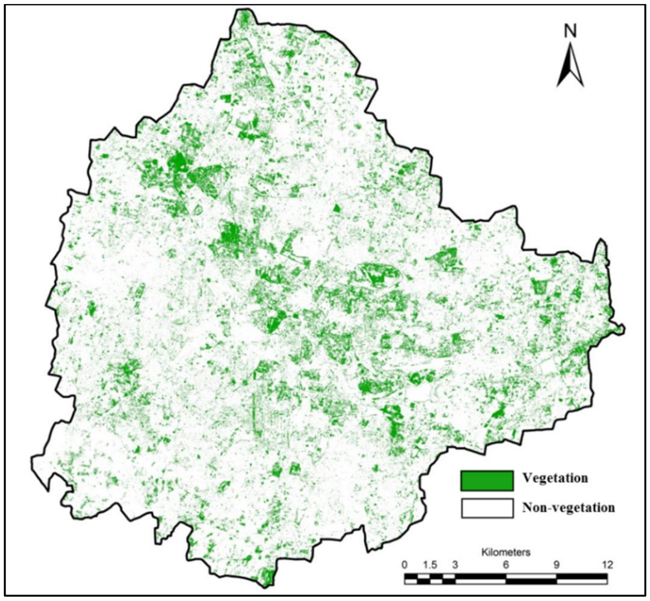


Figure 10: Spatial distribution of vegetation in Bangalore

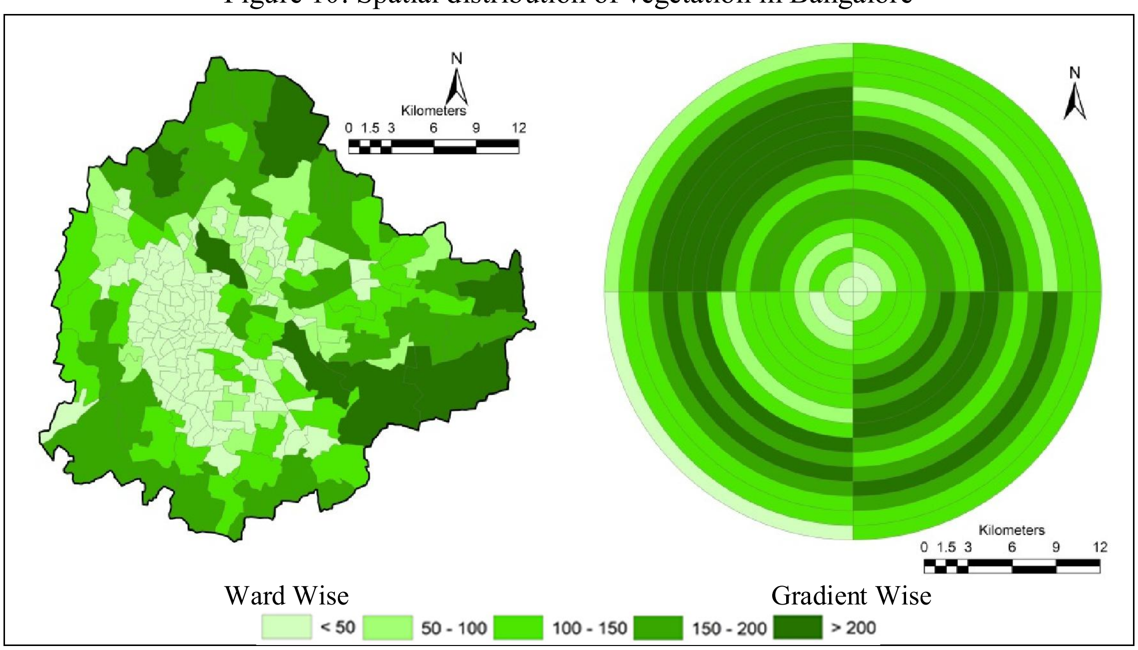


Figure 11: Ward wise spatial extent of vegetation (Hectares)

Tree distribution in wards: A 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 ward-wise 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 1 km incrementing radii circles (with respect to the central business district) to assess the vegetation gradient. Figure 12 depicts vegetation density in each concentric region for 1973 and 2013. Figure 12 illustrates the erosion of vegetation during the last 4 decades. Presence of Lalbhag and Cubbon park in the core area shows higher vegetation density in the respective gradients. Figure 13 illustrates the ward wise vegetation density for 2013. The wards such as Hudi, Aramane nagara and Vasantha pura have a vegetation density greater than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower densities that is 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

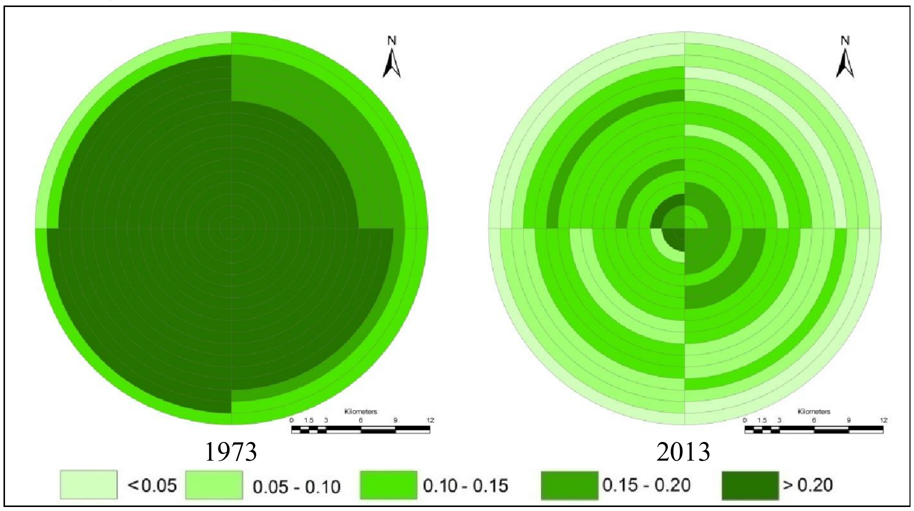


Figure 12: Gradient wise Vegetation density

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 the number of trees based on delineation of canopy from remote sensing data. Figure 15 gives the frequency distribution based on the canopy sizes for the wards, i.e. for i) < 500 trees and ii) > 500 trees.

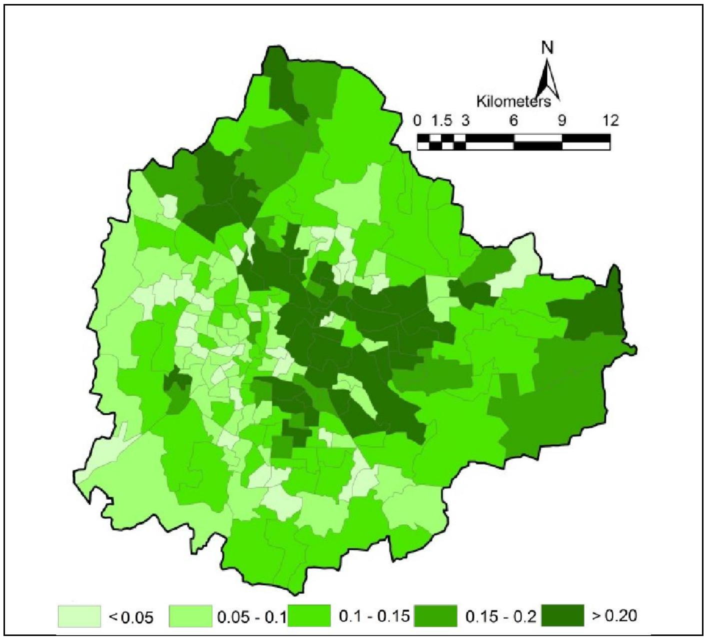
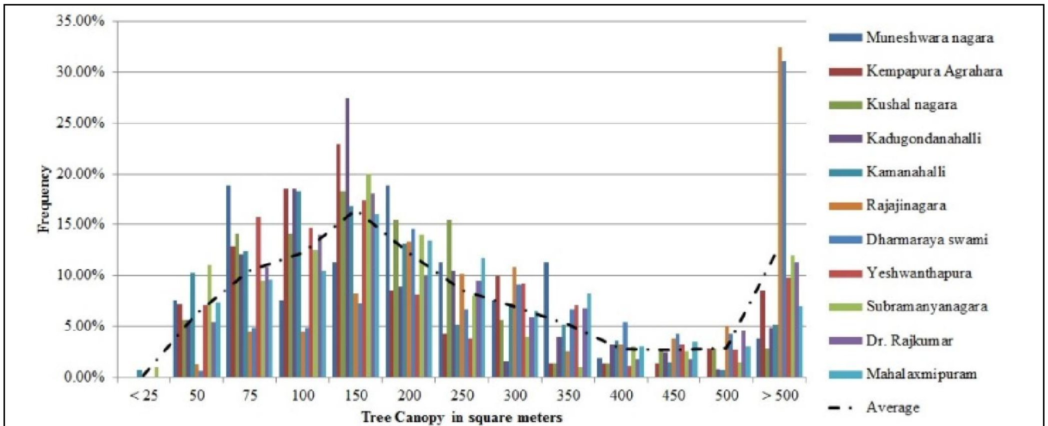
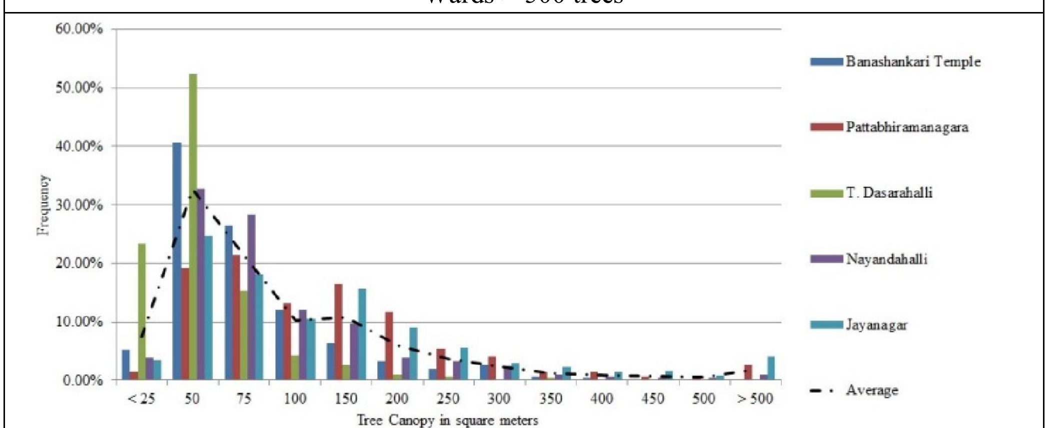


Figure 14: Ward wise vegetation density (2013)



Wards > 500 trees



Wards < 500 trees

Figure 15: Histogram based on canopy size

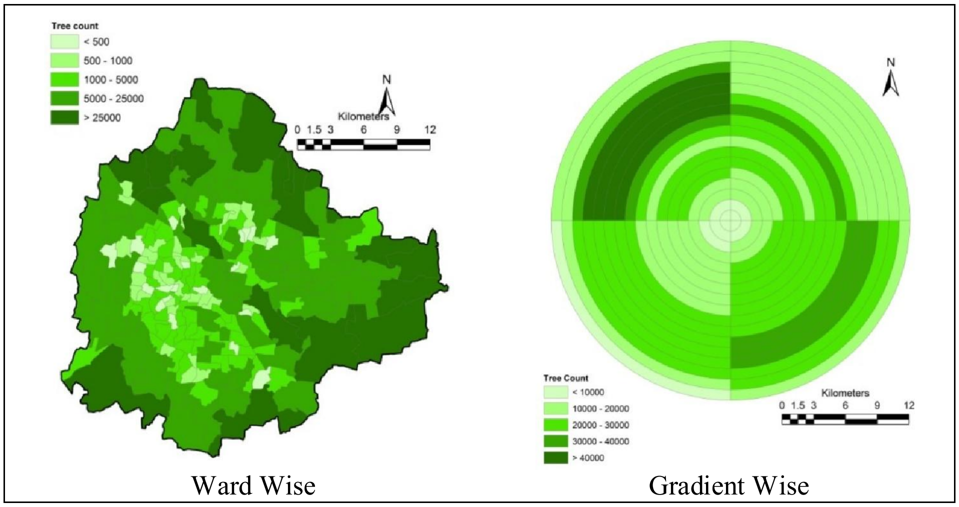


Figure 16: Tree distribution

Based on these as explained in methods section, the total number of trees in each ward was computed. Figure 16 gives the ward wise and gradient wise number of trees. This highlights that wards such as Vathur, Bellandur, Agaram, and Aramane nagara have more than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards have 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 provides the list of trees compiled from various published literatures.

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

a) Tree Census using GPS

b) Trees from remote sensing data through pattern classifiers

Figure 17: Tree Distribution in Indian Institute of Science campus

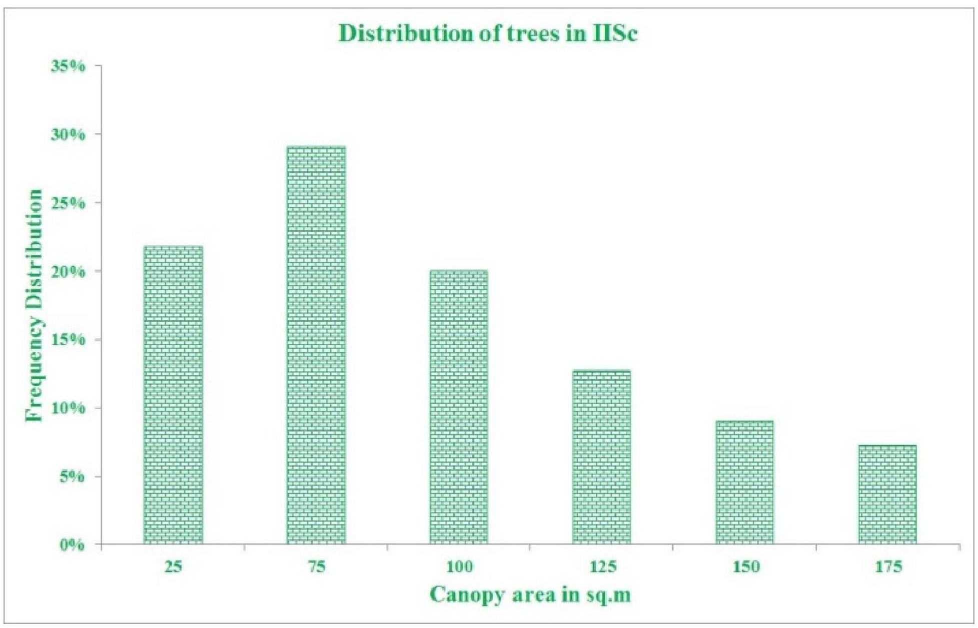


Figure 18: Frequency Distribution based on field measurement

Figure 19 provides the ward wise population during 2013 that was computed considering the growth rate based on the population of 2001 and 2011. This shows that the wards in the core area of the city have a human population greater than 40000 people, whereas the wards towards the periphery have a human population that is less than 30000.

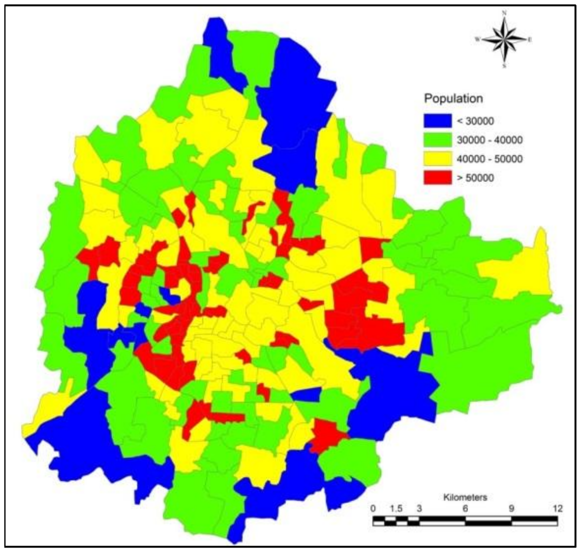


Figure 19: Ward wise population during 2013

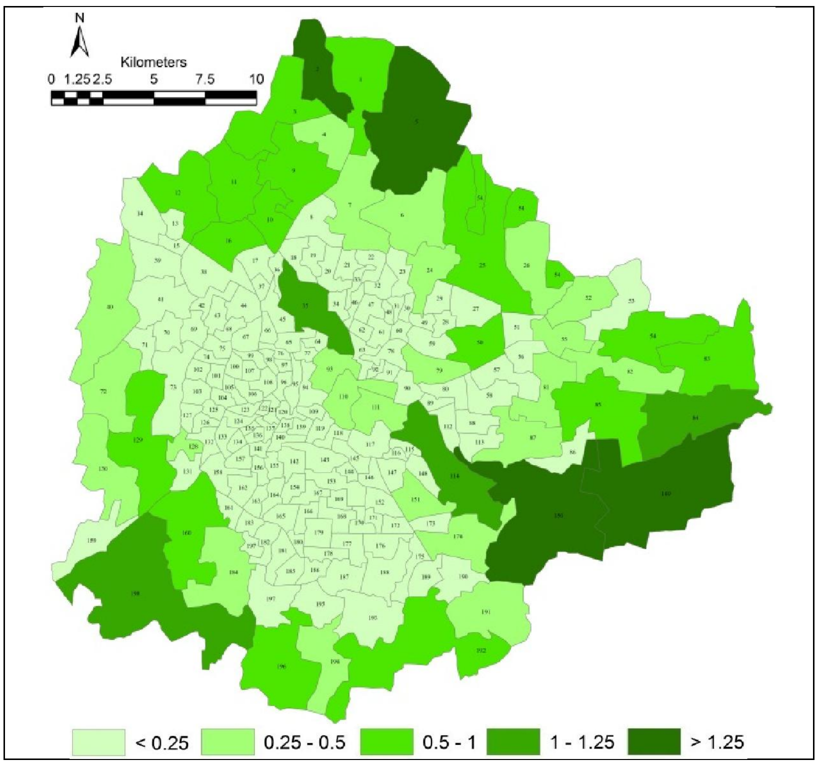


Figure 20: Ward wise tree per person

Figure 20 depicts ward-wise trees per person computed considering the number of trees and human population for each ward. This analysis shows that Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara wards have very few trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people. In contrast to these, wards such as Bellandur, Jakkuru, Varthur, Agaram, Aramane nagara have more than one tree per person implying the presence of at least one tree for every person.

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

Table 4: Comparative assessment of trees across different cities

State	Location	Population	Area (Ha)	Number of Trees	Tree / person	Tree / Hectare	Reference
Gujarat	***Ahmedabad***	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
	Gandhinagar	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
	Junagafh	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
	Brihan Mumbai	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	***Bangalore***	9588910	74100	1478412	0.155	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 Conclusion

Land use analysis based on the fusion of remote sensing data - Resourcesat 2 MSS data with Cartosat 2 shows that the spatial extent of tree vegetation in Bangalore is 100.02 sq.km (14.08%). Spatial extent of vegetation is minimal (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 densities (spatial extent of area under vegetation with respect to the geographical area of a ward) that are greater than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower densities that are 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 greater than 40000 trees, while Chickpete, Padarayanapura, Shivaji nagara, Kempapura Agrahara, Kushal nagara wards have less than 100 trees. Based on these, the total number of trees in Bangalore is about 14,78,412. Computation of trees per person shows that Shivaji nagara, Dayananda nagara, Chickpete, Padarayanapura, Kempapura Agrahara wards have very less number of trees per person (< 0.002). In other words, these wards have less than 1 tree for every 500 people. Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, Aramane nagara have more than one tree per person indicating the presence of at least one tree for every person. Intra city analysis shows that the major cities Gandhinagar, Bangalore, Ahmedabad, and Brhihan Mumbai have spatial extents greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people, which is preceded 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 CO_2 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	Mahalakshmipuram	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	Halsoor	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 Nagara	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	Bilekhalli	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 III

Prominent trees of Bangalore

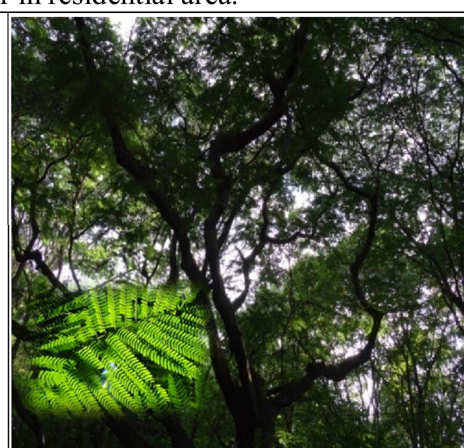
	*Acacia auriculiformis* Cnn. Ex Benth. **Common name**: Australian wattle **Family**: Fabaceae **Description**: A medium size evergreen tree. Leaves alternate, simple, reduced to phyllodes, blade-like and slightly curved. Flowers are minute, loose, yellow-orange elongated inflorescence. Fruit a flat, oblong pod, twisted at maturity. **Flowering**: July- October **Native**: Australia **Location**: Anajana Nagar, Yeshwanthpur, Vijay Nagar and outskirts of city.
Bauhinia purpurea 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, Mahalakshmipuram, Yeshwanthpura, Jaya Nagar East, Jaya Nagar, Rajarajeshwari Nagar, Sadashiva Nagar. Cultivated as avenue tree.	

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, Jaya Nagar, Yeshwanthpur, Yelahanka, Armane Nagar.
Commonly occur in residential area.

Delonix regia (Bojer ex Hook.) Raf.
Common name: Gulmohur
Famliy: 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.

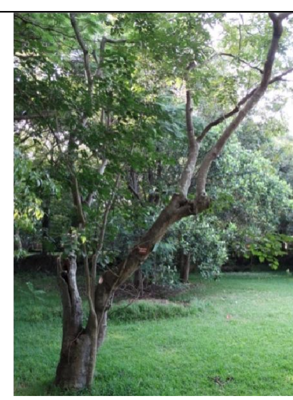


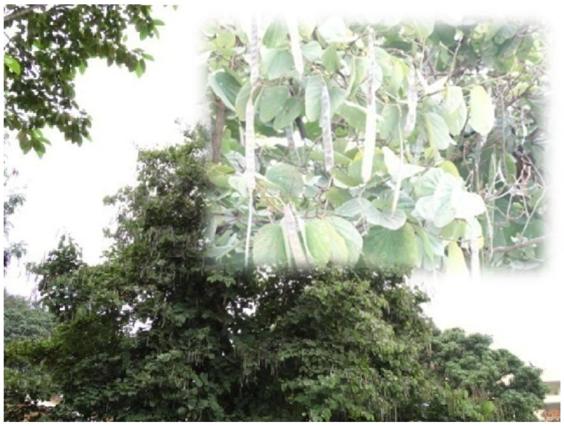
Polyalthia longifolia (Sonn.) Thwaites
Common name: Mast tree
Family: Annonaceae
Description: Tree up to 4 m high. Leaves alternate, simple, shortly-petoiled undualate, acute, shining, membranous when young. Inflorescence a panicle, sometimes in a short-peduncled umbel. Fruits a berry, ovoid, reddish black.
Flowering and Fruits: March –April; April –May
Native: South India
Location: Yeshwanthpur, Rajaji Nagar, Vijay Nagar, Malleshwaram, Mahalakshmipuram.
Cultivated as avenue tree.

Spathodea campanulata 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.

Millingtonia hortensis 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, Jaya Nagar, Sadashiva Nagar, Aramane Nagar.
Cultivated as avenue tree.

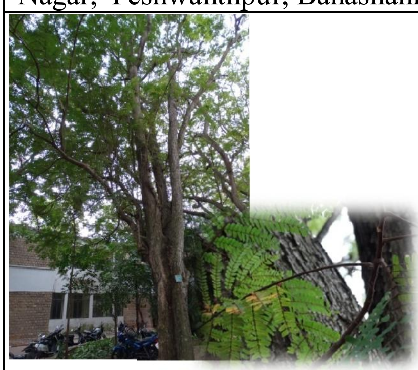
Pongamia pinnata
Common name: Indian elm
Family: Fabaceae
Description: Moderate sized tree upto 7 m high. Leaves alternate, pinnate, stipules small, oblong, cadcous. Inflorescence a panicled raceme, axillary and terminal. Fruit a pod, oblong-obovoid, compressed, woody. Seeds solitary, reniform, brown at both ends.
Flowering and Fruits: March – April
Native: India
Location: Malleshwaram, Mahalakshmipuram, Basaveshwara Nagar, Yelahanka.
It is drought-resistant and has high tolerance level to air pollution.





Bauhinia variegata L.
Common name: Moutain 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, Jaya Nagar, Hebbal.
It is drought-resistant.

Albizia lebbeck (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, Rajaji Nagar, Vijaya Nagar, Yeshwanthpur, Banashankari.

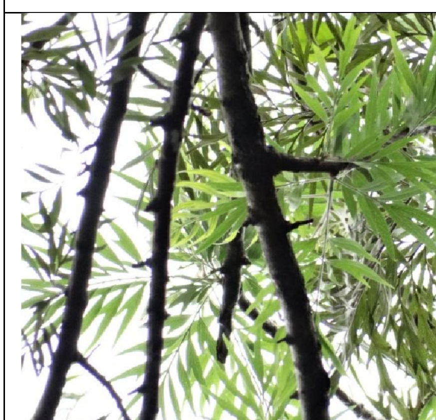


Peltophorum pterocarpum (DC.)
Common name: Copper pod
Family: Fabaceae
Description: A large deciduous tree, upto 20 m high. Leaves are bipinnately compound and pubescent. Flowers are in a terminal panicle, golden yellow with brownish stripes. Fruit is a pod 5-10 cm long, copper coloured.
Flowering: Summer months
Native: Sri Lanka, Sutheast Asia
Location: Malleshwaram, Rajaji Nagar, 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: Proteaceace
Description: A fast-growing evergreen tree. Leaves are dark green dented bipinnatified 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.

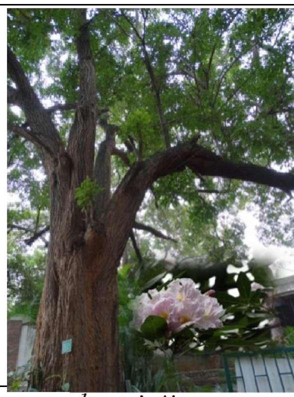
Swietenia macrophylla King
Common name: Honduras mahogany
Family: Meliaceae
Description: A large deciduous tree. Leaves are compound and opposite. Flowers are in axillary panicles, small and cream-coloured, pentamerous. Fruit is a globose woody dehiscent capsule shape like an inverted club. Seeds are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

Cassia fistula
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, Jaya Nagar East, Sanjay Nagar, Yeshwanthpur, Rajajeshwari Nagar, Sadashiva Nagar, Seshadripuram, Yelahanka, Mahalakshmi Layout.

Milletia ovalifolia
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.

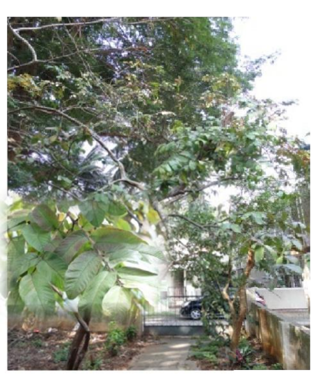
Michelia champaca L.
Common name: Orange champak
Family: Magnoliaceae
Description: Erect tree, up to 10 m high. Leaves alternate, simple, petiolate, ovate-lanceolate, coriaceous and glabrous. Flowers solitary, fragrant, Fruit a capsule, brown, dehiscent.
Flowering and Fruits: March- May.
Native: India, Malaysia
Location: Lalbagh, Mahalakshmi layout, Rajajeshwari Nagar.

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 caduceus. Inflorescence a corymbose spike, bracts spathulate. 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, Jaya Nagar 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 pr 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.

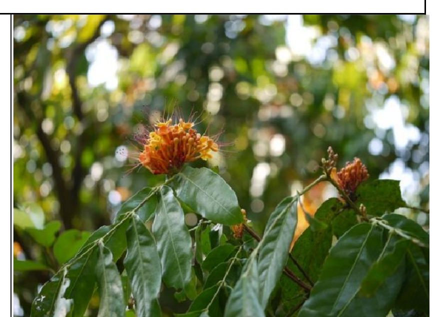


Psidium guajava L.
Common name: Guava
Family: Myrtaceae
Description: A small-sized tree. Leaves are opposite, decussate and elliptic-lanceolate. Flowers are solitary or in pairs at the axils. Petals are white. stamens are many and exserted. Fruit is an edible berry.
Flowering and Fruits: March - May
Native: Tropical America
Location: It is found in almost all residental 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, Rajaji Nagar.

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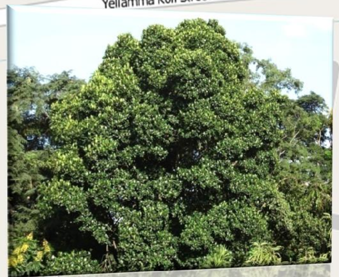
Michelia champaca L.
Common name: **Orange champak**
Family: Magnoliaceae
Description: Erect tree, up to 10 m high. Leaves alternate, simple, petiolate, ovate-lanceolate, coriaceous, glabrous. Flowers solitary, fragrant, Fruit a capsule, brown, dehiscent.

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



Artocarpus heterophyllus Lam.
Common name: **Jack Fruit**
Family: Moraceae
Description: Moderate sized tree up to 6m high. Leaves altenate, 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.

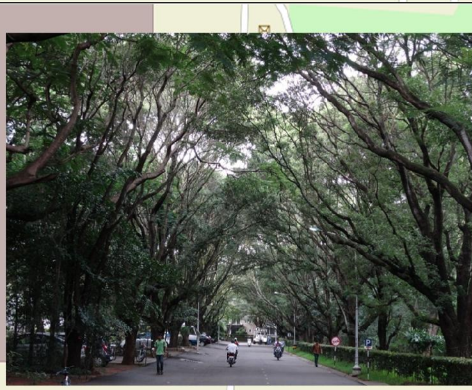
Native: India
Flowers and Fruits : February
Location: Malleshwaram, Rajrajeshwari nagar.

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

Delonix regia (Bojer ex Hook.) Raf.
Common name: **Gulmohur**
Famliy: 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.

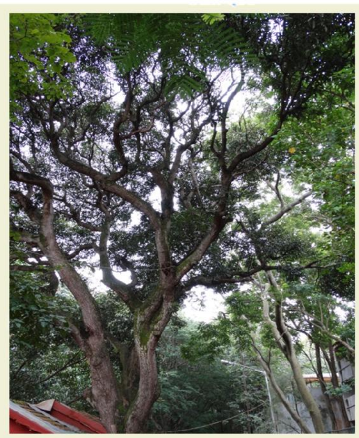


Swietenia mahagoni
Common name: **West Indian Mahogany**
Family: Meliaceae
Description: A large deciduous tree with spreading branches. Leaves are long, pinnately compound with 2-5 pairs of leaflets. Leaves are deciduous to semi-evergreen. Flowers are inconspicuous, unisexual, greenish-yellow in branched 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: Proteaceace
Description: A fast-growing evergreen tree. Leaves are dark green dented bipinnatified 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.

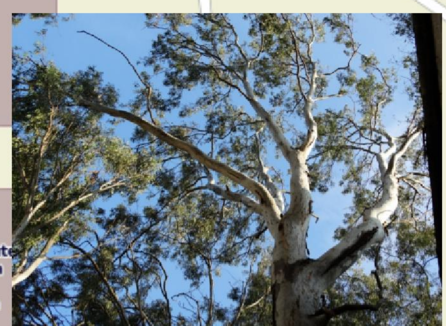


Mangifera indica
Common name: **Mango**
Family: Anacardiaceae
Description: Moderate sized tree, up to 8 m high. Leaves alternate or sub-opposite, simple, exstipulate, lanceolate, undulate, acute or acuminate. Inflorescence a terminal panicle. Flowers polygamous.. fruit a fleshy drupe, orange yellow.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

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

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 clusters with conical 'pixie-cap'. Fruit is woody, dehiscent with protruding teeth.

Flowering: October- January

Native: **Australia**

List of tree species in the Indian Institute of Science (K. Sankar Rao, 2009 and Field work)

Annexure IV

Sl. No	Botanical Name	Common Name	Family	Native	Location
1	*Acacia auriculiformis* Cunn. Ex Benth.	Australian wattle	Fabaceae	Australia	In front of SID
2	*Acacia catechu* (L. f.) Wild.	Black cutch tree	Fabaceae	India	Acacia-phoenix groove next to the swamp (P)
3	*Acacia chundra* (Roxb. Ex Rottl.)	red cutch	Fabaceae	India	Airstrip
4	*Acacia leucophloea* (Roxb.) Wild.	White-barked acacia	Fabaceae	Indomalayan region	Next to CEDT, Airstrip
5	*Acacia nilotica* (L.) Del. Subsp. Indica (Benth.) Brenan	Babul acacia	Fabaceae	India	Vijnanapura campus
6	*Adenanthera pavonina* L.	Coral seed tree	Fabaceae	China, Malaysia	In front of Centtral office-next to Tata statue
7	*Aegle marmelos* (L.) Corr. Serr.	Bael	Rutaceae	India	Main Guest House
8	*Ailanthus triphysa* (Dennst.) Alston	White palle	Simaroubaceae	India, Sri Lanka, Southeasr Asia, Australia.	Next to SSCU among Ficus pandurata
9	*Albizia lebbeck* (L.) Benth.	East indian walnut	Fabaceae	Asia	In front of CST and at several other locations on the campus.
10	*Albizia odoratissima* (L.f.) Benth.	Blacksiris	Fabaceae	Tropical Asia	Main Guest House
11	*Aleurites moluccana* (L.) Wild.	Candle-nut tree	Euphorbiaceae	Malaysia	In front of JNCASR President's Office
12	Alstonia macrophylla Wall. Ex DC.	Batino	Apocynaceae	Sri Lanka	Professor's quarters area
13	*Alstonia scholaris* (L.) R. Br.	Scholar tree	Apocynaceae	India	Next to Biochemistry Department
14	*Anacardium occidentale* L.	Cashew	Anacardiaceae	Northeastern Brazil	Airstrip area
15	*Annona cherimola* Mill.	Cherimoya	Annonaceae	Peru, Ecuador	Nursery
16	*Annona reticulata* L.	Bullock's heart	Annonaceae	Neotropics	Nursery
17	*Annona squamosa* L.	Custard apple	Annonaceae	West Indies	Vijnanapura campus
18	*Aphanamixis polystachya* (Wall.)	Pithraj tree	Meliaceae	Tropical Asia	Next to C mess
19	*Artocarpus altitilis* (Park.) Fosb.	Bread fruit	Moraceae	Malay Peninsula	Staff quarters
20	*Artocarpus heterophyllus* Lam.	Jack fruit	Moraceae	India	Near Faculty Club
21	*Artocarpus hirsutus* Lam.	Wild jack	Moraceae	Tropical Asia	Telecom Bureau premises

22	*Averrhoa carambola* L.	Star fruit	Oxalidaceae	Sri Lanka	One readily accessible trees is in the nursery
23	*Azadirachta indica* A. Juss.	Neem tree	Meliaceae	India	Airstrip and staff quarters
24	*Barringtonia acutangula* (L.)	Indian Oak	Lecythidaceae	Southeast Asia, N. Australia	In front of JNCASR President's Office
25	*Barringtonia asiatica* (L.) Kurz.	Fish poison tree	Lecythidaceae	South Pacific Islands	Archives Cell premises
26	*Bauhinia racemosa* Lam.	Indian kanchan	Fabaceae	Tropics of both hemispheres	Next to Lecture Hall Complex (T)
27	*Bauhinia blakeana* Dunn.	Hong kong orchid tree	Fabaceae	Hong Kong	Main Quadrangle
28	*Bauhinia galpinii* N.E. Br.	Pride of the cape	Fabaceae	South Africa	Nursery
29	*Bauhinia tomentosa* L.	Brazilian orchid tree	Fabaceae	Tropical Asia, Africa	CST area
30	*Bauhinia forficata* Link	Burmese silk orchid	Fabaceae	Brazil, Peru	Jubilee Garden
31	*Bauhinia purpurea* L.	Butterfly tree	Fabaceae	India, Burma, Vietnam	Main Quadrangle and other locations
32	*Bauhinia variegata* L.	Mountain ebony	Fabaceae	India, China	Next to Kabini canteen
33	*Bauhinia variegata* L. var. candida Voigt.	White bauhinia	Fabaceae	China	Nursery
34	*Bauhinia purpurata* (Vieill.)	Purple orchid tree	Fabaceae	Asian tropics	Park in front of Airstrip
35	*Bolusanthus speciosus* (Bolus)	Tree wisteria	Fabaceae	Mozambique	Next to Electrical Engineering
36	*Bombax malabaricum* DC.	Red Silk-cotton tree	Bombacaceae	India	Next to Centre for High Energy Physics
37	*Brassaia actinophylla* Endl. Var. capitata Clarke	Queensland umbrella tree	Araliaceae	Australia	MBU car parking
38	*Broussonetia papyrifera* Vent.	Paper mulberry	Moraceae	East Asia	Behind CES
39	*Broussonetia luzonica* Bureau	Limba bao	Moraceae	Philippines	Miniforest
40	*Brownea coccinea* Jacq.	West indian Mountain rose	Fabaceae	Tropical America	NIAS
41	*Butea monosperma* (Lam.) Taub.	Flame of the forest	Fabaceae	India	Behind Main Guest House
42	*Caesalpinia ferrea* Mart. Ex Tul.	Brazilian ironwood	Fabaceae	Eastern Brazil	TMC Club
43	*Callistemon viminalis* (Soland. Ex Gaertn.) G. Don	Drooping bottle-brush	Myrtaceae	Australia	By the side of Material Research Centre
44	*Calophyllum inophyllum* L.	Alexandran laurel	Clusiacea	Mozambique, Tropical Asia	Biochemistry Department quadrangle
45	*Cananga odorata* (Lam.) Hook.f. & Thoms.	Scented Ylang-Ylang	Annonaceae	Indo-malaysian	Student Hostels area
46	*Cassia fistula* L.	Indian laburnum	Fabaceae	India, China, Southeast Asia	Behind Tata Memorial Library

47	*Cassia grandis* L.f	Brazilian cassia	Fabaceae	Tropical America	Student Hostels area
48	*Cassia javanica* L.	Java cassia	Fabaceae	Southeast Asia	Next to Central Office building
49	*Cassia moschata* Kunth	Bronze shower tree	Fabaceae	Panama, Columbia	Next to Central Offica Building and Nursery
50	*Cassia roxburghii* DC.	Red cassia	Fabaceae	Sri Lanka	Behind Central Office building
51	*Cassia spectabilis* DC.	Popcorn bush cedar	Fabaceae	Tropical Southeast Asia	Along the road to Main Guest House
52	*Cassine paniculata* (Wight & Arn.)	Indian cassine	Celastraceae	India	Main Guest House
53	*Castanospermum australe* Cunn. & Fraser	Australian chestnut	Fabaceae	Australia	Behind old Faculty Club
54	*Casuarina equisetifolia* L.	She-oak	Casuarinaceae	Malaysia, S. Asia, Australia	Next to JN Tata Auditorium
55	*Cedrela odorata* L.	Spanish cedar	Meliaceae	West Indies, Central & South America	Old Faculty Club
56	*Ceiba pentandra* (L.) Gaertn.	Kapok tree	Bombacaceae	South & Central America	Next to D gate
57	*Ceiba speciosa* (A. St. Hil.) Ravenna	Floss-silk tree	Bombacaceae	Brazil, Argentina	In front of Central Office building
58	*Centrolobium microchaete* (Mart. Ex Benth.)	Canary wood	Fabaceae	South America	Krithika hostel
59	*Chukrasia tabularis* A. Juss.	Indian redwood	Meliaceae	India, SE Asia	Near CES
60	*Cinnamomum verum* J.S. Presl	True cinnamon tree	Lauraceae	India, Sri Lanka	Medicinal and Aromatic Plants Garden
61	*Citharexylum fruticosum* L.	Fiddle wood	Verbenaceae	Caribbean Territories	Director's Bungalow premises
62	*Cirtus grandis* (L.) Osbeck	Pomelo	Rutaceae	Southeast Asia	Next to Hoysala Guest House
63	*Clusia rosea* Jacq.	Autograph tree	Clusiacea	Tropical America	Behind Central Office building
64	*Cochlospermum religiosum* (L.)	Yellow silk cotton tree	Cochlospermaceae	Tropical Asia	Main Guest House, Main Quadrangle
65	*Colvillea racemosa* Boj.	Colville's glory	Fabaceae	Madagascar	Main Quadrangle
66	*Cordia lutea* Lam.	Yellow cordia	Boraginaceae	Peru, Ecuador	Nursery
67	*Cordia wallichii* G. Don	Indian cherry	Boraginaceae	West Asia	MBU car parking
68	*Couroupita guianensis* Abul.	Cannon-ball tree	Lecythidaceae	French Guiana	JNCASR Office
69	*Crescentia cujete* L.	Calabash tree	Bignoniaceae	West Indies, Tropical America	Main Quadrangle
70	*Dalbergia latifolia* Roxb.	East indian rosewood	Fabaceae	India	MCB Department, Next to Faculty Club
71	*Dalbergia sissoo* Roxb.	North Indian rosewood	Fabaceae	India	Main Quadrangle
72	*Delonix regia* (Bojer ex Hook.) Raf.	Gulmohur	Fabaceae	Madagascar	Gulmohur Marg

73	*Duadanga grandiflora* (Roxb. Ex DC.) Walp.	Lampatti	Sonneratiaceae	Cambodia, E.India, Laos	Miniforest
74	*Dillenia indica* L.	Elephant apple	Dilleniaceae	India	Next to MBU Parking
75	*Diospyros cordifolia* Roxb.	Mountain persimmon	Ebenaceae	India, Sri Lanka, Malaysia, Australia	Main Quadrangle
76	*Diospyros ebenum* Koenig.	Ceylon ebony	Ebenaceae	India	Main Guest House
77	*Diospyros melanoxylon* Roxb.	Bale	Ebenaceae	India	Main Guest House
78	*Drypetes roxburghii* (Wall.) Hurus	Indian amulet tree	Euphorbiaceae	India	Main Guest House
79	*Elaeocarpus grandis* F. Muell.	Blue-marble tree	Elaeocarpaceae	Australia	Director's Bungalow and Main Guest House
80	*Emblica officinalis* Gaertn.	Indian gooseberry	Euphorbiaceae	Southeast Asia	Nursery
81	*Enterolobium contortisiliqum* (Vell.)	Pacara earpod	Fabaceae	Brazil, Bolivia, Paraguay, Argentina	Student Council
82	*Eriobotrya japonica* (Thunb.) Lindley	Loquat	Rosaceae	China	Director's Bungalow and Duplex Quarters
83	*Erythrina umbrosa* Kunth	Crimson Mortel tree	Fabaceae	Neotropics, India	Swamp (P)
84	*Erythrina suberosa* Roxb.	Corky coral tree	Fabaceae	India, SE Asia	Airstrip
85	*Erythina standleyana* Krukoff	Tiger wood	Fabaceae	Central America	C mess area
86	*Erythroxylum monogynum* Roxb.	Bastard sandal of India	Erythroxylaceae	India	Semi-wild area (J)
87	*Eucalyptus tereticornis* Sm.	Forest red gum	Myrtaceae	Australia	Nilgiri marg
88	*Eugenia uniflora* L.	Surinam cherry	Myrtaceae	Surinam, Guyana	Nursery
89	*Filicium decipiens* (Wt. & Arn.)	Fern leaf tree	Sapindaceae	India	Next to IPC
90	*Ficus auriculata* Lour.	Elephant year fig tree	Moraceae	Southeast Asia	Rohini hostel
91	*Ficus benghalensis* L.	Banyan tree	Moraceae	India	Behind Aerospace Engineering
92	*Ficus benjamina* L.	Benjamin fig	Moraceae	India, Malaya	Main Quadrangke, Director's Bunglow
93	*Ficus drupacea* var. pubescens (Roth) Corner	Mysore fig	Moraceae	India	Area next to Jubilee Garden
94	*Ficus elastica* Roxb. Ex Hornem.	India rubee tree	Moraceae	Southeast Asia	Next to Archives Cell
95	*Ficus pandurata* Hance	Fiddle leaf fig	Moraceae	Tropical West Africa	Next to SSCU
96	*Ficus infectoria* sensu Roxb. - Type I	Indian White fig	Moraceae	India, Nepal, Sri Lanka	Main Guest House

97	*Ficus infectoria* sensu Roxb.-Type II	Pakur	Moraceae	India	Next to SSCU
98	*Ficus virens* Aiton (Ficus infectoria sensu Roxb. -Type III)	Spotted White Fig	Moraceae	India, SE Asia	Vijnanapura campus
99	*Ficus racemosa* L.	Cluster Fig	Moraceae	India	Department of Instrumentation
100	*Ficus religiosa* L.	Peepal tree	Moraceae	India, Burma	Next to MRC
101	*Firmiana colorata* (Roxb.) R. Br.	Coloured Sterculia	Sterculiaceae	India	Materials Engineering
102	*Flacouratia inermis* Roxb.	Batoko plum	Flacouratiaceae	Philippines	Next to JN Tata Auditorium
103	*Calamus prasinus* Lak. & Renuka	Ontibetha	Arecaceae	India	Miniforest
104	*Caryota mitis* Lour.	Clustered Fish-tail palm	Arecaceae	Tropical Asia	By the side of Central Office building
105	*Caryota urens* L.	Fish-tail palm	Arecaceae	Sri Lanka, India	In front of Central Office building
106	*Cocos nucifera* L.	Coconut palm	Arecaceae	Indo-Pacific	Nursery
107	*Cyrtostachys renda* Blume	Red sealing wax palm	Arecaceae	Malaysia, Borneo	JNCASR city office premises
108	*Dypsis lutescens* (Wendl.) Beentze & Dransfield	Golden cane palm	Arecaceae	Madagascar	At several locations, in front of ECE
109	*Hydristele wendlandiana* (C. Moore & F. Muell.) H. Wendl. & Drude	Florence fall palm	Arecaceae	Tropical Australia	Main Guest House
110	*Livistona chinensis* (Jacq.) R. Br. Ex Mart.	Chinese fan palm	Arecaceae	South China	In front of Electrical Engineering Department
111	*Livistona rotundifolia* (Lam.) Mart.	Roundleaf fan palm	Arecaceae	Southeast asia	Behind SID building
112	*Phoenix roebelinii* O'Brien	Pigmy date palm	Arecaceae	Laos, Thailand, Possibly Myanmar	Park between Lecture hall complex and admissions office
113	*Phoenix rupicola* T. Anders	Dwarf date palm	Arecaceae	India, Bhutan	In front of Main Guest House
114	*Rhapis excelsa* Henry	Lady palm	Arecaceae	South China	Registrar's Quarters
115	*Phoenix sylvestris* (L.) Roxb.	Wild date palm	Arecaceae	India	Swimming pool area
116	*Pritchardia pacifica* Seem. & H. Wendl.	Fiji fan palm	Arecaceae	Tonga, Fiji Islands	Instrumentation premises
117	*Ptychosperma macarthuri* Nichols	Macarthur palm	Arecaceae	New Guinea, Australia	Next to Automation Department
118	*Roystonea regia* (H.B.K) O. F. Cook	Cuban royal palm	Arecaceae	Cuba	Next to Lecture Hall Complex (T)
119	*Syagrus romanzoffianum* (Cham.)	Glassman	Arecaceae	Brazil	Next to Mathematics

120	*Thrinax parviflora* Sw.	Jamaican Thatch palm	Arecaceae	Jamaica	Biochemistry Quadrangle, Electrical Engineering
121	*Garcinia indica* (Thouars) Choisy	Coccum	Clusiaceae	India	Miniforest
122	*Gliricidia sepium* (Jacq.) Kunth ex Walp.	Quickstick	Fabaceae	South America	Main Quadrangle
123	*Gmelina arborea* Roxb.	White teak	Verbenaceae	India	Next to water Tunnel Lab
124	*Grevillea robusta* Cunn. Ex R. Br.	Silver oak	Proteaceace	Australia	Silver Oak Marg
125	*Grewia asiatica* sensu Masters	Phalsa	Tiliaceae	South Asia	Next to Mechanical Engineering
126	*Guazuma ulmifolia* Lam.	Honey-fruit tree	Sterculiaceae	Central America	Next to MBU
127	*Heritiera littoralis* Dyrand.	Looking glass tree	Sterculiaceae	Old world tropics	Near C mess
128	*Hibiscus tiliaceus* L.	Yellow mallow Tree	Malvaceae	Tropical Asia	Main Guest House, Gymkhana
129	*Jacaranda acutifolia* Humb. & Bonpl.	Jacaranda	Bignoniaceae	South America	Main Quadrangle
130	*Joannesia princeps* Vell.	Araranut Tree	Euphorbiaceae	Coastal Brazil	Behind former faculty club
131	*Khaya senegalensis* (Desr.) A. Juss.	African mahogany	Meliaceae	Central America	On the way to NIAS
132	*Kigelia africana* (Lam.) Benth.	African sausage tree	Bignoniaceae	Tropical West Africa	Jubilee Garden
133	*Lagerstroemia speciosa* (L.) Pers.	Pride of india	Lythraceae	India	Main Quadrangle
134	*Lepisanthes tetraphylla* (Vahl) Radlk.	Wild aphania	Sapindaceae	Tropical Africa. S. & SE Asia, Australia	Main Quadrangle
135	*Leucaena latisiliqua* (L.) Gillis	Subabool	Fabaceae	Central America	Semi-wild area
136	*Limonia acidissima* L.	Wood apple	Rutaceae	India	Main Quadrangle
137	*Litchi chinensis* Sonn.	Litchi	Sapindaceae	South China	Nursery
138	*Lonchocarpus minimiflorus* J.D. Smith	Chapleno	Fabaceae	Trinidad, Tobago	By the side of JN Tata Library
139	*Madhuca indica* J. Gmelin	Butter tree	Sapotaceae	India	One specimen is in front of Tata Book House and another next to Science Informatio Centre
140	*Magnolia grandiflora* L.	Lily tree	Magnoliaceae	Tropical America	On either side of Tata Statue
141	*Majidea zanguebarica* Oliv.	Velvet-seed tree	Sapindaceae	Tropical Kenya	Main Quadrangle
142	*Malpighia glabra* L.	Barbados cherry	Malpighiaceae	Tropical America	NIAS premises
143	*Mangifera indica* L.	Mango tree	Anacardiaceae	India	Nursery

144	*Manihot glaziovii* Muell. -arg.	Ceara rubber tree	Euphorbiaceae	Central America	Behind Main Guest House
145	*Manilkara zapota* (L.) P. Royen	Sapodilla	Sapotaceae	Central America	Main Guest House
146	*Markhamia lutea* (Benth.) K.Schum.	Siala	Bignoniaceae	Tropical Africa	On the way to D gate
147	*Melaleuca bracteate* F. Muell.	River tea tree	Myrtaceae	Australia	One specimen is in Nursery
148	*Melaleuca leucodendron* L.	Punk tree	Myrtaceae	Australia	Next to Central Office building
149	*Melia azedarach* L.	Persian Lilac	Meliaceae	Australia	CST
150	*Melia dubia* Cav.	China berry	Meliaceae	India, Tropical Asia, Angola, Australia	In front to CEDT, next to SERC
151	*Mesua ferrea* L.	Ceylon ironwood	Clusiaceae	Sri Lanka	NIAS
152	*Michelia longifolia* Blume	White champaka	Magnoliaceae	China	Professor's quarters area
153	*Michelia champaca* L.	Orange champak	Magnoliaceae	India, Malaysia	Student hostels area
154	*Millettia peguensis* Ali	Moulmein rosewood	Fabaceae	Myanmar	Next to SERC
155	*Millingtonia hortensis* L.f.	Indian cork tree	Bignoniaceae	Myanmar	Main Quadrangle, next to High Energy Physics
156	*Mimusops elengi* L.	Indian medlar	Sapotaceae	India	CST
157	*Mitragyna parviflora* (Roxb.) Korth.	True kadamb	Rubiaceae	India, Sri Lanka, Bangladesh	Miniforest
158	*Moringa oleifera* Lam.	Drumstick tree	Moringaceae	India	Nursery and Staff Quarters
159	*Morus alba* L.	White mulberry	Moraceae	China	Behind MRC
160	*Muntingia calabura* L.	Singapore cherry	Elaeocarpaceae	South America	At several locations on the campus, Nursery
161	*Murraya koenigii* (L.) Spreng.	Curry leaf tree	Rutaceae	India, Sri Lanka, China, Laos, Myanmar	Several trees occur scattered on the campus, particularly in the backyards of staff quarters.
162	*Neolamarckia cadamba* (Roxb.) Bosser	Kadamb tree	Rubiaceae	India	Behind Central Office building
163	*Ochroma lagopus* Sw.	Balsa	Bombacaceae	Panama, Columbia	Near CST
164	*Oncoba spinosa* Forssk.	Snuff-box tree	Flacouratiaceae	South Africa	On the roadside, Next to Nursery
165	*Parkia biglandulosa* Wt. & Arn.	Badminton ball tree	Fabaceae	Malaysia	In front of CEDT
166	*Peltophorum africanum* Sond.	African wattle	Fabaceae	South Africa	On either side of road from the second gate
167	*Peltophorum pterocarpum* (DC.) Back. Ex K. Heyne	Copper pod	Fabaceae	Sri Lanka, Sutheast Asia	On either side of the road from the second gate

168	*Persea americana* Miller	Avocado	Lauraceae	Southern Mexico	In front of CST, Vijnanapura campus
169	*Persea macrantha* (Nees) Kosterm.	Indian persea	Lauraceae	India, Sri Lanka	CES
170	*Phyllanthus acidus* (L.) Skeels	Star gooseberry	Euphorbiaceae	Brazil	Vijnanapura campus
171	*Phyllanthus polyphykkus* Wild.	Wild gooseberry	Euphorbiaceae	India	On the way to Jubilee Garden
172	*Pithecellobium dulce* (Roxb.) Benth.	Manila tamarind	Fabaceae	Mexico, S. America, West Indies	Vijnanapura campus
173	*Plumeria obtusa* L. var. sericiflora	Cuban frangipani	Fabaceae		
174	*Plumeri obtusa* L. var. obtusa	Temple tree	Fabaceae		
175	*Plumeria rubra* L. forma rubra	Pagoda tree	Fabaceae		
176	*Plumeria rubra* L. forma tricolor	frangipani tree	Fabaceae		
177	*Plumeria rubra* L. forma lutea	Yellow frangipani	Fabaceae		
178	*Plumeria rubra* L. forma acutifolia	Crimson temple tree	Fabaceae		
179	*Polyalthia longifolia* (Sonn.) Thwaites	Mast tree	Annonaceae	South India	As avenue trees in front of Civil Engineering
180	*Pongamia pinnata* (L.) Pierre	Indian elm	Fabaceae	India	Medicinal and Aromatic Plants Garden
181	*Pseudobombax ellipticum* (H.B.K.) Dug.	Shaving brush tree	Bombacaceae	Mexico	Next to Stores and Purchase, Main Guest House
182	*Psidium guajava* L.	Guava	Myrtaceae	Tropical america	VIjnanapura campus, Nursery
183	*Pterocarpus marsupium* Roxb.	Kino tree	Fabaceae	India	Next to Greenhouse in the Nursery
184	*Pterospermum acerifolium* (L.) Wild.	Dinnerplate tree	Sterculiaceae	India	Next to C mess
185	Pterygota alata (Roxb.) R. Br.	Buddha's coconut	Sterculiaceae	India	Behind Main Guest House
186	*Reutealis trisperma* (Blco.) Airy Shaw	Philippine tung tree	Euphorbiaceae	Malaysian Archipelago, Philippines	Next to Materials Research Centre, Vijnanapura campus
187	*Salix tetrasperma* Roxb.	Indian willow	Salicaceae	Southeast Asia, India	Swamp (P)
188	*Samanea saman* (Jacq.) Merr.	Rain tree	Fabaceae	Tropical America, West Indies	Next to Central Office on either side of the road
189	*Santalum album* L.	Sandal wood	Santalaceae	India	At several locations on the campus, a few specimens are next to Main Guest House
190	*Sapindus laurifolius* Vahl	Soapnut	Sapindaceae	South India	Airstrip area

191	*Sapium sebiferum* (L.) Roxb.	Chinese tallow tree	Euphorbiaceae	China, Japan	Southeaast corner of Biochemistry
192	*Saraca asoca* (Roxb.) de Wilde	Flowering ashoka	Fabaceae	India, Sri Lanka	On either side of Central office building
193	*Schleichera oleosa* (Lour.) Oken	Lac tree	Sapindaceae	India	Faculty club
194	*Schotia brachypetala* Sonder	Tree fuchsia	Fabaceae	South Africa	Behind Physics
195	*Semecarpus anacardium* L.f	Marking nut	Anacardiaceae	Sub Himalayan (India)	Behind Wind Tunnel
196	*Sesbania grandiflora* (L.) Poiret	Vegetable hummingbird	Fabaceae	Indonesia	Nursery
197	*Shorea roxburghii* G. Don	White meranti	Dipterocarpacea e	India	Next to Water Tunnel Lab
198	*Simarouba glauca* DC.	Paradise tree	Simaroubaceae	North America	Biochemistry Quadrangle
199	*Spathodea campanulata* P. Beauv.	African tulip tree	Bignoniaceae	Tropical Africa	In front of Central Office Building
200	*Spondias pinnata* (L.f.) Kurz	Hog-plum	Anacardiaceae	India	Nursery
201	*Streblus asper* Lour.	Sandpaper tree	Moraceae	Sri Lanka, India	On the way to NIAS
202	*Swietenia macrophylla* King	Honduras mahogany	Meliaceae	Tropical America, Mexico, Brazil	Main Guest House
203	*Swietenia Mahagoni* (L.) Jacq.	West indian mahogany	Meliaceae	Caribbean Territories	Mahogany marg
204	*Syzygium aromaticum* (L.) Merr. & Perry	Cloves	Myrtaceae	Moluccas	Duplex Quarters
205	*Syzygium cumini* (L.) Skeels	Indian blackberry	Myrtaceae	South- & Southeast Asia	Next to Students Hostels area
206	*Syzygium jambos* (L.) Alston	Rose apple	Myrtaceae	Southeast Asia	Main Guest House
207	*Syzygium laetum* (Buch. -Ham.)	Madle	Myrtaceae	Endemic to India	Miniforest
208	*Syzygium nervosum* DC.	Rai jamun	Myrtaceae	India	Former Faculty Club
209	*Syzygium samarangese* (Bl.) Merr. & Perry	Java apple	Myrtaceae	Malay Archipelago	Nursery
210	*Tabebuia aurea* (Manso) benth. & Hook.f. ex S. Moore	Caribbean trumpet tree	Bignoniaceae	South America	Main Quadrangle
211	*Tabebuia chrysotricha* (Mart. Ex DC.) Standl.	Golden trumpet tree	Bignoniaceae	Brazil, South America	Next to Electrical Engineering
212	*Tabebuia impetiginosa* (Mart. Ex DC.) Standl.	Pink trumpet tree	Bignoniaceae	South America	In front of SID
213	*Tabebuia pallida* (Lindley) Miers	Cuban pink trumpet tree	Bignoniaceae	West Indies	Vijananapura Campus

214	*Tabebuia rosea* (Bertol) DC.	Rosy trumpet	Bignoniaceae	Tropical South America	At several places, behind MCB and in the Vijnanapura campus
215	*Tabernaemontana divericata* L. R. Br. Ex Roem. & Schult.	Pinwheel flower	Apocynaceae	India	Staff quarters
216	*Talauma mutabilis* Bl.	Kavthi Chapha-yellow	Magnoliaceae	Tropical America	Nursery
217	*Tamarindus indica* L.	Tamarind	Fabaceae	Tropical Africa	Next to MBU
218	*Tecoma castanifolia* (D. Don) Melch.	Chestnutleaf trumpet-bush	Bignoniaceae	Trop. S. America (Ecuador, Colombia)	Nursery
219	*Tectona grandis* L.f	Teak	Verbenaceae	Southeast Asia	Main Guest House, Miniforest
220	*Terminalia arjuna* (Roxb. Ex DC.) Wight & arn.	Arjun, white murdah	Combretaceae	India	Main Quadrangle
221	*Terminalia catappa* L.	Indian almond	Combretaceae	Andaman (India)	CES Quadrangle, in front of Materials Engineering
222	*Terminalia crenulata* Roth	Crocodile bark tree	Combretaceae	India, Southeast Asia	Medicinal and Aromatic Plants Garden, Gymkhana grounds
223	*Thespesia populnea* (L.) Sol. Ex Corr. Serr.	Portia tree	Malvaceae	India, Africa, Pacific Isles	NIAS
224	*Thevetia peruviana* (Pers.) Merr.	Yellow oleander	Apocynaceae	West indies	Next to High Energy Physics
225	*Tipuana tipu* (Benth.) Kuntze	Rosewood	Fabaceae	Northern Bolivia, Northern Argentina	Nursery, Main Quadrangle
226	*Toona ciliata* M. Roemer	Indian mahogany	Meliaceae	India, Southeast Asia	Behind Main Guest House
227	*Trema orientalis* (L.) Blume	Pigeon wood	Ulmaceae	India, Nepal, Polynesia, Australia, Tropical Africa	Ring road next to NIAS
228	*Vitex altissima* L.f	Chaste tree	Verbenaceae	Tropical Asia	Miniforest, Airstrip area
229	*Wrightia tinctoria* (Roxb.) R. Br.	Milky way	Apocynaceae	Indomalayan region	Next to MBU
230	*Ziziphus mauritiana* Lam.	Ber, Indian Jujube	Rhamnaceae	India	Main Quadrangle
231	*Parkinsonia aculeata* L.	Jerusalem thorn	Fabaceae	Subtropical America	Airstrip area
232	*Prosopis juliflora* (Sw.) DC.	Mesquite tree	Fabaceae	Mexico, S. America, Caribbean	Airstrip area

List of tree species in the Bangalore (Ramaswamy and Razi, 1973)

Sl. No	Botanical Name	Family	Location
1	*Casuarina equisetifolia*	Casuarinaceae	Yelahanka, Ramanagaram
2	*Salix tetrasperma*	Salicaceae	Ramanagaram
3	*Holoptelea integrifolia*	Ulmaceae	Ramanagaram, Jayachanarajendra Technological Institute.
4	*Trema orientalis*	Ulmaceae	Savandurga, Ramanagaram
5	*Broussonetia papyrifera*	Moraceae	SVR 503, 2740 Bangalore
6	*Streblus asper*	Moraceae	Savandurga, Anekal
7	*Artocarpus heterophyllus*	Moraceae	Melekote
8	*Ficus benghalensis*	Moraceae	Kanakapura
9	*Ficus benjamina*	Moraceae	
10	*Ficus racemosa*	Moraceae	Bidadi, Kanva
11	*Ficus religiosa*	Moraceae	Bannerghatta
12	*Ficus tomentosa*	Moraceae	Savandurga
13	*Santalum album*	Santalaceae	Bannerghatta, Ramanagaram, Anekal
14	*Phytolacca dioica*	Phytolaccaceae	SVR 2479 Bangalore
15	*Michelia champaca*	Magnoliaceae	SVR 574, Keshava Iyengar Road
16	*Polyalthia cerasoides*	Annonaceae	Savandurga
17	*Polyalthia longifolia*	Annonaceae	Bannerghatta
18	*Miliusa velutina*	Annonaceae	Savandurga
19	*Annona muricata*	Annonaceae	
20	*Persea americana*	Lauraceae	Hebbal
21	*Moringa oleifera*	Moringaceae	Melekote
22	*Eriobotrya japonica*	Rosaceae	
23	*Pithecellobium dulce*	Mimosaceae	Kengeri, Savandurga, Anekal, Hebbal
24	*Samanea saman*	Mimosaceae	Indian Institute of Science
25	*Albizia amara*	Mimosaceae	Savandurga, Ramanagaram
26	*Albizia lebbeck*	Mimosaceae	Bannerghatta
27	*Albizia odoratissima*	Mimosaceae	
28	*Acacia nilotica*	Mimosaceae	Ramanagaram
29	*Acacia catechu*	Mimosaceae	Ramanagaram, Kanakapura, Savandurga
30	*Acacia chundra*	Mimosaceae	Savandurga, Ramanagaram
31	*Acacia ferruginea*	Mimosaceae	Savandurga
32	*Acacia leucophloea*	Mimosaceae	Savandurga, Hebbal, Bannerghatta
33	*Dichrostachys cinerea*	Mimosaceae	Savandurga, Bannerghatta, Ramanagaram
34	*Saraca asoca*	Caesalpiniaceae	
35	*Tamarindus indica*	Caesalpiniaceae	Hebbal
36	*Amherstia nobilis*	Caesalpiniaceae	
37	*Brownea grandiceps*	Caesalpiniaceae	

38	*Bauhinia purpurea*	Caesalpiniaceae	Savandurga
39	*Bauhinia racemosa*	Caesalpiniaceae	Savandurga, Bannerghatta, Ramanagaram
40	*Bauhinia variegata*	Caesalpiniaceae	Savandurga
41	*Cassia fistula*	Caesalpiniaceae	Ramanagaram, Savandurga, Hebbal
42	*Cassia renigera*	Caesalpiniaceae	
43	*Cassia roxburghii*	Caesalpiniaceae	
44	*Cassia siamea*	Caesalpiniaceae	Bannerghatta, Savandurga
45	*Cassia surattensis*	Caesalpiniaceae	Savandurga
46	*Parkinsonia aculeata*	Caesalpiniaceae	Ramanagaram
47	*Caesalpinia coriaria*	Caesalpiniaceae	Jalahalli
48	*Delonix elata*	Caesalpiniaceae	Ramanagaram
49	*Delonix regia*	Caesalpiniaceae	
50	*Peltophorum pterocarpum*	Caesalpiniaceae	
51	*Millettia peguensis*	Fabaceae	
52	*Gliricidia sepium*	Fabaceae	
53	*Sesbania grandiflora*	Fabaceae	
54	*Dalbergia sissoo*	Fabaceae	Melekote
55	*Pterocarpus indicus*	Fabaceae	
56	*Pongamia pinnata*	Fabaceae	
57	*Erythrina suberosa*	Fabaceae	Ramanagaram
58	*Erythrina indica*	Fabaceae	Ramanagaram, Anekal
59	*Butea monosperma*	Fabaceae	
60	*Limonia acidissima*	Rutaceae	Savandurga
61	*Aegle correa*	Rutaceae	
62	*Citrus grandis*	Rutaceae	
63	*Ailanthus excelsa*	Rutaceae	Savandurga
64	*Commophora caudata*	Burseraceae	
65	*Swietenia mahogani*	Meliaceae	
66	*Melia azedarach*	Meliaceae	Ramanagaram
67	*Melia composita*	Meliaceae	Savandurga
68	*Azadirachta indica*	Meliaceae	Ramanagaram
69	*Phyllanthus acidus*	Euphorbiaceae	
70	*Phyllanthus emblica*	Euphorbiaceae	
71	*Putranjiva roxburghii*	Euphorbiaceae	
72	*Mallotus philippensis*	Euphorbiaceae	Savandurga
73	*Manihot glaziovii*	Euphorbiaceae	Venugopal 1255 Hebbal, Yaraguntaiah 1172 Hebbal, Muniswamy 1753 Hebbal
74	*Gelonium lanceolatum*	Euphorbiaceae	
75	*Euphorbia nivulia*	Euphorbiaceae	Savandurga
76	*Mangifera indica*	Anacardiaceae	Yeshwanthpur, Hebbal
77	*Anacardium occidentale*	Anacardiaceae	Srinivasiah 1363 Hebbal

78	*Spondias pinnata*	Anacardiaceae	Hebbal
79	*Schinus molle*	Anacardiaceae	
80	*Catha edulis*	Celastraceae	
81	*Cassine glauca*	Celastraceae	
82	*Sapindus laurifolius*	Sapindaceae	
83	*Nephelium litchi*	Sapindaceae	
84	*Filicium decipiens*	Sapindaceae	
85	*Muntingia calabura*	Tiliaceae	
86	*Thespesia populnea*	Malvaceae	
87	*Guazuma ulmifolia*	Sterculiaceae	
88	*Pterospermum acerifolium*	Sterculiaceae	
89	*Sterculia guttata*	Sterculiaceae	
90	*Sterculia urens*	Sterculiaceae	
91	*Firmiana colorata*	Sterculiaceae	
92	*Cola acuminata*	Sterculiaceae	
93	*Shorea talura*	Dipterocarpaceae	
94	*Cochlospermum religiosum*	Cochlospermum	
95	*Lagerstroemia speciosa*	Lythraceae	
96	*Terminalia arjuna*	Combretaceae	Anekal, Bannerghatta
97	*Terminalia bellerica*	Combretaceae	Savandurga
98	*Terminalia chebula*	Combretaceae	Savandurga
99	*Terminalia paniculata*	Combretaceae	Kanakapura, Savandurga
100	*Anogeissus latifolia*	Combretaceae	Bannerghatta, Anekal, Bannerghatta
101	*Syzygium cumini*	Myrtaceae	Melekote
102	*Syzygium jambos*	Myrtaceae	Ramanagaram, Melekote
103	*Syzygium operculatum*	Myrtaceae	
104	*Eucalyptus globulus*	Myrtaceae	
105	*Callistemon linearis*	Myrtaceae	
106	*Memecylon umbellatum*	Melastomataceae	Bannerghatta, Devanahalli
107	*Pentapanax leschenaultii*	Araliaceae	Ramanaragaram, Bannerghatta
108	*Alangium salviifolim*	Alangiaceae	Savandurga, Ramanagaram
109	*Madhuca indica*	Sapotaceae	Anekal
110	*Mimusops elengi*	Sapotaceae	
111	*Manilkara hexandra*	Sapotaceae	
112	*Diospyros melanoxylon*	Ebenaceae	
113	*Ligustrum roxburghii*	Oleaceae	
114	*Plumeria rubra L. forma acuminata*	Apocynaceae	
115	*Alstonia scholaris*	Apocynaceae	
116	*Wrightia tinctoria*	Apocynaceae	Ramanaragaram, Savandurga, Bannerghatta
117	*Wrightia tomentosa*	Apocynaceae	Savandurga

118	*Cordia alba*	Ehretiaceae	
119	*Cordia dichotoma*	Ehretiaceae	
120	*Cordia gharaf*	Ehretiaceae	Bannerghatta
121	*Citharexylum spinosum*	Verbenaceae	
122	*Tectona grandis*	Verbenaceae	Bannerghatta
123	*Premna tomentosa*	Verbenaceae	
124	*Vitex altissima*	Verbenaceae	Savandurga, Anekal, Bannerghatta
125	*Vitex negundo*	Verbenaceae	
126	*Gmelina abrorea*	Verbenaceae	Bannerghatta, Anekal
127	*Solanum verbascifolium*	Solanaceae	Bannerghatta, Anekal, Savandurga, Hebbal
128	*Millingtonia hortensis*	Bignoniaceae	
129	*Jacaranda mimosifolia*	Bignoniaceae	
130	*Sterospermum suaveolens*	Bignoniaceae	
131	*Kigelia pinnata*	Bignoniaceae	
132	*Spathodea campanulata*	Bignoniaceae	
133	*Mitragyna parviflora*	Plantaginaceae	Savandurga
134	*Ixora notoniana*	Plantaginaceae	Savandurga, Bannerghatta

List of trees species in Lalbagh (2004)

Sl. No.	Botanical Name	Native	Family
1	*Mangifera indica* Linn	India	Anacardiaceae
2	*Pleiogynium solandri* Engl	Australia	Anacardiaceae
3	*Annona cherimola* Mill	Central America, South America and West Indies	Annonaceae
4	*Annona reticulata* Linn	Neotropics	Annonaceae
5	*Polyalthia longifolia*	South India	Annonaceae
6	*Polyalthia pendula*	India	Annonaceae
7	*Alstonia macrophylla* Wall	Indonesia, Malaysia, Philippines, Sri Lanka, Thailand, Viet Nam	Apocynaceae
8	*Cerbera manghas* Linn	Java	Apocynaceae
9	*Cerbera odollam* Gaertn.	Southeast Asia, tropical Pacific Islands	Apocynaceae
10	*Plumeria alba* Aubl	Malaya	Apocynaceae
11	*Ilex paraguariensis* St. Hill	Argentina, Columbia, Paraguay, Uruguay, Brazil	Aquifoliaceae
12	*Brassaia actinophylla* F.J. Muell	Australia, New Guinea and Java	Araliaceae
13	*Agathis robusta* Bailey.	Australia	Araucariaceae
14	*Araucaria bidwillii* Hook	Australia	Araucariaceae
15	*Araucaria cookii* Hook	New Caledonia	Araucariaceae
16	*Araucaria cunninghamii*	Australia, Indonesia	Araucariaceae

17	*Araucaria excelsa* Hort	Australia	Araucariaceae
18	*Attalea cohune* Mart	Handurus	Arecaceae
19	*Caryota urens* L	Sri Lanka, India	Arecaceae
20	*Cocos nucifera* Linn	Indo-Pacific	Arecaceae
21	*Cocos schizophylla* Mart	Brazil	Arecaceae
22	*Kentia macarthurii*	New Guinea, and Australia.	Arecaceae
23	*Elaeis guineensis* Jacq	Tropical west African	Arecaceae
24	*Kentia wendlandiana*	Northern Territory, Queensland	Arecaceae
25	*Phoenix sylvestris* Roxb	India	Arecaceae
26	*Roystonea regia* O.F. Cook	Cuba, Panama	Arecaceae
27	*Bignonia crispa* Buch Han		Bignoniaceae
28	*Bignonia megapotamica*	Tropical America	Bignoniaceae
29	*Crescentia cujete* Linn	Tropical America	Bignoniaceae
30	*Jacaranda mimosifolia*	Argentina, Bolivia	Bignoniaceae
31	*Kigelia pinnata* Jacq	Tropical Africa	Bignoniaceae
32	*Millingtonia hortensis* L	Myanmar	Bignoniaceae
33	*Parmentiera cereifera*	Panama	Bignoniaceae
34	*Spathodea campanulata*	Tropical Africa	Bignoniaceae
35	*Stereospermum chelonoides*	Myanmar	Bignoniaceae
36	*Stereospermum suaveolens*	India, Burma	Bignoniaceae
37	*Stereospermum xylocarpum*	India	Bignoniaceae
38	*Stereospermum colais*	India, Burma	Bignoniaceae
39	*Tabebuia avellanedae*	Argentina	Bignoniaceae
40	*Tabebuia rosea*	Tropical South America	Bignoniaceae
41	*Tabebuia spectabilis*	India, Venezula	Bignoniaceae
42	*Tabebuia triphylla*	Caribbean; North America	Bignoniaceae
43	*Adansonia digitata*	Tropical Africa	Bombacaceae
44	*Bombax malabaricum*	India	Bombacaceae
45	*Bombax ellipticum*	Mexico	Bombacaceae
46	*Bombax scopulorum*	China, India	Bombacaceae
47	*Ceiba pentandra*	South & Central America	Bombacaceae
48	*Pachina insigne*	India	Bombacaceae
49	*Cordia myxa* L	India, Tropical America	Boraginaceae
50	*Canarium commune*	Indonesia, Papau New Guinea, New Britain, New Ireland	Burseraceae
51	*Garuga pinnata*	India, Malaya	Burseraceae
52	*Amherstia nobilis* Wall	Burma	Fabaceae
53	*Bauhinia hookeri* Mull	Australia	Fabaceae
54	*Bauhinia krugii* Linn	India, Burma	Fabaceae
55	*Bauhinia purpurea* Linn	India, Burma,Vietnam	Fabaceae

56	*Bauhinia variegata* Linn	Indian, China	Fabaceae
57	*Caesalpinia coriaria*	Caribbean, Mexico, Central America, northern South America.	Fabaceae
58	*Cassia bacillaris* Gaertn	India Malaya	Fabaceae
59	*Cassia javanica* Linn	Southeast Asia	Fabaceae
60	*Cassia renigera*Wall	Burma	Fabaceae
61	*Cassia siamea* Lam	Malaya, Asia	Fabaceae
62	*Colvillea racemosa*	Madagascar	Fabaceae
63	*Hardwickia binata*	India	Fabaceae
64	*Hymenaea courbaril*	Central and South America	Fabaceae
65	*Peltophorum ferrugineum*	Australia	Fabaceae
66	*Poinciana regia* Boj	Madagascar	Fabaceae
67	*Saraca cauliflora* Baker	India, Malaya	Fabaceae
68	*Saraca thaipingensis*	Malaya	Fabaceae
69	*Tamarindus indica* Linn	Tropical Africa	Fabaceae
70	*Garcinia cambogia* Roxb	India	Clusiaceae
71	*Garcinia indica* Choisy	India	Clusiaceae
72	*Garcinia livingstonei*	Tropical Africa	Clusiaceae
73	*Mammea americana* Linn	West Indies	Clusiaceae
74	*Ochrocarpus longifolius*	India	Clusiaceae
75	*Cochlospermum gossypium*	India, Burma, Thailand	Cochlospermaceae
76	*Alangium lamarckii*	India	Cornaceae
77	*Cupressus benthamii*	Mexico	Cupressaceae
78	*Cupressus funebris*	China	Cupressaceae
79	*Thuja orientalis* Linn	China, Japan	Cupressaceae
80	*Dillenia indica* Linn	Southeast Asia, Southwest China	Dilleniaceae
81	*Shorea talura* Roxb	India, Burma	Dipterocarpaceae
82	*Diospyros discolor* Willd	African Tropics	Ebenaceae
83	*Diospyros embryopteris*	Sri Lanka, Western Ghats	Ebenaceae
84	*Diospyros macrophylla*	Indomalaysia	Ebenaceae
85	*Diospyros mespiliformis*		Ebenaceae
86	*Aleurites fordii* Hemsl	Central Asia	Euphorbiaceae
87	*Aleurites trispernma*	Blanco Philippines	Euphorbiaceae
88	*Anda gomesii* A. Juss	South Brazil	Euphorbiaceae
89	*Hura crepitans* Linn	Tropical America	Euphorbiaceae
90	*Mallotus philippensis*	Australia, Tropical and Subtropical Asia	Euphorbiaceae
91	*Mischodon zeylanicus*	Sri Lanka, S. India, Andaman	Picrodendraceae
92	*Phyllanthus emblica*	Tropical, Subtropical Asia	Phyllanthaceae
93	*Putranjiva roxburghii*	Tropical Asia	Putranjivaceae

94	*Sapium insigne* Frimen	India	Euphorbiaceae
95	*Trewia nudiflora* Linn	India to Philippines	Euphorbiaceae
96	*Erythrina umbrosa*	Neotropics, India	Fabaceae
97	*Erythrina suberosa*	India, SE Asia	Fabaceae
98	*Aberia caffra* Harv. R. Sonal	Africa, Australia	Flacourtiaceae
99	*Flacourtia cataphracta*		Flacourtiaceae
100	*Asparagus plumosus*		Liliaceae
101	*Lafoensia microphylla*	Brazil	Lythraceae
102	*Lagerstroemia flos-reginae*		Lythraceae
103	*Lagerstroemia thorelli*		Lythraceae
104	*Lagerstroemia tomentosa*	Burma	Lythraceae
105	*Michelia champaca*	India, Malaysia	Magnoliaceae
106	*Magnolia grandiflora*	Tropical America	Magnoliaceae
107	*Hiptage madablota*	America	Malpighiaceae
108	*Thespesia populnea*	India, Africa, Pacific Isles	Malvaceae
109	*Amoora rohituka*	Asian Tropics	Meliaceae
110	*Cedrela odorata* Linn	Asutralia White Cedar	Meliaceae
111	*Cedrela toona*	Malaya, Australia	Meliaceae
112	*Melia umbraculifera*	India	Meliaceae
113	*Swietenia mahagoni* Linn	Caribbean Territories	Meliaceae
114	*Swietenia macrophylla*	Tropical America, Mexico, Brazil	Meliaceae
115	*Acacia ferruginea* DC	Sri Lanka	Fabaceae
116	*Adenanthera pavonina*	Australia	Fabaceae
117	*Albizia lebbeck* Benth	Asia	Fabaceae
118	*Albizia richardiana*	Madagascar	Fabaceae
119	*Calliandra brevipes*	Brazil	Fabaceae
120	*Pithecellobium saman*	Bolivia, Brazil, Ecuador, Paraguay and Peru	Fabaceae
121	*Prosopis pubescens*	California, Mexico	Fabaceae
122	*Artocarpus integrifolia* L	India, Malya	Moraceae
123	*Ficus benjamina* L	India, Malaya	Moraceae
124	*Ficus benghalensis*	India	Moraceae
125	*Ficus cunninghamii*	India Burma	Moraceae
126	*Ficus elastica* Roxb	India	Moraceae
127	*Ficus glomerata*	India	Moraceae
128	*Ficus krishnae*		Moraceae
129	*Ficus religiosa* L	India, Burma	Moraceae
130	*Streblus asper*	Sri Lanka, India	Moraceae
131	*Barringtonia acutangula*	Southeast Asia, N. Australia	Myrtaceae

132	*Callistemon pinifolius*	New South Wales	Myrtaceae
133	*Eucalyptus tereticornis*	Australia	Myrtaceae
134	*Eugenia fragrans*	S. Florida to Trop. America	Myrtaceae
135	*Eugenia excelsa*	Australia	Myrtaceae
136	*Eugenia jambolana*	South & Southeast Asia	Myrtaceae
137	*Melaleuca leucadendron*	Australia	Myrtaceae
138	*Averrhoa carambola*	Sri Lanka	Oxalidaceae
139	*Andira fraxinifolia*	Brazil	Fabaceae
140	*Andira inermis*	Asian tropics	Fabaceae
141	*Butea frondosa*	Indomalesia	Fabaceae
142	*Dalbergia lanceolaria*	India	Fabaceae
143	*Dalbergia sissoo*	India	Fabaceae
144	*Gliricidia maculata*		Fabaceae
145	*Milletia ovalifolia*	Burma	Fabaceae
146	*Pterocarpus acerifolium*	Indian Origin, Java	Fabaceae
147	*Pterocarpus echinatus*	African Tropic	Fabaceae
148	*Pterocarpus indicus*	India, Burma	Fabaceae
149	*Pterocarpus marsupium*	India	Fabaceae
150	*Tipuana tipu* Benth	S. America	Fabaceae
151	*Juniperus procera*	African Tropic	Cupressaceae
152	*Bursaria spinosa*	Asian Tropic	Pittosporaceae
153	*Podocarpus taxifolia*	Australia	Podocarpaceae
154	*Coffea arabica Linn*	Ethiopia	Rubiaceae
155	*Gardenia jasminoides*	China, India to Japan	Rubiaceae
156	*Gardenia latifolia*	India	Rubiaceae
157	*Nauclea parvifolia*	Indian Subcontinent to Myanmar	Rubiaceae
158	*Stephegene diversifolia*	Bruma	Rubiaceae
159	*Filicium decipiens* Thw.	India	Sapindaceae
160	*Nephelium lappaceum*	Indonesia, Malaysia, Singapore, Thailand, Vietnam	Sapindaceae
161	*Nephelium litchi*	China	Sapindaceae
162	*Nephelium longan*	China	Sapindaceae
163	*Sapindus trifoliatus*	India	Sapindaceae
164	*Sapindus emarginatus*	India, Sri Lanka	Sapindaceae
165	*Achras sapota*	Central America, Mexico	Sapotaceae
166	*Bassia latifolia*	India	Sapotaceae
167	*Chrysophyllum cainito*	Belize, Caribbean	Sapotaceae
168	*Mimusops elengi*	India	Sapotaceae
169	*Cola acuminata*		Sterculiaceae
170	*Guazuma tomentosa*	Tropical America	Sterculiaceae

171	*Heritiera macrophylla*	India (Arunachal Pradesh, Assam, Meghalaya), Indochina, Myanmar (Burma), Thailand, Vietnam	Sterculiaceae
172	*Pterospermum acerifolium*	India,	Sterculiaceae
173	*Sterculia foetida*	India, Burma	Sterculiaceae
174	*Berria quinquelocularis*	Zelon	Tiliaceae
175	*Cithaexylum substratum*	Asian tropic	Verbenaceae
176	*Tectona grandis*	Southeast Asia	Verbenaceae
177	*Vitex peduncularis*	Burma	Verbenaceae
178	*Guaiacum officinale*	West Indies	Zygophyllaceae

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List of common tree species found in Bangalore (based on field work)

Sl.No	**Botanical Name**	**Family**	**Native**
1	*Acacia auriculiformis*	Fabaceae	Australia
2	*Millingtonia hortensis*	Bignoniaceae	Myanmar
3	*Spathodea campanulata*	Bignoniaceae	Tropical Africa
4	*Bauhinia variegata*	Fabaceae	India, China
5	*Polyalthia longifolia*	Annonaceae	South India
6	*Tabebuia aurea*	Bignoniaceae	South America
7	*Delonix regia*	Fabaceae	Madagascar
8	*Peltophorum pterocarpum*	Fabaceae	Sri Lanka, Sutheast Asia
9	*Roystonea regia*	Arecaceae	Cuba
10	*Pongamia pinnata*	Fabaceae	India
11	*Cocos nucifera*	Arecaceae	Indo-Pacific
12	*Murraya koenigii*	Rutaceae	India, Sri Lanka, China, Laos, Myanmar
13	*Casuarina equisetifolia*	Casuarinaceae	Malaysia, S. Asia, Australia
14	*Tectona grandis*	Verbenaceae	Southeast Asia
15	*Mangifera indica*	Anacardiaceae	India
16	*Grevillea robusta*	Proteaceace	Australia
17	*Ficus religiosa*	Moraceae	India, Burma
18	*Swietenia macrophylla*	Meliaceae	Tropical America, Mexico, Brazil
19	*Jacaranda mimosifolia*	Bignoniaceae	Brazil

20	*Eucalyptus tereticornis*	Myrtaceae	Australia
21	*Albizia lebbeck*	Fabaceae	Asia
22	*Bauhinia purpurea*	Fabaceae	India, Burma, Vietnam
23	*Bombax malabaricum*	Bombacaceae	India
24	*Callistemon lanceolatus*	Myrtaceae	Australia
25	*Cassia fistula*	Fabaceae	India, China, Southeast Asia
26	*Cassia spectabilis*	Fabaceae	Tropical Southeast Asia
27	*Castanospermum australe*	Fabaceae	Australia
28	*Dolichandrone platycalyx*	Bignoniaceae	East Africa
29	*Enterolobium cyclocarpum*	Fabaceae	Mexico, Central and South America
30	*Lagerstroemia speciosa*	Lythraceae	India (Western Ghats)
31	*Michelia champaca*	Magnoliaceae	India, Malaysia
32	*Milletia ovalifolia*	Fabaceae	Myanmar (Burma)
33	*Parkia biglandulosa*	Fabaceae	Malaysia
34	*Samanea saman*	Fabaceae	Tropical America, West Indies
35	*Saraca asoca*	Fabaceae	India, Sri Lanka
36	*Tabebuia rosea*	Bignoniaceae	Tropical South America
37	*Tabebuia avellanedae*	Bignoniaceae	South America
38	*Tabebuia argentea*	Bignoniaceae	Brazil
39	*Plumeria obtusa* L. var. obtusa	Fabaceae	West Indies, Mexico
40	*Thespesia populnea*	Malvaceae	Coastal forest of India and Burma, Tropical Asia, Africa
41	*Solanum grandiflorum*	Solanaceae	South America
42	*Butea monosperma*	Fabaceae	India
43	*Psidium guajava* L.	Myrtaceae	Tropical America

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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.

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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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 socioeconomic 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

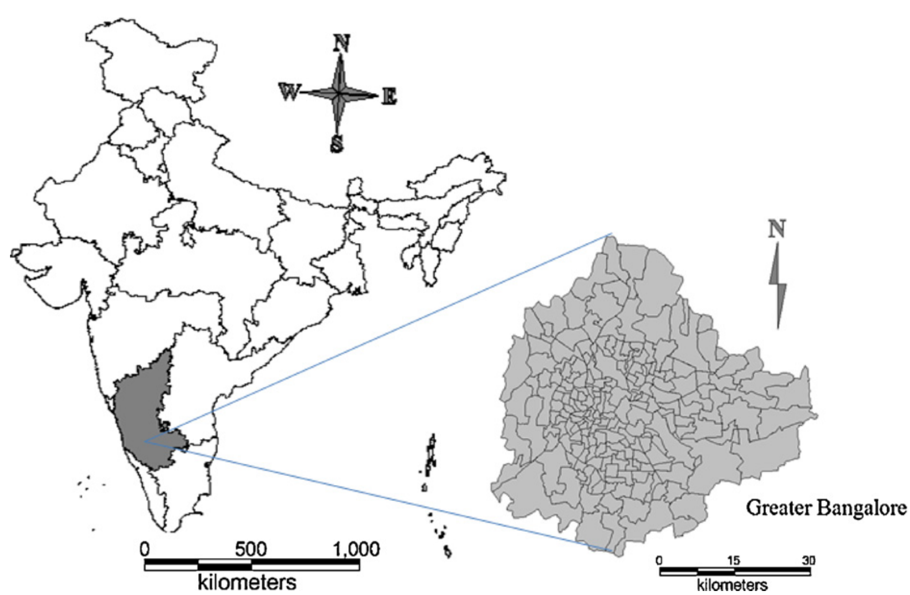


Fig. 1. Study area: Greater Bangalore.

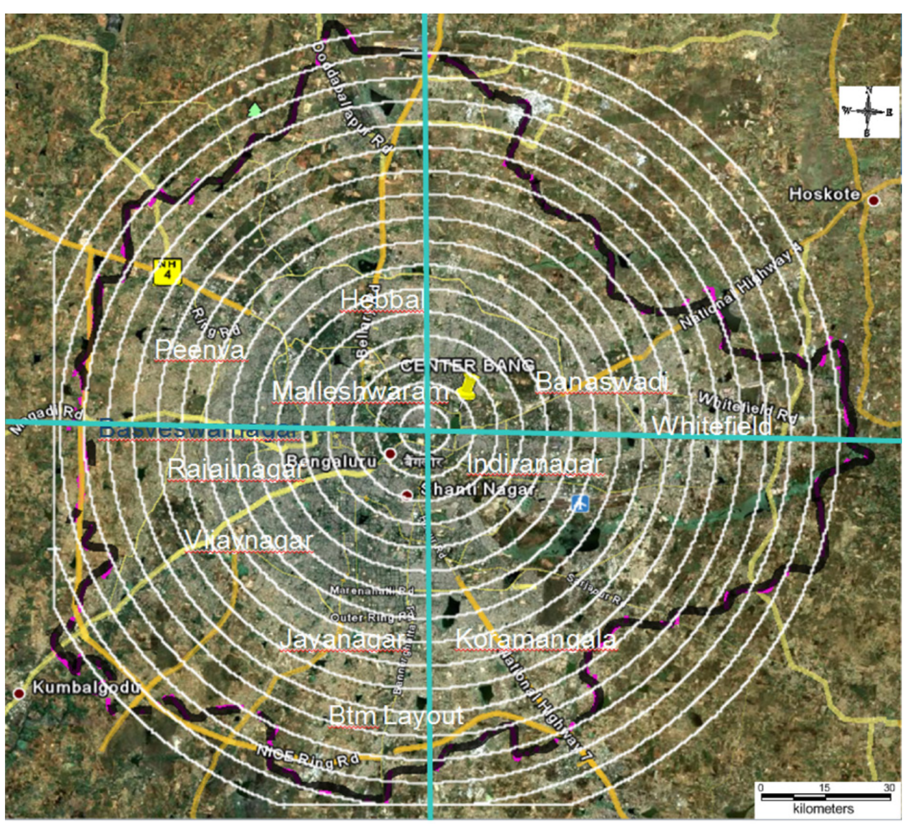
Table 1
Materials used in the analysis.

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 $\mathrm{AM} = \sum_{j=1}^{n} x_{ij} \left[\left(\frac{a_{ij}}{\sum_{j=1}^{a} a_{ij}} \right) \right]$	≥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 $\mathrm{LSI} = \frac{e_i}{\min e_i}$ 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 $\mathrm{CLUMPY} = \begin{bmatrix} \frac{G_i - P_i}{P_i} \quad \text{for} \quad G_i < P_i \& P_i < 5, \text{ else} \\ \frac{G_i - P_i}{1 - P_i} \end{bmatrix}$ $G_i = \left(\frac{g_{ii}}{\sum_{k=1}^{m} g_{ii}} - \min e_i \right)$ g_{ii} = number of like adjacencies (joins) between pixels of patch type (class) I based on the *double-count* method. g_{ik} = number of adjacencies (joins) between pixels of patch types (classes) i and k based on the *double-count* 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≤ CLUMPY ≤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 $AI = \left[\sum_{i=1}^{m} \left(\frac{g_{ii}}{\max \to g_{ii}} \right) P_i \right] \times 100$ 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≤AI≤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 $\mathrm{IJI} = \frac{-\sum_{i=1}^{m} \sum_{k=i+1}^{m} [(e_{ik}/E) \ln(e_{ik}/E)]}{\ln(0.5[m(m-1)])} \times 100$ 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 ≤ IJI ≤ 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 sq km and lies between the latitude 12°39′00″ to 13°13′00″N and longitude 77°22′00″ to 77°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

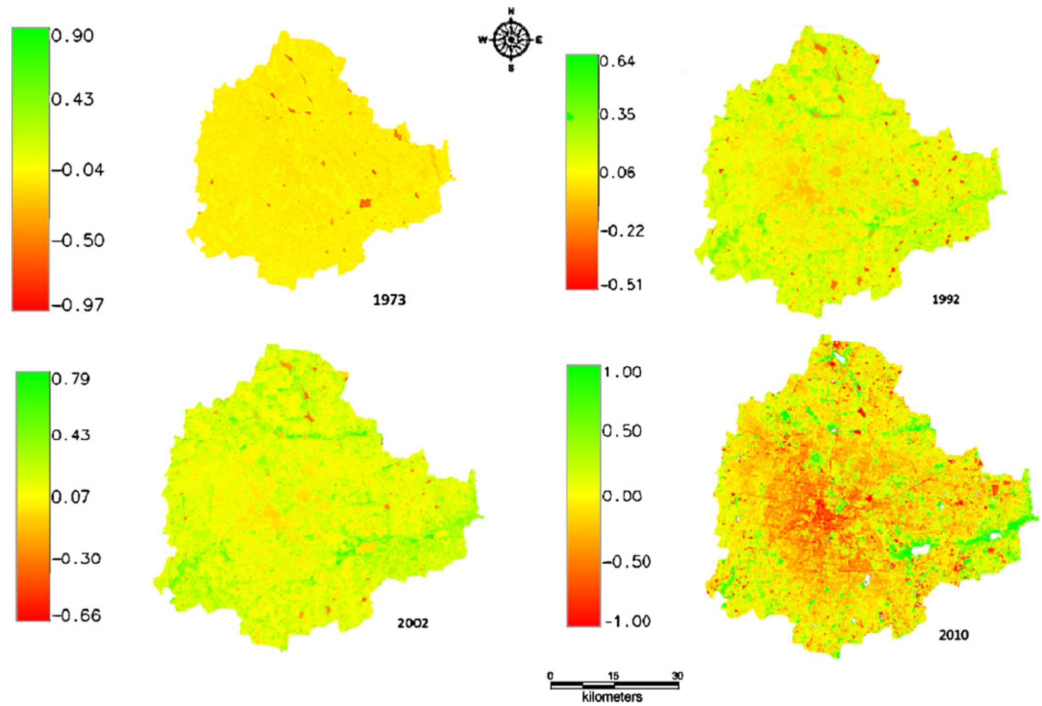


Fig. 3. Land cover changes from 1973 to 2010.

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) toposheets 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→	Urban		Vegetation		Water		Others	
Year ↓	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.

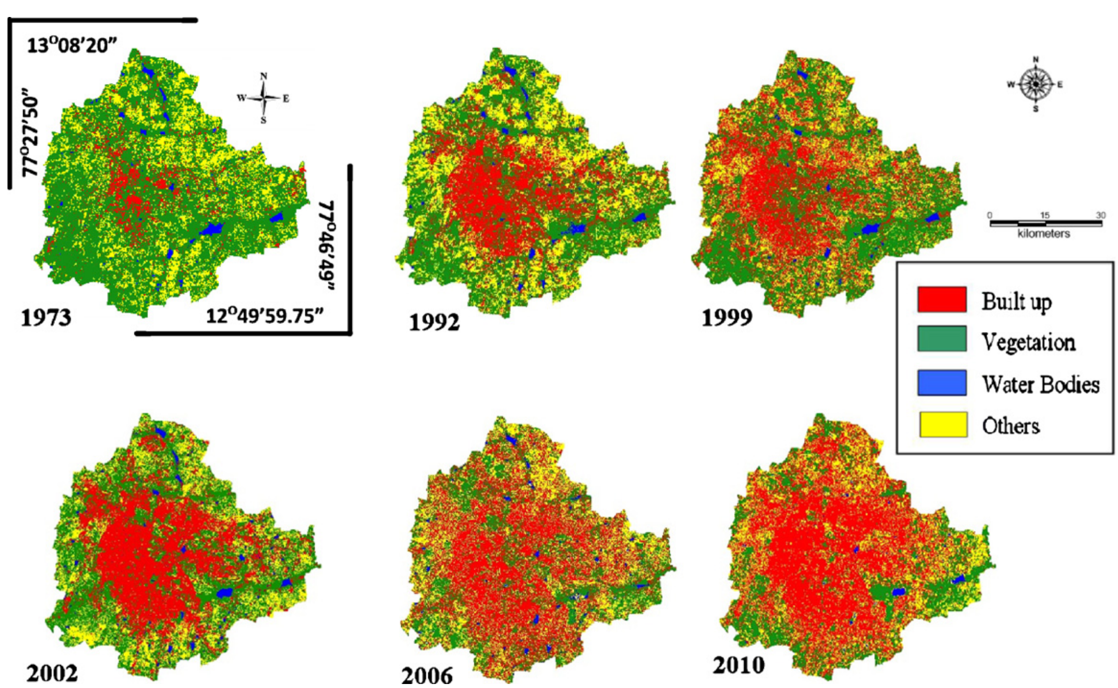


Fig. 4. Land use changes in Greater Bangalore.

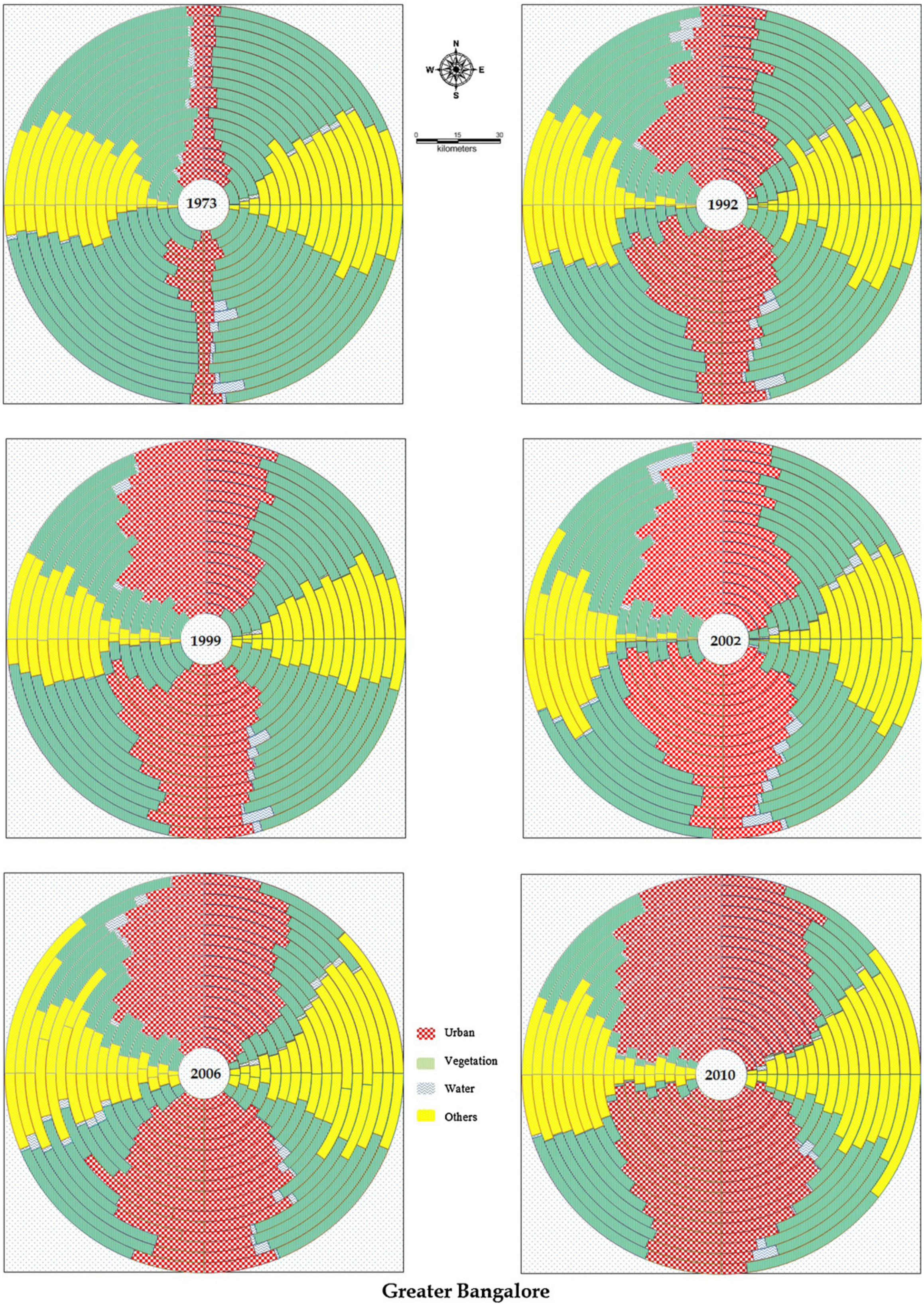


Fig. 5. Zone-wise and Gradient-wise temporal land use.

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

Further each zone was divided into concentric circle of incrementing 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.

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

where *Pi* 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 $\log n$.

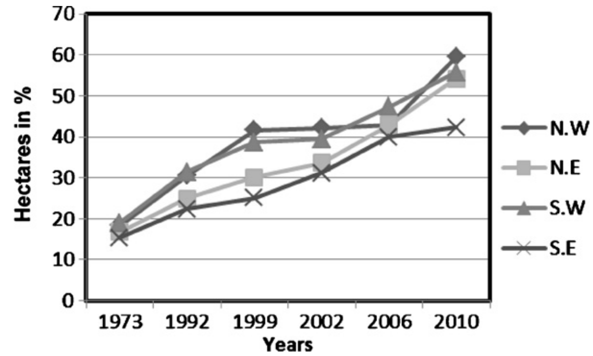


Fig. 6. Built up density across years from 1973 to 2010.

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

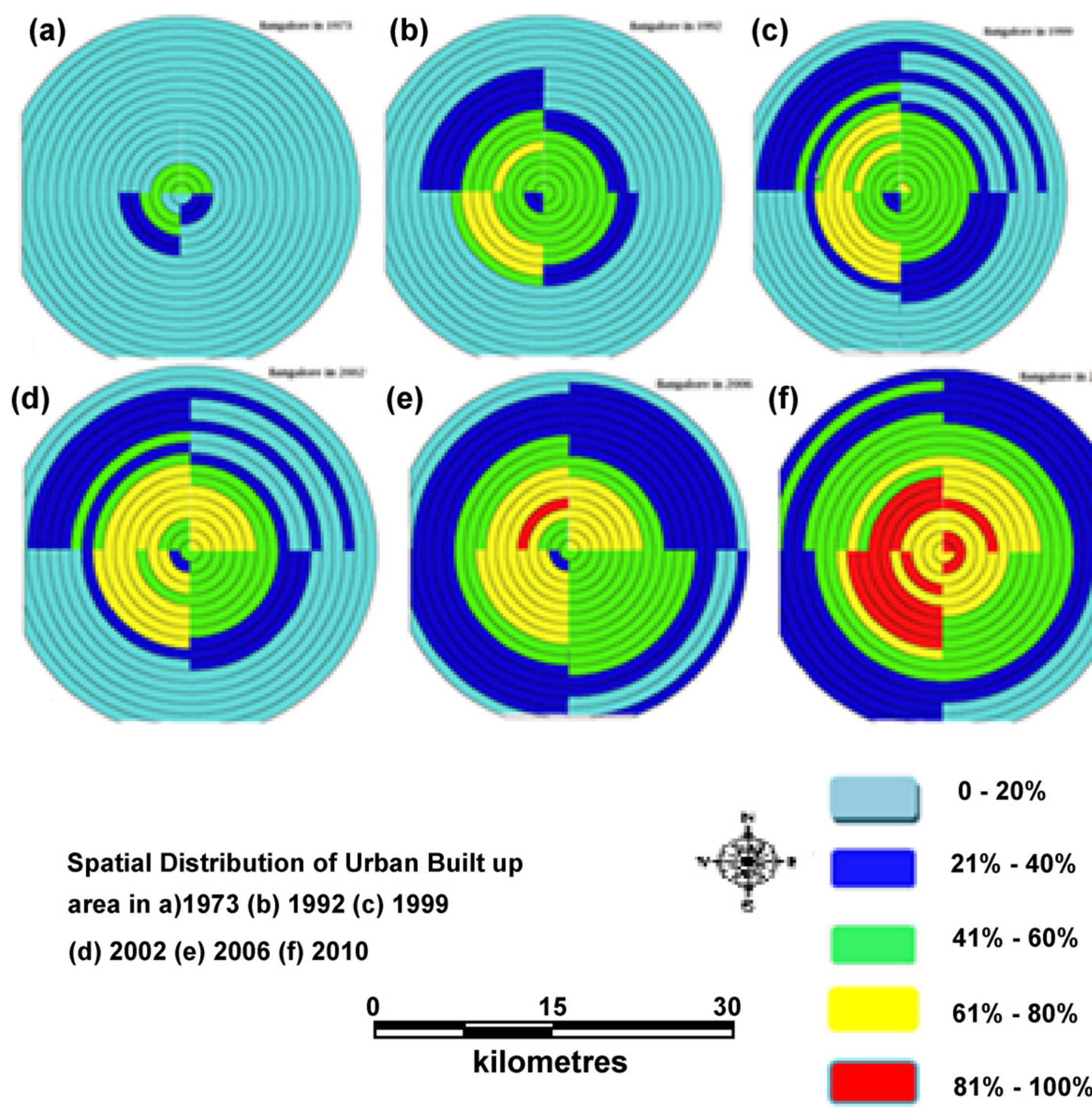


Fig. 7. Gradient analysis of Greater Bangalore- Builtup density circlewise and zonewise.

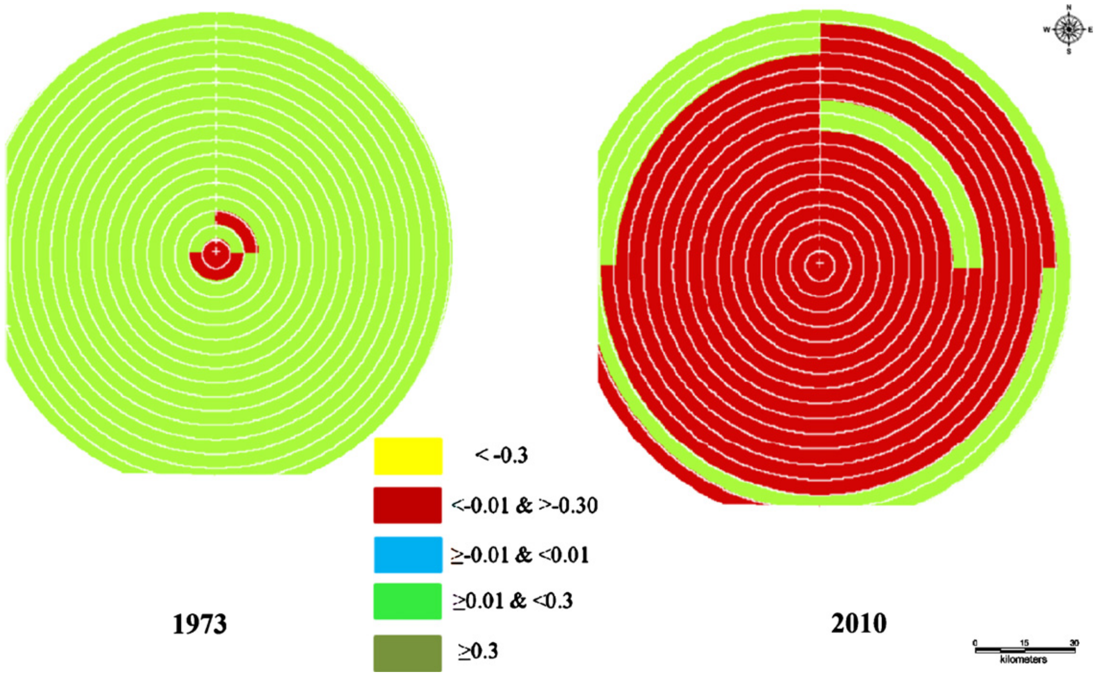


Fig. 8. NDVI gradients – circlewise and zone wise.

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

$$\alpha\,\text{density} = \frac{\text{total population}}{\text{total built up}} \tag{2}$$

$$\beta\,\text{density} = \frac{\text{total population}}{\text{total geographic area}} \tag{3}$$

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, interspersion 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

a. 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.
b. 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

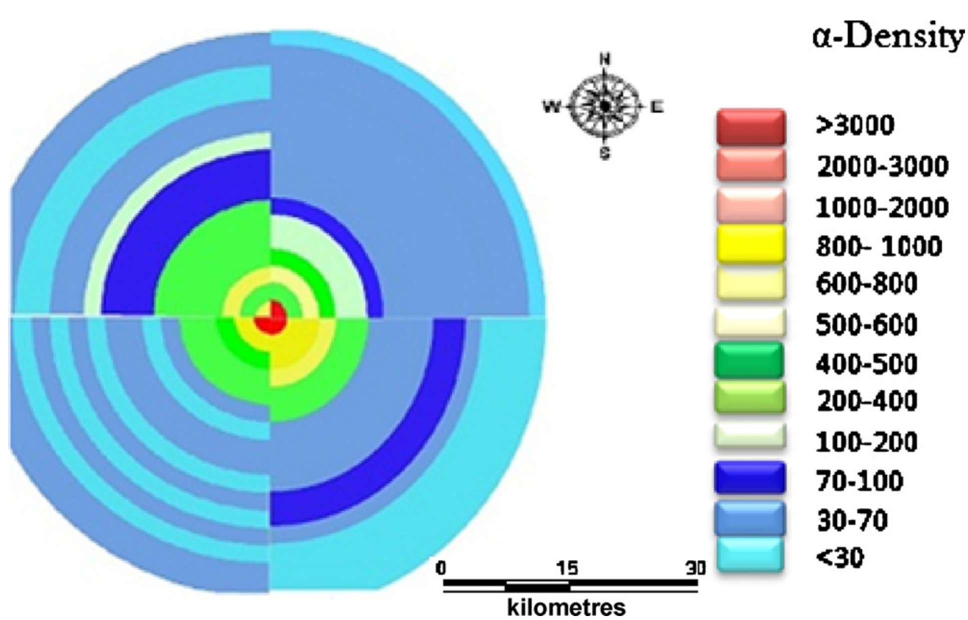


Fig. 9. Alpha density– zonewise for each local regions.

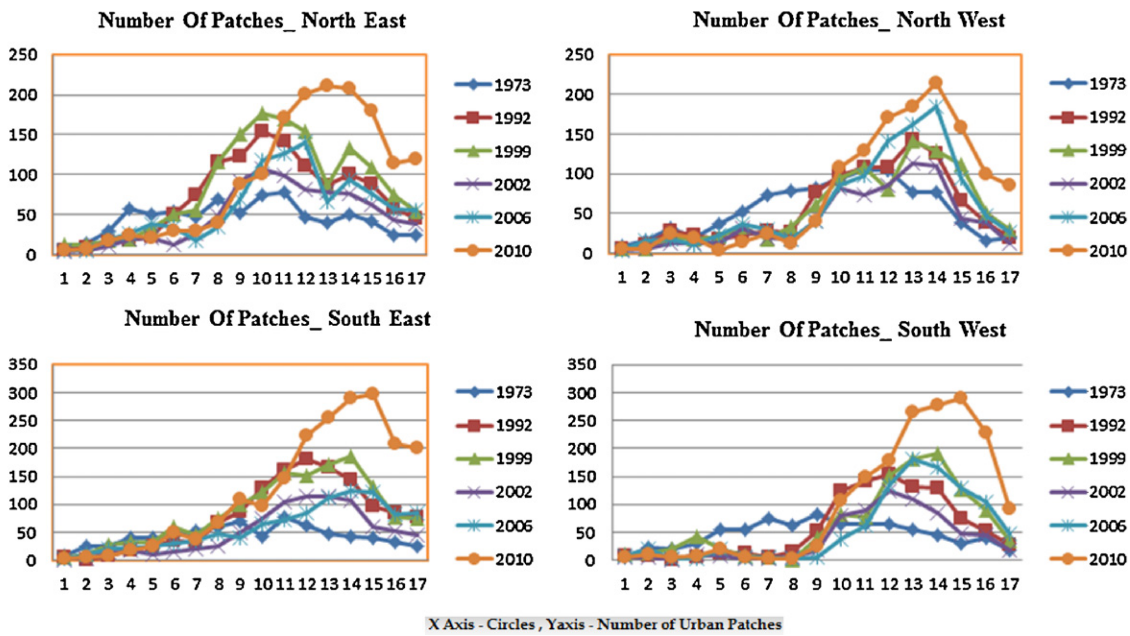


Fig. 10. Number of patches – direction-wise/circle-wise.

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

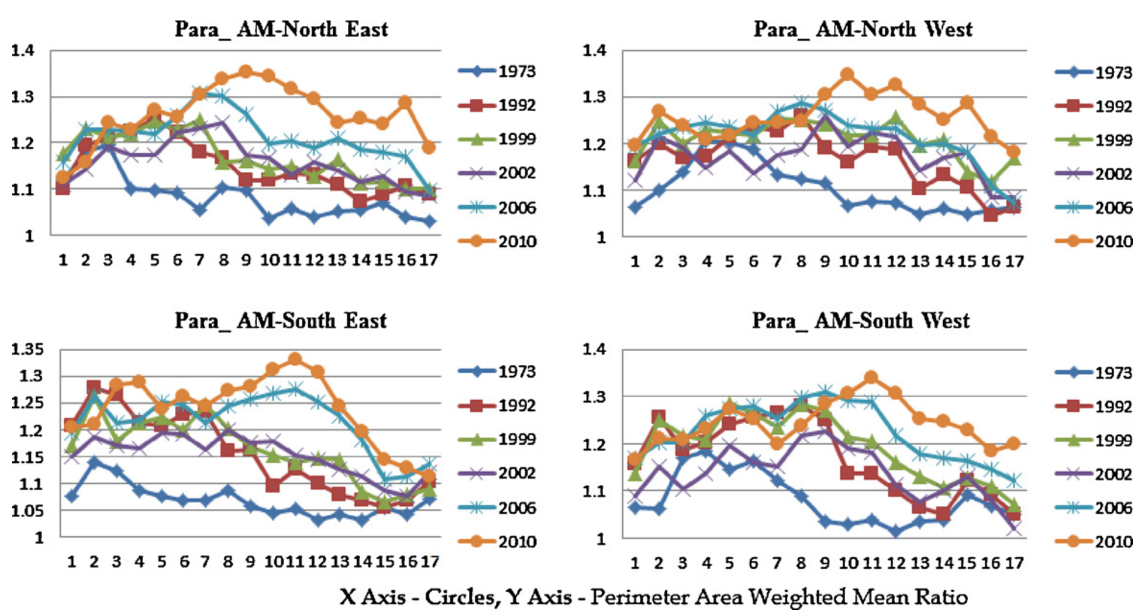


Fig. 11. PARA_AM – direction-wise/circle-wise.

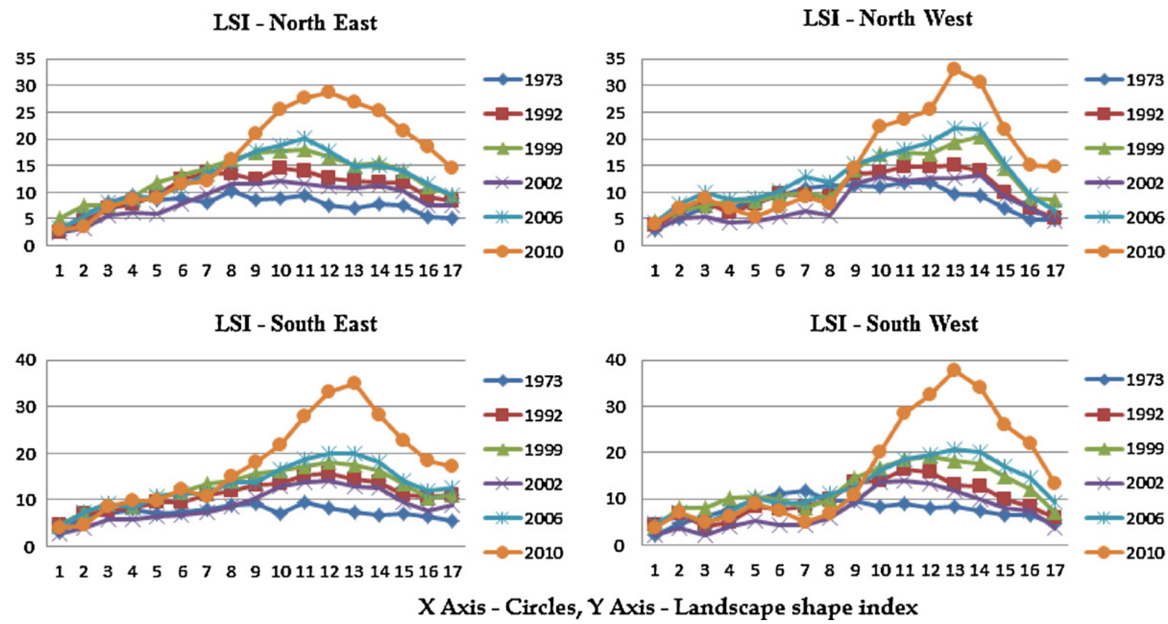


Fig. 12. LSI – direction-wise/circle-wise.

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

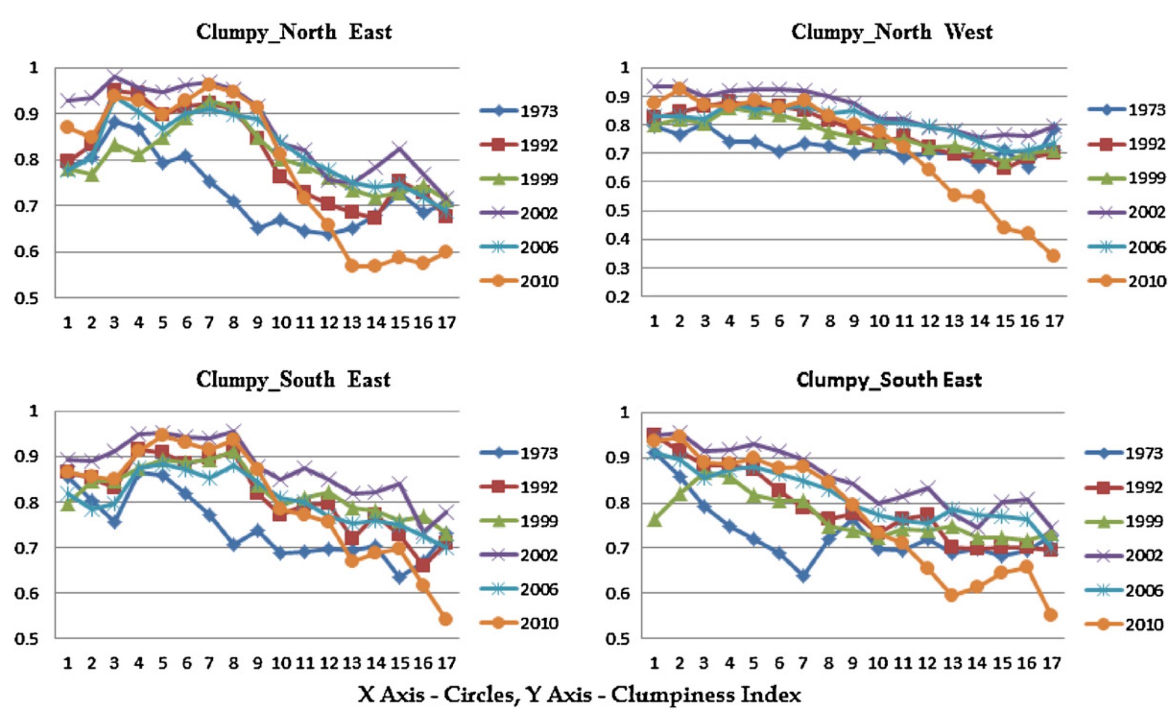


Fig. 13. Clumpiness Index – direction-wise/circle-wise.

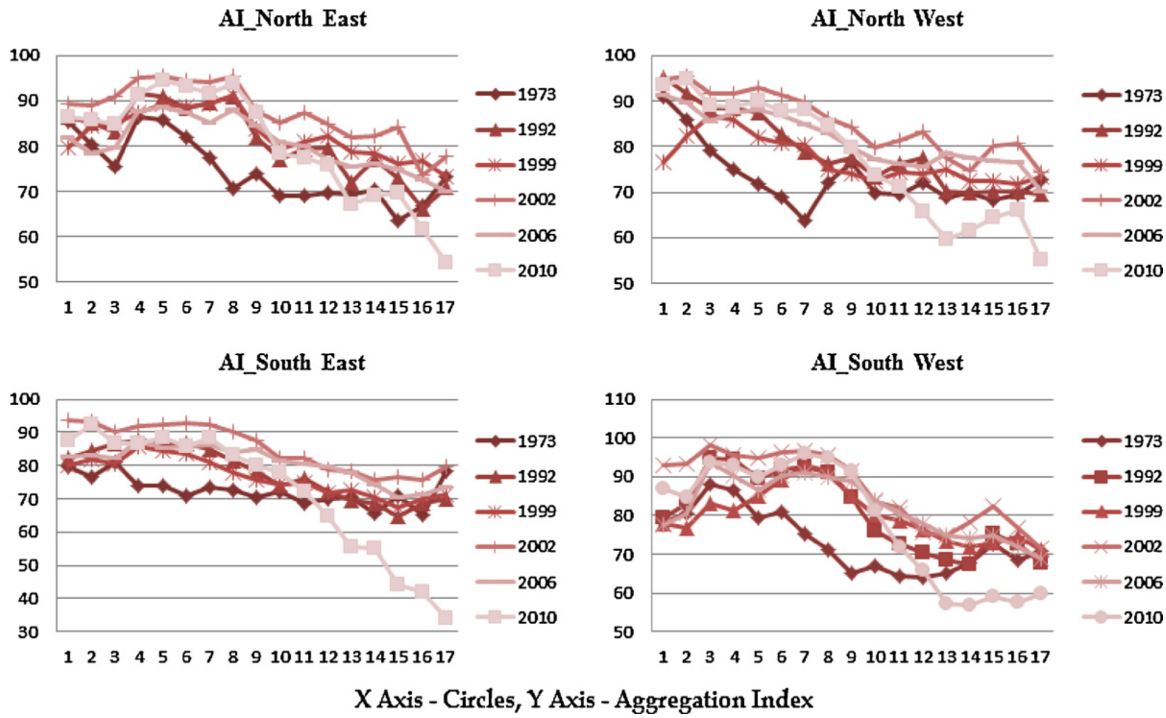


Fig. 14. Aggregation Index – direction-wise/circle-wise.

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

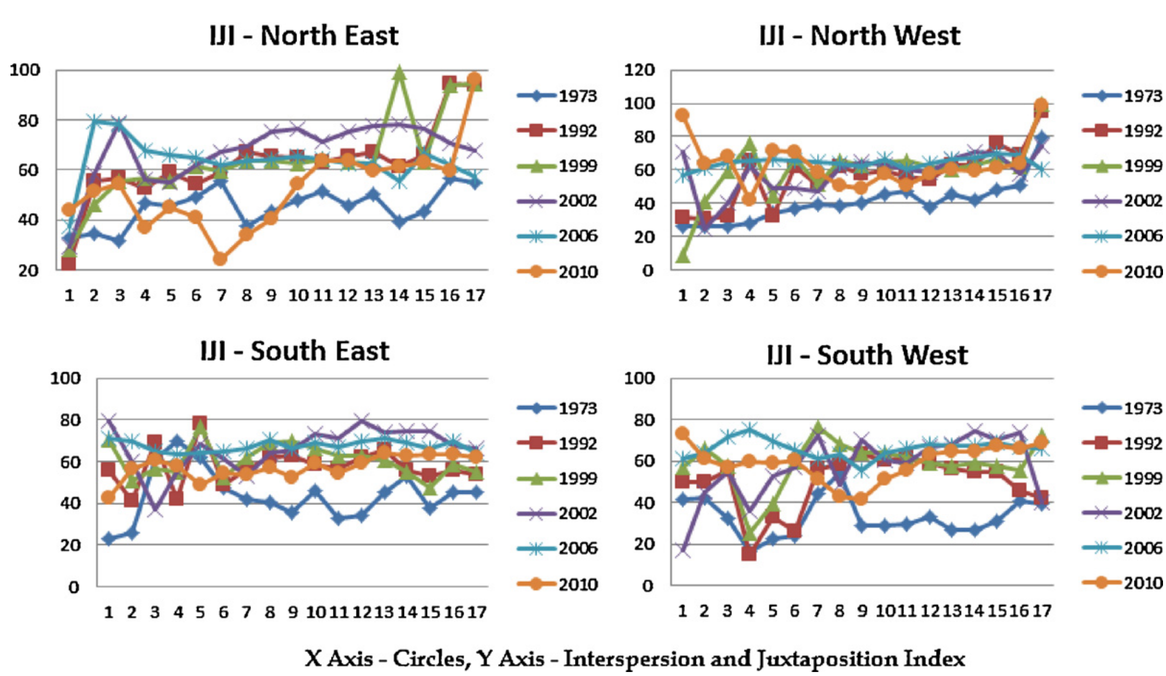


Fig. 15. Interspersion and Juxtaposition – direction-wise/circle-wise.

(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 Southwest 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 charecterised 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 km^2. 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 km^2 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.

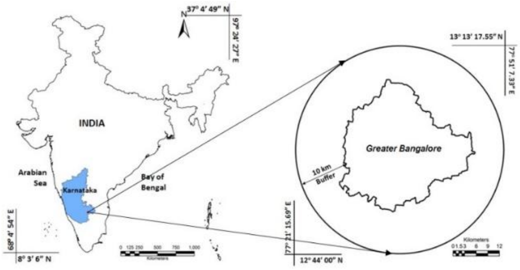

Fig.1. Study Area- greater Bangalore with 10 km buffer

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 Markovain random process properties with various constrains 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

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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,

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

Where: R(i) = suitability value in cell(i), a = particular driver map, A = the number of driver maps,
Wa= the weight of driver map $\boldsymbol{a}$, 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 predicated 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.

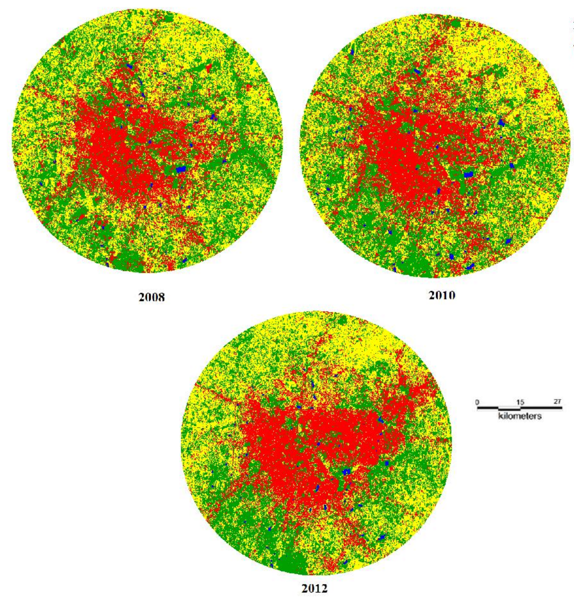

Fig. 2. Land use transitions during 2008 to 2012

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.

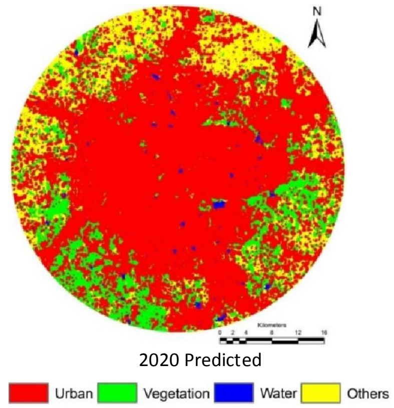

Fig.5. Predicted land use map for 2020

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

Table 3: Land use 2020

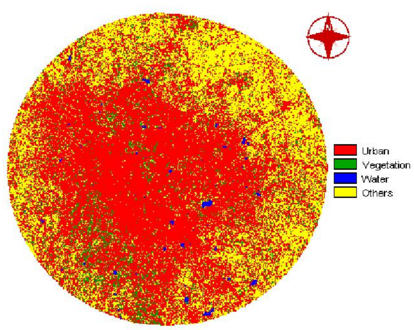

Fig. 6: Predicted growth of Bangalore by 2020 using LCM

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.

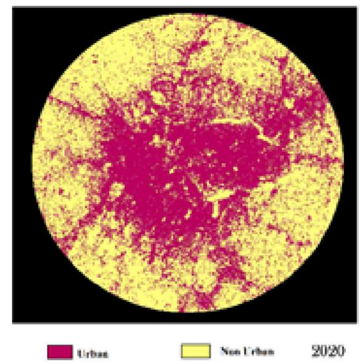

Fig. 7: Predicted growth of Bangalore by 2020 using Geomod

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.

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