Indian Forester, 143 (4) : 307-320, 2017
http://www.indianforester.co.in

ISSN No. 0019-4816 (Print)
ISSN No. 2321-094X (Online)

GREEN SPACES IN BENGALURU: QUANTIFICATION THROUGH GEOSPATIAL TECHNIQUES

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ABSTRACT

Green spaces in the urban landscape include public and private lands (parks, streets, backyards) consisting of trees, shrubs and, herbs, etc. COP21– recently concluded United Nations Climate conference at Paris acknowledges the need to limit warming to well below 2 °C (3.6 ° F) above pre-industrial levels and the need to try to limit the temperature increase to 1.5 °C through carbon neutrality and de-carbonisation mechanisms to avoid the worst climate impacts. World Health Organization stipulates minimum green space of 9.5 m^2/person considering the services (oxygen, moderation of micro climate) and goods in the urban environment. Estimates indicate that about 6 kg of carbon is sequestered by a tree annually. Per capita respiratory carbon ranges from 192 to 328 kg/year depending on physiology of humans (525-900 gms/day/person depending on the age and physiology). Land use analysis show that the spatial extent of tree vegetation in Bangalore is 100.02 km^2. (14.08%) and total number of trees in Bangalore is about 14,78,412 trees. Computation of trees per person show that Bangalore has one tree for every 7 persons, which highlights of crossing the threshold of urbanization. Overall improvements in human well-being in urban areas necessitate at least 33% green space that ensures at least 1.15 trees/person.

Key words: Bengaluru, Bangalore, Trees, Tree density, Vegetation density, Trees per person.

Introduction

Green spaces in urban environment aid in maintaining the biodiversity through the sustenance of ecological processes. Green spaces predominantly with vegetation plays a vital role in an urban ecosystem by moderating microclimate, apart from sequestration of greenhouse gases (CO_2, etc.) and also aid in the percolation of water. Urban vegetation includes trees, shrubsand herbs in public and private lands (parks, streets, backyards) in the landscape dominated by paved surface. Enormous environmental, ecological, economic and social benefits from urban vegetation documented that include removal of air pollutants such as Sulphur dioxide (SO_2), Nitrogen oxides (NOx), Carbon dioxide (CO_2), particulate matter by leaf stomata and by the leaf surfaces especially if their surfaces are waxy, spiny or hairy (Li *et al*., 2014; Vailshery *et al*., 2013; Ghose *et al.*, 2005; Khan and Abbasi, 2000; Chaturvedi *et al*., 2013; Ghauri *et al*.,2007; Yang *et al*., 2005; Harris and Manning, 2010; Dwivedi *et al*., 2009; Inkilainen *et al*., 2013; Secon, 2010), dust removal by leaves of Mango (*Mangifera indica*), Ashoka (*Polyalthia longifolia*), Pongamia (*Derris indica*) and Umbrella - *Thespepsia populnea* (Shetye and Chaphekar,1980*;* Ghose *et al*., 2005). Trees act as a barrier which helps to reduce noise pollution by absorbing and blocking urban noise, reducing stress for people in the region (Zannin *et al*., 2006). Furthermore, urban trees function as natural 'air conditioners' which influences the use of local energy use (electricity and cooling) in the residential areas and offices (Sudha and Ravindranath, 2000).

Urban vegetation helps in the hydrologic cycle as about 10-18% of the precipitation absorbed by leaves gets back to the atmosphere through evaporation. Significant part of precipitation gets percolated through plant roots, which help in recharging ground water aquifers. Due to microbial interactions between soil and plant roots, the soil is porous and permeable, which allows infiltration of water, aiding in recharging groundwater aquifers and sub-surface regions. Infiltration to an extent of 40-45% (of precipitation) in the landscape covered with the native vegetation also helps in mitigating flooding episodes. The extent of vegetation cools the urban climate, which however depends upon the type and composition of the vegetation. Reports reveal unshaded suburban area is approximately 2.5^{0}C warmer than compared to the open rural area and unshaded suburban site warmer by 1^{0}C compared to the shaded area.

Ability to reduce the air temperature depends on the tree size and canopy characteristics. World Health

Inventorying of trees show that Bangalore city has about 14,78,412 trees, ratio of 1 tree: 7 persons

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Organization recommended minimum green space of 9.5 m^2/person) considering the services (oxygen, moderation of micro climate) and goods in the urban environment. Trees play major role in accommodating arboreal species of insects, birds, etc. Trees also have aesthetics value, which adds beauty to the surrounding by adding color, softening harsh lines of building and contributes to the character of their environment.

Industrialization, coupled with unplanned urbanisation, associated deforestation and other anthropogenic activities have increased the emission of greenhouse gases such as Carbon dioxide (CO_2), Methane (CH_4), Nitrogen oxide (NOx), Sulphur dioxide (SO_2). About 75% of CO_2 is emitted due to the burning of fossil fuels during the past 20 years (Schneider, 1989) and the atmospheric carbon dioxide concentration increased (Trenberth and Kevin, 2007) from 280 ppm (pre industrial) to 382 ppm, (2006), and to 390 ppm (2011). This has led to an increase in the atmospheric temperature by trapping the certain wavelength of radiation in the atmosphere. Trees, wetlands and soil in the urban area serves as sink to capture and store the atmospheric carbon dioxide (Negi and Gupta, 2013; Nowak and Crane, 2002). Urban vegetation plays a vital role as it moderates micro climate apart from sequestration of greenhouse gases (CO_2, etc.) and also aid in the retention of water. Estimates indicate that about 6 tons of carbon is sequestered by 1 hectare of forests annually and this accounts to about 6 kg/tree/year (Secon, 2010). The per capita human respiratory carbon ranges from 192 to 328 kg/year, which means at least 8 trees per person are required to sequester respiratory CO_2 in a region.

Rapid pace of urbanization is the dominant anthropogenic phenomenon worldwide (Ramachandra *et al*., 2012). Unplanned urban development has telling impacts on the environment in the developing countries, evident from higher pollutants in air, contamination of water and land (Gairola, 2013). Population in India has increased from 63 (1950) to 127 million (2011). India's urban population stands next to China and the demand of land has increased substantially for various human needs. The vegetation cover, wetlands and other natural ecosystem have been retreating with the expansion of cities (Gairola, 2013; Zhou *et al*., 2011). Urbanization being a global phenomenon involving unprecedented expansion of land cover which in turn led to rapid increase in urban extent and growth of unplanned regions (Ramachandra and Bharath, 2012). Unplanned urbanization and lack of optimal management of natural resources by city officials has led to the gradual decline in the urban service such as water quality, air quality, inadequate infrastructure, poor quality of life, etc. (Escobedo *et al*., 2011; Ramachandra *et al*., 2011). Trees have potential to moderate air temperature through shading, reduction of surface temperature and through evaporative cooling (McPherson *et al*., 1994). Urban heat island refers to the trend in which urban pockets are warmer than their surroundings, which is caused by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities coupled with decrease in vegetation and water bodies (Ramachandra and Kumar, 2010; Song, 2013). Table 1 lists the efforts towards quantification of ecological services.

Trees have potential to moderate air temperature through reduction of surface temperature and evaporative cooling (McPherson *et al*., 1994). In order to understand the current tree cover traditional practices of tree counting has inherent problems such as requirement of extensive labour and biasedness. Remote sensing and geographic information system (GIS) makes timely unbiased spatial information accessible. Multi resolution remote sensing data aid in capturing this dynamics. Fusion

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 and water pollution.	Brack, 2002
Reduce the use energy for cooling and heating.	Simpson, 1998
Reduces the atmospheric CO_2 concentration	Yousif and Tahir, 2013
Reduces the surface water runoff	Armson *et al*., 2013
Mitigation of Urban heat islands	Sung, 2013
Improve air quality	Vos *et al*., 2013
Aesthetic value, reduction of storm water runoff, energy saving	McPherson *et al*., 2011
Mitigation of urban heat island effect	Zhang *et al*., 2013
Flood control	Sung and Li, 2010

of data from multiple sensors aids in delineating objects with comprehensive information due to the integration of spatial information present in the high resolution (HR) panchromatic (PAN) image and spectral information present in the low resolution (LR) Multispectral (MS) images. Image fusion techniques integrate both PAN and MSS and can be performed at pixel, feature and decision levels.

This work optimises geospatial techniques using multi-resolution data (spatial and temporal) with open source GIS (Geographic Information system) to understand the green cover in Greater Bangalore. Remote sensing image fusion techniques are useful to integrate a lower spatial resolution MSS (Multi spectral data) spatial data with a higher spatial resolution PAN (panchromatic) data. Fusion of multi resolution data aided in taking advantage of spectral and spatial resolutions for identification of features in urban areas because the characteristic of urban objects are determined not only by their spectra but also by their structure, shape and size. The main aim of the study is to estimate the current green space through quantification of 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.

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 encompassing an area of 741 km^2) is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state (Fig. 1).

Bengaluru is the principal administrative, cultural, commercial, industrial, and knowledge capital of the state of Karnataka. The present name Bengaluru has its origin to 'benga', the local term for Pterocarpus marsupium, a species of dry and moist deciduous tree, and ooru, meaning town (Ramachandra and Mujumdar, 2006;

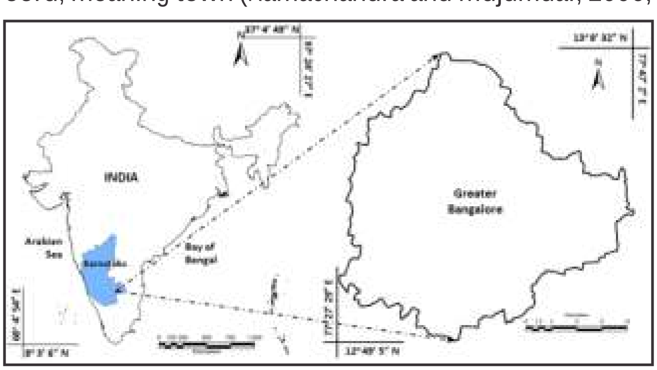

Fig. 1: Study area Greater Bangalore / Bengaluru / Bruhat Bengaluru / Bangalore

Sudha and Ravindranath, 2000). The city is now subdivided 8 zones with 198 wards under the jurisdiction of BBMP. Bangalore is the 5th largest metropolis in India (Ramachandra *et al*., 2012a; Sudhira *et al*., 2007). Population of Bangalore urban (BBMP limits) has increased by 48%, from 5.84 millon in 2001 (Census, 2001) to 8.64 million (Census, 2011) in 2011. The population density in the region has increased from 7881 persons/km^2 (2001) to 11664 persons/km^2 (2011).

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

Bengaluru (Bangalore) was known as 'Garden city of India' due to its lush green cover with diverse fauna and two nationally recognized institutions and defense establishment's green campuses, botanical gardens - Cubbon Park and Lalbagh, etc. Currently Bangalore is second fastest and ?fth largest metropolis in India and has experienced unprecedented expansion of urban area 69 km^2 in 1949 to 741 km^2 in 2010 (Ramachandra and Kumar, 2010; Ramachandra *et al*., 2012b). Bangalore city population has increased enormously from 6,537,124 (in 2001) to 9,588,910 (in 2011), accounting to decadal growth of 46.68%. The vegetation of Bangalore was classified as dry deciduous forest-type (Champion and Seth, 1968) under the *Terminalia-Anogeissus latifolia-Tectona* series (Puri *et al*., 1983). The city enjoys the salubrious climate throughout the year.

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

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

Bangalore began to evolve into a city of small–scale industries from 1965 onwards. Globalisation and consequent opening of Indian markets gave impetus to IT (Information Technology) and BT (Biotechnology) sectors and now the city is recognized as IT hub. Bangalore also houses numerous leading commercial and educational institutions, industries like textile, aviation, space, etc. The immediate consequence of this growth also created pressure on infrastructure and basic amenities like water supply, energy, public transportation, land etc. Large plots and colonial bungalows with home gardens gave way to multi-storied apartment blocks with just small patches of lawn. In terms of natural flora, Bangalore city had 979 species in 542 genera, 133 families (Ramaswamy and Razi, 1973). Due to the rapid unplanned urbanization and urban sprawl, the spatial extent of Bangalore increased from 69 km^2 (1949) to 741 km^2 (2010). Now Bangalore is the ?fth largest metropolis in India with a population of about 8.4 million (Census, 2011).

Urban ecosystems are the consequence of the intrinsic nature of humans as social beings to live together (Ramachandra *et al*., 2012a; Ramachandra and Kumar, 2009). The process of urbanisation is contributed by the adoption of concentrated growth model with infrastructure initiatives, consequent population growth and migration. Unplanned urbanisation during the post globalisation era has drastically altered the landscape with the disappearance of green cover and water bodies, leading to alterations in the drainage characteristics of natural catchments, or drainage areas, which has enhanced the rate of surface runoff. Drainage systems are unable to cope with the increased volume of water, and are often blocked due to indiscriminate disposal of solid wastes. Encroachment of wetlands, floodplains, etc. obstructs flood-ways causing loss of natural flood storage. Apart from these, major implications of urbanisation are:

- *Loss of wetlands and green spaces*: Urbanisation has telling influences on the natural resources such as decline in green spaces (vegetation) including wetlands and / or depleting groundwater table. 925% increase in paved surfaces (built-up, roads, etc.) with the decline of 78% vegetation and 79% water bodies is noticed during the four decades (1973-2014). Quantification of number of trees in the region using remote sensing data with field census reveal 1.5 million trees and human population is 9.5 million, indicating one tree for seven persons in the city.
- *Floods*: Conversion of wetlands to residential layouts has compounded the problem by removing the interconnectivities in an undulating terrain. Encroachment of natural drains, alteration of topography involving the construction of high-rise buildings, removal of vegetative cover, reclamation of wetlands are the prime reasons for frequent flooding even during normal rainfall post 2000.
- *Decline in groundwater table*: Studies reveal the removal of wetlands has led to the decline in water table. Water table has declined to 300 m from 28 m over a period of 20 years after the reclamation of lake with its catchment for commercial activities. In addition, in an intensely urbanized area such as Whitefield, etc. groundwater table has now dropped to 400 to 500m.
- *Heat island*: Surface and atmospheric temperatures are increased by anthropogenic heat discharge due to energy consumption, increased land surface coverage by artificial materials having high heat capacities and conductivities, and the associated decreases in vegetation and water pervious surfaces, which reduce surface temperature through evapotranspiration.
- *Increased carbon footprint*: Due to the adoption of inappropriate building architecture, the consumption of electricity has increased in certain corporation wards drastically. The building design conducive to tropical climate would have reduced the dependence on electricity. Higher energy consumption, enhanced pollution levels due to the increase of private vehicles, traffic bottlenecks have contributed to carbon emissions significantly. Apart from these, mismanagement of solid and liquid wastes has aggravated the situation.

Bangalore's urban vegetation comprises of trees are *Alstonia scholaris, Artocarpus heterophyllus* (Jack fruit), *Azadirachta indica* (Neem), *Bombax cieba* (Red silk cotton), *Butea monosperma, Ficus bengalensis* (Aladamara), *F. religiosa* (Ashwatha), *Gmelina arborea, Kigelia pinnata* (Sausage tree), *Lagerstroemia speciosa* (Pride of India), *Mangifera indica* (Mango), *Madhuca longifolia* (Mehwa or Ippe), *Melia composita* (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* (Coppar pod), *Spathodea companulata* (African tulip tree), *Tabebuia spectabilis, Polythia longifolia*, etc. Trees have various important roles to play in the ecosystem.In recent years, the increase in vehicular traffic has also increased the Carbon dioxide, Nitrogen, Sulphur dioxide and suspended particulate matter in the environment. Air pollution and reduction in the green vegetation induced the urban heat island effect which results in variation in microclimate.

Bangalore is also known for their lakes, which are paradise for ecology. In 1962 Bangalore had 265 water bodies due to the rapid urbanization the water bodies decreased to 98 in 2010. As the city grew over the space and time, inner areas got more crowded and congested (Ramachandra *et al*., 2012a). Road network has increased and also being widened by axing the numerous road trees. Many lakes and tanks were encroached and converted to residential layouts, multi-storey buildings, playgrounds, bus stands etc. and some lakes were used for dumping of municipal solid waste or building debris (Sudhira *et al*., 2007).

Bangalore is located on a ridge with natural water courses along the three directions of the Vrishabhavaty, Koramangala-Challaghatta (K&C) and Hebbal-Nagavara valley systems. The drainage allows the flows to Cauvery through its tributaries Arkavathi (East flowing), Pinakini/ Pennar (East Flowing) and Shimsha (West Flowing).

Objective

Objective of this study is to mapgreen spaces and quantify number of trees in Bangalore city (Bruhat Bangalore) and compute ward wise tree density and trees per person.

Data

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

Method

To quantify ward-wise the number of trees per person in Bangalore, the protocol followed is given in Figure 2, which include i) Land use analysis using remote sensing, ii) land use changes using temporal remote sensing data, iii) deriving tree canopy, iv) canopy distribution in each ward, v) field data analysis – tree canopy distribution, vi) computation of number of trees in all wards based on field knowledge using remote sensing data, vii) computation of metrics (tree density, number of trees per person).

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

a) *Temporal 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

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)	2000-2013	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

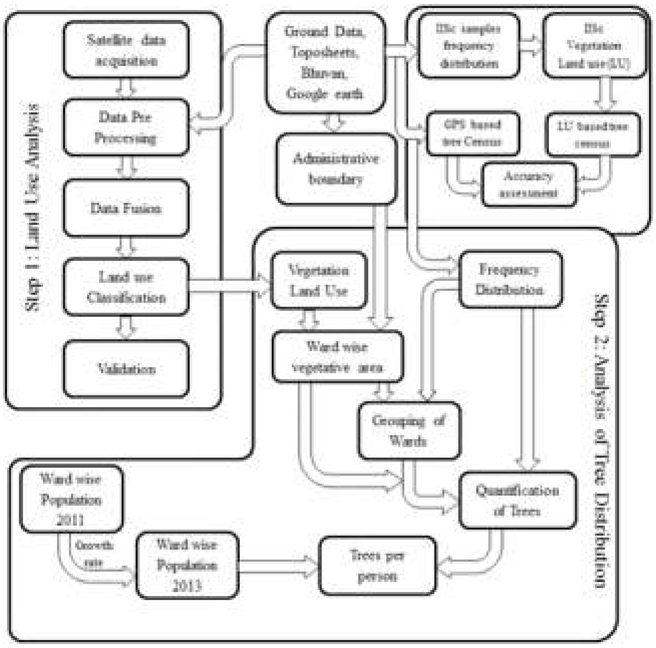

Fig. 2: Method used for data analysis

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 v) 60% of the training data has been used for classification, while the balance is used for validation or accuracy assessment. Land use analysis was carried out using supervised pattern classifier - Gaussian maximum likelihood algorithm. This has been proved superior classifier as it uses various classification decisions using probability and cost functions. Mean and covariance matrix are computed using estimate of maximum likelihood estimator (Ramachandra *et al.*, 2013a; Vinay *et al*., 2012; Ramachandra *et al*., 2013b). Temporal remote sensing data was classified (described in Table 3) into four categories: i) built up; ii) vegetation; iii) water; iv) others.

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. Statistical assessment of classifier performance based on the performance of spectral classification considering reference pixels is done which include computation of kappa (κ) statistics and overall (producer's and user's) accuracies. The classification of the data has been completed using "GRASS"–Geographic Resource Analysis Support System (http://ces.iisc.ernet.in/grass) open source GIS software by considering four land use classes.

b) *Resourcesat and Cartosat data Pre-processing:* The multi spectral remote sensing data (Resourcesat 2) and Cartosat 1 were geometrically corrected using ground control points collected from topographic maps, virtual remote sensing data as well as using GPS. This involved rectification of horizontal shifts. Resourcesat data has spatial resolution of 5.8 m (with multi spectral resolutions) and Cartosat data resolution is 2.7m. Fusion of these data, helped in optimizing spatial and spectral resolutions, which aided in mapping the canopy of trees.

c) *Data Fusion:* Fusion of data from multiple sensors aids in delineating objects with comprehensive information due to the integration of spatial information present in the high resolution (HR) panchromatic (PAN) image and spectral information present in the low resolution (LR) Multispectral (MS) images. Image fusion techniques integrate both PAN and MSS and can be performed at pixel levels. Data fusion (Resource sat and Cartosat data) was performed using algorithms - Hyperspectral Color Space resolution (HCS) merge, High Pass Filter (HPF) fusion, Modified Intensity Hue Saturation (MHIS) fusion, Wavelet Fusion.

d) *Fused data Classification:* Fused remote sensing data was classified into four categories (Table 3), all these four classes were combined to two land use classes i.e., Vegetation (Trees) and non-vegetation. The fused high resolution satellite images were classified using the Gaussian Maximum Likelihood Classifier (MLC) algorithm (Lillesand *et al*., 2004) to classify each pixel into a particular land use class. Fused data was classified using MLC with help of training data sets that were acquired from the field and supplementary data from Bhuvan and Google earth.

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

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

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

a) *Data Collection:* Trees with its canopy (spatial extent) were mapped in select wards (covering 10% of Bengaluru's spatial extent) using pre-calibrated GPS. Tree canopy of these trees werealso delineated using higher spatial resolution virtual data (Bhuvan, Google Earth). This gave information such as species wise canopy spatial extent and number of species in sampled wards.

b) *Frequency distribution:* Based on the field data, histogram (frequency distribution) of tree canopy were computed. Administrative wards were grouped based on number of tress as i) wards with >500 trees and ii) <500 trees. The number of trees in each ward is computed (based on the tree distribution in each of sampled wards).

c) *Computation of metrics:* Metrics such as population density, tree density and number of trees per person in each ward was computed. Population for 2013 was estimated under each ward based on the decadal growthand population of 2011 9based on population census data of 2011) using equation 1.

$$P2013(i) = P2011(i)*(1+n*r(i)) \quad ...1$$

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.

Number of trees per person in each ward is computed using equation 2.

$$TpP(i) = \frac{Tree(i)}{P2013(i)} \quad ... 2$$

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

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

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

TpP(B) - Tree per person in Bangalore

d) Validation:Trees extracted from remote sensing data (for each ward) was compared with the field data using equation 4. Frequency distribution of canopy (based on size) was also compared with the field data. Census of trees in Indian institute of Science campus (178 hectares spatial extent) was done using GPS. Data collected from field include spatial location of a tree, size of its canopy, habit (tree/shrub/ climber/ herb), species details. Canopy of these trees were also digitized using virtual data (Google Earth, Bhuvan). Frequency distribution of trees based on the canopy data was computed. Canopy mapping for the campus was done using fused remote sensing data (with spatial resolution of 2.7 m Cartosat and Multi spectral data (5.8 m spatial resolution) of Resourcesat). Canopy were grouped based on size and histogram 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

Results and Discussion

Land use dynamics: Table 4 and Figure3 gives an insight to the temporal land use changes during 1973 to 2013. 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) and 73.72% in 2013. The sudden increment in urbanization post 1990's could be observed due to the industrial revolution (in Peenya, Rajajinagar, Koramangala). Post 2000, Government's push

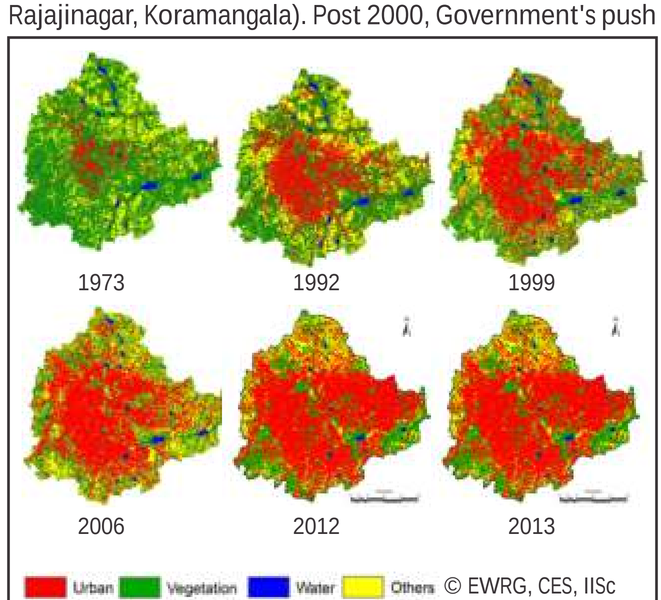

Fig. 3: Land use dynamics

Table 4: 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
2013	50440	73.72	10050	14.69	445.95	0.65	7485	10.94

to software sectors led to the large scale land use changes with urbanization at White field, Electronic city, Domlur, Hebbal, due to private players and development of Special Economic Zones. Bangalore, once branded as the Garden city due to dense vegetation cover, which has declined from 68.27% (1973) to less than 15% (2013). Similar to vegetation, Bangalore was also known as city of lakes for numerous lakes that were present (209 lakes). The impact of urbanization has diminished lake bodies (93 lakes as per 2011) (Fig. 4) and also loss of feeder canals (rajakaluve). 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). During the last four decades, there has been 925% increase in paved surfaces (buildings, roads, etc.) with the decline of vegetation (78%) and water spread area (79%), highlights unplanned urbanisation leading to the loss ecology and biodiversity.

Image fusion: Fusion of multispectral data (Resourcesat 2) and Cartosat (2.7 m) data was done using algorithms – Hyper-spectral 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 wavelet) were heavy intensive process which consumed 12 cores and 36 hrs of times on cloud computing networked systems. Among these, HCS provided better results, which aided in digitization of tree canopies in Bengaluru.

The land use analysis was carried out using HCS fused remote sensing data using the supervised classifier based on Gaussian Maximum Likelihood Classifier (MLC). Categories include two classes - vegetation and non-vegetation (built-up, water bodies, open area, etc.). Figure 5 illustrates the spatial distribution of vegetation (tree canopy). Accuracy assessment show the overall accuracy of 91.5% the kappa of 0.86 indicating higher agreement of the classified data and field data. Results highlight that spatial extent of tree vegetation is about 100.02 km^2 (14.08%).

Tree distribution in wards: Vector layer of wards (administrative boundaries in Bangalore city) is overlaid on Figure 5, to extract the vegetation information for each ward. Figure 6 shows the ward wise distribution of vegetation and ward-wise tree statistics. Spatial extent of vegetation is minimum (less than 1 hectare) in wards such as Chickpete, Shivajinagara, KempapuraAgrahara, Padarayanapura, while wards such as Varthur, Bellandur,

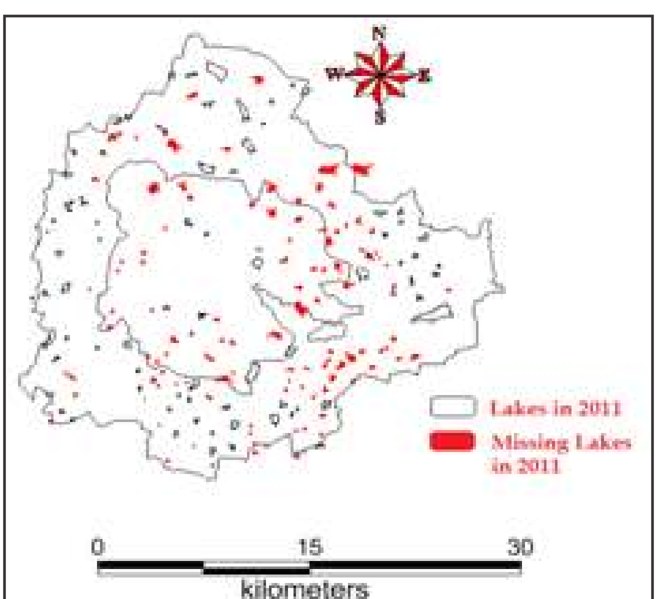

Fig. 4: Lakes of Bangalore

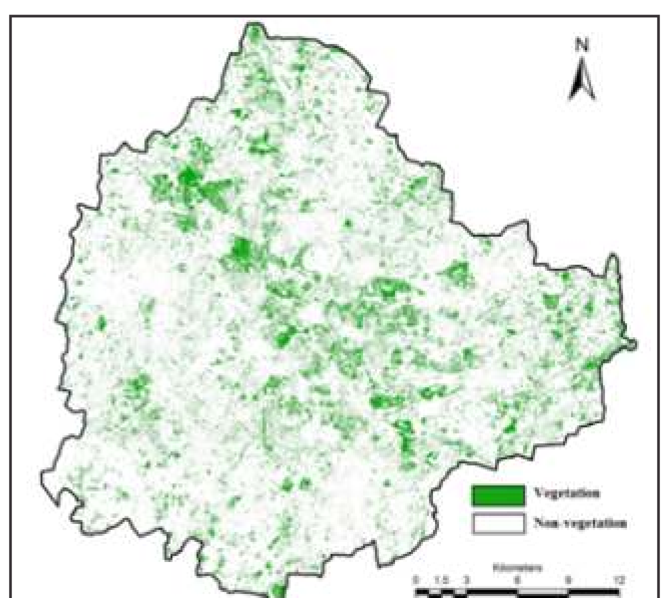

Fig. 5: Spatial distribution of vegetation in Bangalore

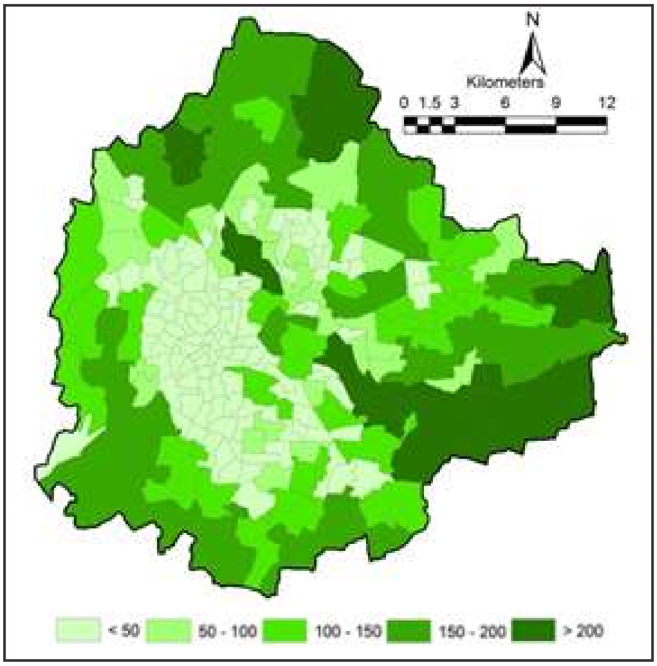

Fig. 6: Ward wise spatial extent of vegetation (Hectares)

Agaram have higher vegetation cover (> 300 hectares).

Bangalore was divided into 1km incrementing radii circles (with respect to the central business district) to assess the vegetation gradient. Figure 7depicts vegetation density in each concentric regions in 1973 and 2013. Fig. 7 illustrates the decline of vegetation during the last 4 decades. Presence of Lalbagh, Cubbon park, Indian Institute of Science campus, etc. in the core area show better vegetation density in the respective gradients. Fig. 8 illustrates ward wise vegetation density for 2013. The wards such as Hudi, Aramanenagara and Vasanthapura have higher vegetation density of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura havelower density with less than 0.015.Average vegetation density in Bangalore is about 0.14 (i.e., vegetation density: 0.14; Area of Bruhat Bangalore: 741km^2, Area under vegetation: 100.20 km^2)

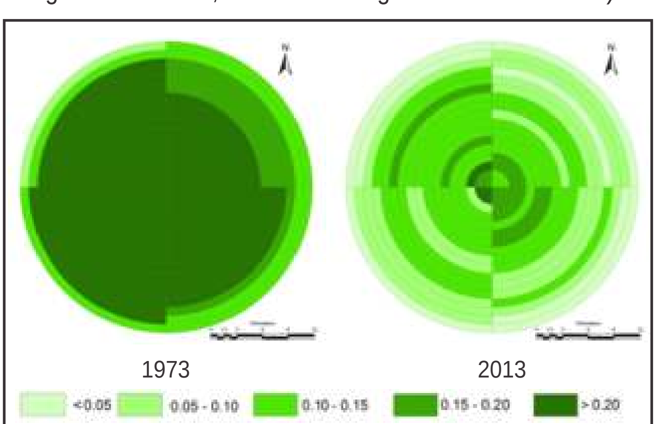

Fig. 7: Gradient wise Vegetation density

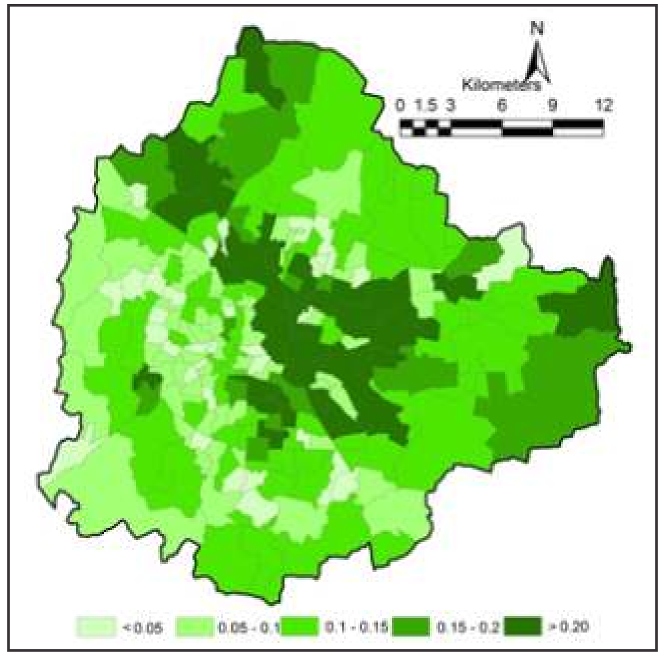

Fig. 8: Ward wise vegetation density (2013)

Field data was collected using GPS in select wards (covering 10% City's spatial extent), which include tree census with the canopy dimensions. Canopy was also delineated using online Google Earth (http://Earth.google.com). This helped in quantifying number of trees based on delineation of canopy from remote sensing data. Figure 9 gives the frequency distribution based on the canopy size for wards i) < 500 trees and ii) > 500 trees. Based on these, number of trees in each ward are computed. Wards such as Vathuru, Bellanduru, Agaram, Aramane Nagara have the trees greater than 40000 trees, while Chickpete, Padarayanapura,

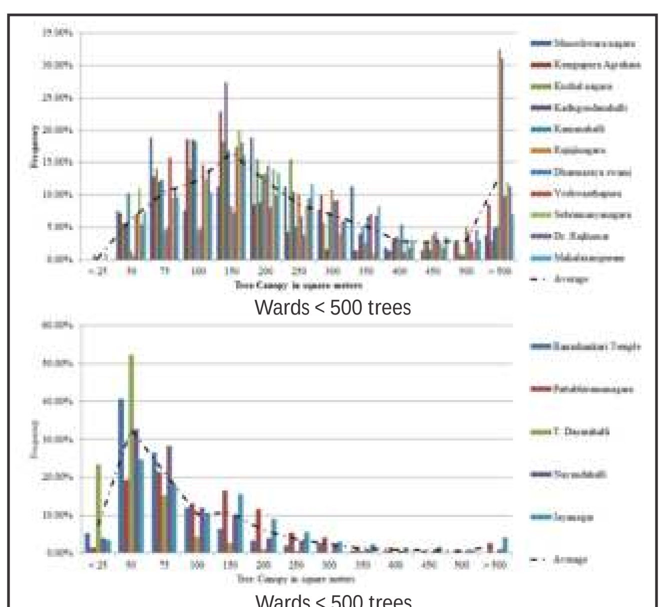

Fig. 9: Histogram of trees based on canopy size

Shivaji Nagara, Kempapura Agrahara, Kushal Nagara wards have trees less than 100 trees. Based on these, total number of trees in Bangalore is about 14,78,412 trees. Annexure I provides details of prominent trees in Bangalore.

Validation of tree quantification was done in select wards of Bangalore. Fig. 10a gives the tree distribution based on field census in Indian Institute of Science (IISc) Campus (Spatial extent 178 hectares) and Fig. 10b gives the canopy distribution based on pattern classifier. Total number of trees as per the census is 22,201 and Fig. 11 gives the frequency distribution of canopy classes. Based on the remote sensing data, IISc campus with spatial extent of 178 hectares has canopy cover of 107.85 hectares and number of trees as 22,616. This means the accuracy of tree estimation based on canopy delineation using fused remote sensing data of 2.7 m spatial resolution is 97%.

Figure 12 depicts the ward wise population during 2013, computed considering the growth rate based on the population of 2001 and 2011. This shows wards in the core area of the city have population more than 40000 persons, whereas the wards towards the periphery have population less than 30000. Figure 13 depicts ward wise trees per person computed considering number of trees and population for the respective ward. This analysis shows that Shivaji Nagara, Dayananda Nagara, Chickpete, Padarayana pura, Kempapura Agrahara wards have very less number of trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people. Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, AramaneNagara have trees more than one per person indicating the presence of one tree for every person.

a) Tree Census using GPS. b) Trees from remote sensing data through pattern classifiers.

Fig. 10: Tree Distribution in Indian Institute of Science campus

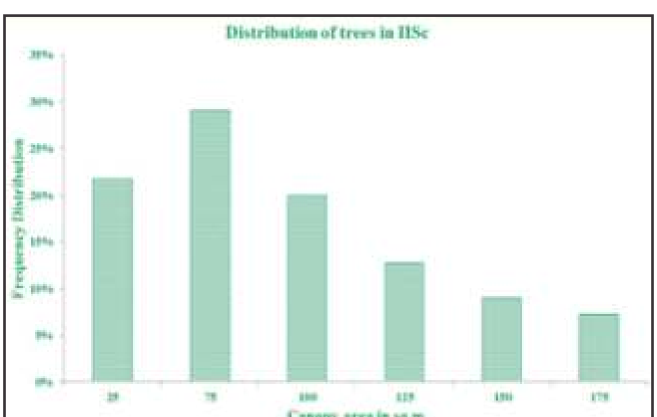

Fig. 11: Frequency Distribution based on field measurement.

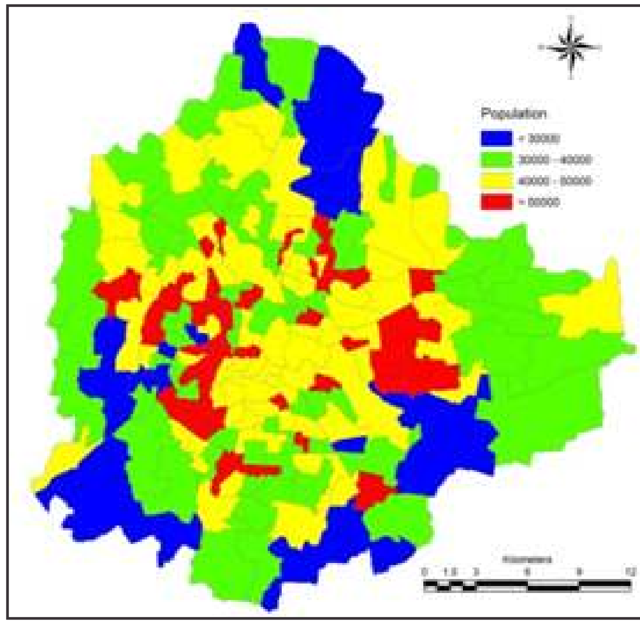

Fig. 12: Ward wise population during 2013

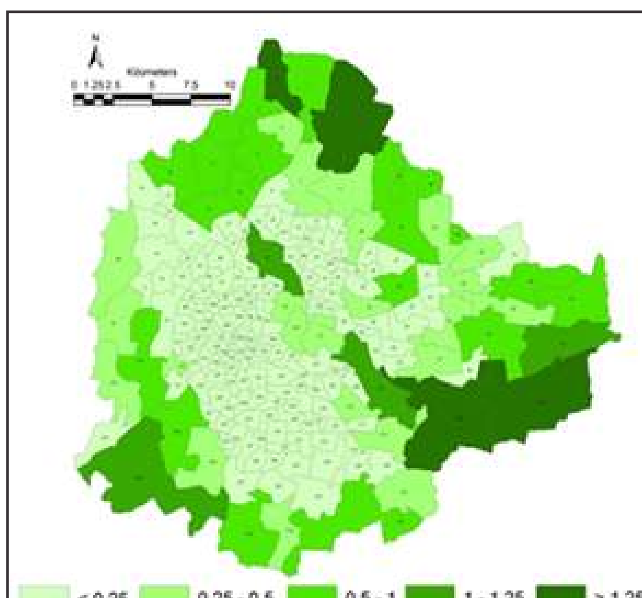

Fig. 13: Ward wise trees per person

Table 5: Comparative assessment of trees across different cities

State	Location	Population	Area (Ha)	Number of Trees	Trees/ person	Trees/ Hectare	Reference
Gujarat	Ahmedabad	5570590	46985	617090	0.111	13.13	Singh, 2013
	Surat	4462000	39549	333970	0.075	8.44	
	Vadodara	1666700	16264	747190	0.448	45.94	
	Gandhinagar	208300	57000	866670	4.161	15.20	
	Rajkot	1287000	10400	139520	0.108	13.42	
	Bhavnagar	593770	5320	485950	0.818	91.34	
	Junagafh	320250	5670	76690	0.239	13.53	
	Jamnagar	529310	3434	45880	0.087	13.36	
Maharashtra	Nagpur	2405421	21717	2143838	0.891	98.72	NMC, 2012
	Nashik	1486973	25900	2055523	1.382	79.36	
	Brihan Mumbai	12478447	43771	1917844	0.154	43.82	
	Kalyan*	472208	5198	212795	0.451	40.94	
	Thane	1818872	12700	45262	0.025	3.56	
	Navi Mumbai	1119477	16205	478120	0.427	29.50	
	Nanded	550564	4906	101310	0.184	20.65	
	Mira and Bhayandar	814655	7904	150000	0.184	18.98	
Karnataka	Bangalore	9582199	74100	1478412	0.155	19.95	calculated

* Kalyan and Dombivali, combined together has population of 1,246,381 and area of 137.15 km^2, proportion of area was used to calculate population of Kalyan city

Comparative analyses of trees per person based on published literatures, reveal that Gandhinagar in Gujarat and Nashik in Maharashtra has more than 1 tree per person (Singh, 2013), while most of other cities are less than one tree per person. Major cities such as Gandhinagar, Bangalore, Ahmadabad, Brihan Mumbai are with spatial extent greater than 400 km^2. Gandhinagar has 416 trees for every 100 people (4 tress per person) followed by Nasik (2 tress per person) Bangalore with 16 trees (one tree per 7 persons), Brihan Mumbai with 15 trees and Ahmadabad with 11 trees. Table 5 lists city wise number of trees and trees per person, which highlights of 4 trees per person in Gandhinagar, 2 trees per person in Nasik compared to one tree for 7 persons in Bangalore.

Conclusions

Land use analysis using remote sensing data show 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, Shivaji nagara, Kempapuraagrahara, Padarayanapura, while wards such as Varthur, Bellandur, Agaram have higher vegetation cover (> 300 hectares). The wards such as Hudi, Aramanenagara and Vasanthapura have higher vegetation density (spatial extent of area under vegetation to the geographical are of a ward) of more than 0.4, while Chickpete, Laggere, Hegganahalli, Hongasandra, Padarayanapura have lower density with less than 0.015. Bangalore has an average vegetation density of 0.14. Mapping of trees based on canopy delineation coupled with field data show that wards such as Vathuru, Bellanduru, Agaram, Aramanenagara have the trees greater than 40000 trees, while Chickpete, Padarayanapura, Shivajinagara, Kempapura Agrahara, Kushalnagara wards have trees less than 100 trees. Based on these, total number of trees in Bangalore is about 14,78,412 trees. Computation of trees per person show that Shivajinagara, Dayananda nagara, Chickpete, Padarayanapura, KempapuraAgrahara wards have very less number of trees per person (< 0.002). This highlights that these wards have less than 1 tree for every 500 people. Compared to this, wards such as Bellanduru, Jakkuru, Varthuru, Agaram, Aramanenagara have trees more than one per person indicating the presence of one tree for every person. Intra city analysis show that major cities such as Gandhinagar, Bangalore, Ahmadabad, Brhihan Mumbai are with spatial extent greater than 400 sq.km. Gandhinagar has 416 trees for every 100 people followed by Bangalore with 16 trees, Brihan Mumbai with 15 trees and Ahmadabad with 11 trees. This is contrary to the required green of 9.5 m^2/person to meet the ecological demand of humans. Per capita daily respiratory carbon ranges from 540-900 grams (depending on the age and physiology) and a native tree sequesters annually about 6 kg of carbon, necessitating at least 8 trees per person.

Reduced vegetation cover with unplanned urbanization has serious implications for the city's environmental and ecological health. This highlights the city has crossed the threshold of urbanization evident from a range of psychological, social and health impacts for residents including dramatic increase in recent times of instances such as higher instances of domestic violence, obesity, enhanced asthma levels, traffic bottlenecks, road accidents, etc. Overall improvements in human well-being and community vitality necessitate urban planners to maintain at least 33% green cover in the region. In such a case there would be at least 1.15 trees/person in the city.

Acknowledgement

Author's grateful to Dr. Vamana Acharya, Chairman, Karnataka State Pollution Control Board for assigning this task to us, which is academically rewarding. We thank Karnataka state Pollution Control Board for the financial support. We acknowledge the sustained financial and infrastructure support to our ecological and environmental research from (i) the Ministry of Environment, Forests and Climate Change, Government of India, (ii) NRDMS Division, the Ministry of Science and Technology (DST), Government of India and (iii) Indian Institute of Science.

बैंगलूरू में हरित स्थान : भूस्थानिक तकनीकों के जरिए परिमाणन

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सारांश

शहरी भूदृश्य में हरित स्थान में वृक्षों, झाड़ियों एवं शाकों को मिलाकर सार्वजनिक एवं निजी भूमियां (पार्क, सड़कें, आहाता) शामिल हैं सी ओ पी 21- पेरिस में हाल में सम्पन्न संयुक्त राष्ट्र जलवायु सम्मेलन ने पूर्व औद्योगिक स्तरों से ऊपर 2 डि.से. (3.6^0F) से नीचे तापन सीमित रखने की आवश्यकता एवं कार्बन तटस्थता और विकार्बनीकरण क्रियाविधि के जरिए 1.5 डि.से. तक तापमान वृद्धि को सीमित करने के प्रयास को मान्यता दी है ताकि बदतर जलवायु प्रभावों से बचा जा सके। शहरी पर्यावरण में सेवाओं (आक्सीजन, सूक्ष्म जलवायु का नियमन) और सामानों पर विचार करते हुए विश्व स्वास्थ्य संगठन ने 9.5 एम^2/ व्यक्ति के न्यूनतम हरित स्थान की शर्त रखी है। आकलन दर्शाते है कि एक वृक्ष द्वारा सालाना करीब 6 किलो कार्बन पृथक्कृत किया जाता है। प्रति व्यक्ति श्वसन कार्बन 192 से 328 कि. ग्रा प्रति वर्ष तक है जो मानवों की दैहिकी पर निर्भर है (आयु और दैहिकी पर निर्भर 525-900 ग्रा. प्रति दिन प्रति व्यक्ति)। भूमि उपयोग विश्लेषण दर्शाते है कि बंगलौर मे वृक्ष वनस्पति की स्थानिक सीमा 100.02 वर्ग कि.मी. (14.08 %) है और बंगलौर में वृक्षों की कुल संख्या करीब 14,78,412 वृक्ष है। प्रति व्यक्ति वृक्षों के परिकलन दर्शाते है कि बंगलौर में प्रत्येक 7 व्यक्तियों पर एक वृक्ष है, जो शहरीकरण की सीमा को दर्शाता है। शहरी इलाकों में मानवीय कल्याण के समग्र सुधार के लिए न्यूनतम 33 प्रतिशत हरित स्थान की अपेक्षा अनिवार्य हैं, जो न्यूनतम 1.15 वृक्ष प्रति व्यक्ति की सुनिश्चितता करते हैं।

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Annexure I

Prominent trees of Bangalore

Acacia auriculiformis Cnn. Ex Benth.
Bauhinia purpurea L.
Bombax malabaricum DC.
Cassia spectabilis DC.
Cocos nucifera L.
Delonix regia (Bojer ex Hook.) Raf.
Polyalthia longifolia (Sonn.) Thwaites
Spathodea campanulata P. Beauv.
Millingtonia hortensis L.f.
Pongamia pinnata
Bauhinia variegata L.
Albizia lebbeck (L.) Benth
Peltophorum pterocarpum (DC.)
Roystonea regia (H.B.K) O.F.Cook
Casuarina equisetifolia L.
Tectona grandis L.f
Grevillea robusta Cunn. Ex R. Br.
Swietenia macrophylla King
Cassia fistula
Milletia ovalifolia
Michelia champaca L.
Samanea saman (Jacq.) Merr.
Tabebuia rosea (Bertol) DC.
Murraya koenigii
Psidum guajava L.
Mangifera indica
Saraca asoca (Roxb.) de Wilde
Thespesia populnea (L.) Sol. Ex Corr. Serr.
Solanum grandiflorum
Parkia biglandulosa
Lagerstroemia speciosa (L.) Pers.
Castanospermum australe Cunn. & Fraser
Butea monosperma
Enterolobium cyclocarpum
Tabebuia impetiginosa (Mart. Ex DC.) Standl.
Tabebuia aurea (Manso) benth. & Hook.f. ex S. Moore
Dolichandrone platycalyx
Eucalyptus tereticornis
Callistemon viminalis (Soland. Ex Gaertn.) G. Don

Acacia auriculiformis Cnn. Ex Benth.

Spathodea campanulata P. Beauv

Cassia fistula