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City–forest relationship in Nagpur: One of the greenest cities of India

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ABSTRACT

There are sporadic reports on urban forests in Indian cities. Nagpur is one of the greenest cities of India with 18 per cent of its area under forests and plantations, 17 per cent under cultivation and 2 per cent under water bodies. The present study showed that natural vegetation of the city is very well diversified with a representation of 59 per cent vegetation including 124 trees species belonging to 38 families as compared with the overall district vegetation statistics. Air quality in the city is relatively better with lower SO_2 (6 $\mu g/m^3$), NO_2 (18 $\mu g/m^3$) and Respirable Suspended Particulate Matters (RSPM, 53 $\mu g/m^3$) as against National Ambient Air Quality Standards (2009) for cities in India of 80, 80 and 100 $\mu g/m^3$, respectively. It was also noted that the diversity in natural forests which are being protected is greater than the plantations undertaken by the civic authorities and private sector efforts. The study thus demonstrated the positive relationship of the city with diversified vegetation cover for cleaner environment. The analysis is expected to guide formulation of strategies for maintaining green space in the city.

Introduction

The word 'urban forest' is likely to conjure up images of the concrete jungle that metropolitan cities have become all over the world. However, it has a more pleasant connotation and it is actually the sum of all street trees, residential trees, park trees, and greenbelt vegetation including trees on unused public and private land, in transportation and utility corridors and on watershed lands. Urban forestry is therefore the care and management of all these trees located in and around cities (Krishnan, 2007). In developing countries, about 44 per cent of the population currently lives in urban areas, but in the next 20–30 years, developing countries in Asia and Africa are likely to cross that historic threshold, joining Latin America in having a majority of urban residents (Montgomery, 2008; UN-Habitat, 2009). The World Health Organization suggests ensuring at least a minimum availability of 9 m^2 green open space per city dweller.

Worldwide there has been an increasing awareness for forest conservation, however forest areas are mostly being considered in isolation. Urban impacts on forest ecosystems and vice versa is a complex but frequently over-looked problem as conservation efforts have traditionally been forest-based. There is a need to consider the forest as part of continuum of the urban landscape. Evidence suggests that urban forest resources can play an active role in providing goods and services to alleviate poverty, improve livelihoods, and enhance wellbeing in developing countries (Kuchelmeister, 2001). Such beneficial activities are not yet institutionalized, though they are carried out by the poor ones through illegal grazing, collection of fuel wood, etc. The main focus of attention in urban forestry is on environmental services.

Measuring environmental urban forest benefits and translating these into monetary value in North America has greatly contributed to a situation in which policy makers and citizens appreciate more the value of the urban forest. Concern about global warming has facilitated the dissemination of in-depth knowledge about the functions of urban trees in microclimates, air quality improvement and carbon dioxide reduction in industrialized countries, especially in North America (Kuchelmeister, 1998). The situation can also be viewed as an opportunity to consider the educated, aware and conscious urban population as a tool for forest conservation. The urban areas constitute significant conservation potential due to increasing concern for ecological preservation, since most of the concern for environment originates and gets institutionalized in the urban areas.

In the Indian context, while most urban areas in the Indo-Gangetic plains have emerged from an agrarian landscape, the same is not true of the towns in the Deccan Plateau, where Nagpur is located. Due to the uneven terrain of the region, while the agrarian landscape gave way to urban in the lower areas, the forest were cut and made way for the township on the higher grounds. In recent times, however, the forests are being protected and sometimes being converted into what is called as 'city forests' or 'urban forest'. As India becomes more urbanized urban population growth seriously threatens biodiversity – especially in peri-urban areas.

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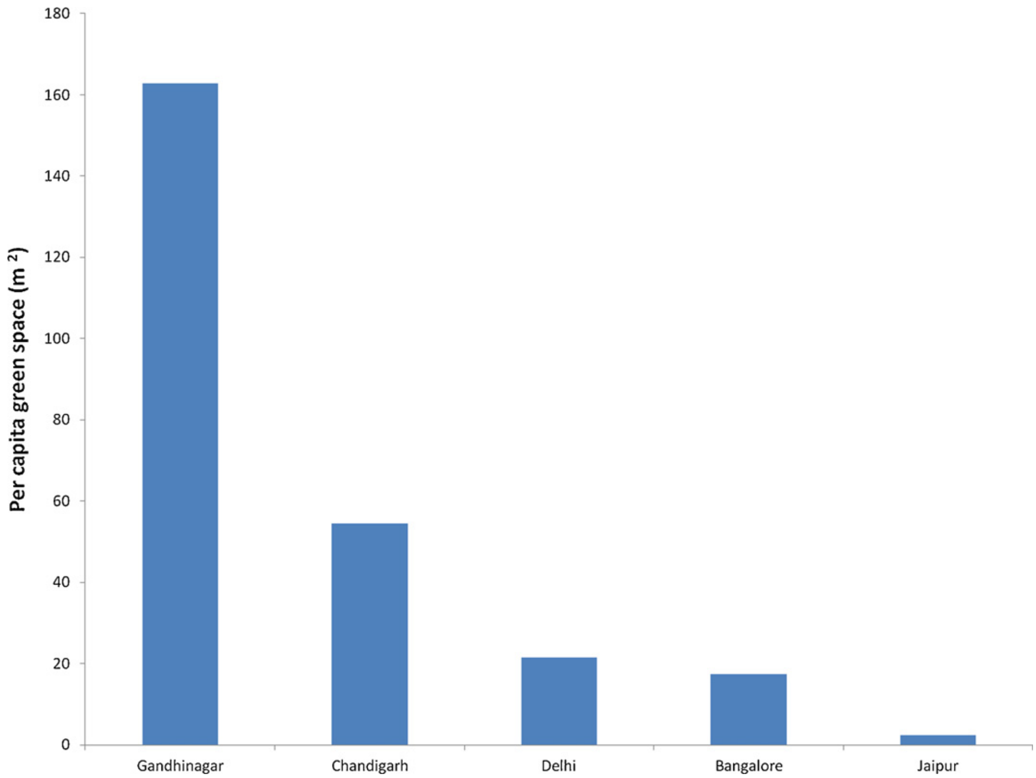

Fig. 1. Per capita green space in selected Indian cities.

Rapid urbanization in India is bringing complex changes to ecology, economy and society (DeFries and Pandey, 2010). During the last 50 years the population of India has grown two and a half times, but the urban population has grown nearly five times (Taubenböck, 2009). About 60% of this urban population growth is attributable to natural growth, and the remaining 40% is due to migration and spatial expansion (Sivaramakrishnan et al., 2005). At a more regional scale, statistics in Rajasthan brings out an interesting aspect of growth. Over the last two and half decades spatial growth of cities has often been three times faster than the growth of population (Jat et al., 2008). Undoubtedly, urbanization will continue to have substantial impact on the ecology, economy and society at local, regional, and global scales.

With the exception of a few cities, Indian urban forests are not well-studied. There are, however, some studies on Bangalore (Sudha and Ravindranath, 2000; Nagendra and Gopal, 2010), Chandigarh (FSI, 2009; Chaudhry and Tewari, 2010) and Delhi (FSI, 2009). Some issue-specific studies such as work on biodiversity and carbon storage are also available for Bhopal (Dwivedi et al., 2009), Delhi (Khera et al., 2009), Jaipur (Verma, 1985; Dubey and Pandey, 1993), Mumbai (Zerah, 2007) and Pune (Patwardhan et al., 2001). A comparative study by Chaudhry et al. (2011) shows that Gandhinagar in Gujrat state has the maximum per capita green space (Fig. 1).

However, it is notable that all the cities selected and studied are national/state headquarters (capital city). There is no information on second tier cities of India especially those witnessing fast growth post liberalization of economy. A few studies are also available for specific locations within the urban ecosystems, such as NEERI Campus, Nagpur (Gupta et al., 2008) and Indian Institute of Science Campus, Bangalore (Mhatre, 2008).

Central India has always been the land under thick forests, also referred as the 'Secret India', as most of this land was not on anyone's route to trade or conquest. The great dynasties that fought over India from north and south passed to the west or up and down the eastern seaboard. The highlands of Central India remained a formidable barrier to outside interference for many centuries, allowing diverse and unusual societies to flourish.

Nagpur is a classic example of such urban growth. While the eastern part of the city comprise lower regions and have an agriculture background, the western parts are hilly and table lands where forests have been cut and given way to urban utilities and residences. The city is poised for accelerated urban growth because of the '*Multi-modal International Cargo Hub and Airport at Nagpur*' (*MIHAN*) project. It is the biggest economical development project currently underway in India in terms of investments. The project aims to exploit the central location of Nagpur and convert the present airport into a major cargo hub with integrated road and rail connectivity. The project is expected to add 12 million people to city's population by means of direct and indirect employment. This study was conducted to assess and record the status of urban forest in Nagpur city so that the effects of rapid urbanization could be evaluated at later date.

Study area

The study area, Nagpur city is the third populous city (2.398 million residents) of Maharashtra state with decadal growth of 19.21% during the period 2001–2011, which is higher than the state average (16%) for urban population. The population density is 11,000/km^2 as compared to state average of 365 and national average 382 persons/km^2. At national level, Nagpur is the 13th largest urban conglomeration in India and 114th largest city in the world. It ranks as 143rd largest urban area in world in terms of population. The city is growing fast with economic development of the country and is identified by the state to become the biggest cargo hub of the country because of its strategic location. It is practically located at the geographical centre of India and is therefore also called as

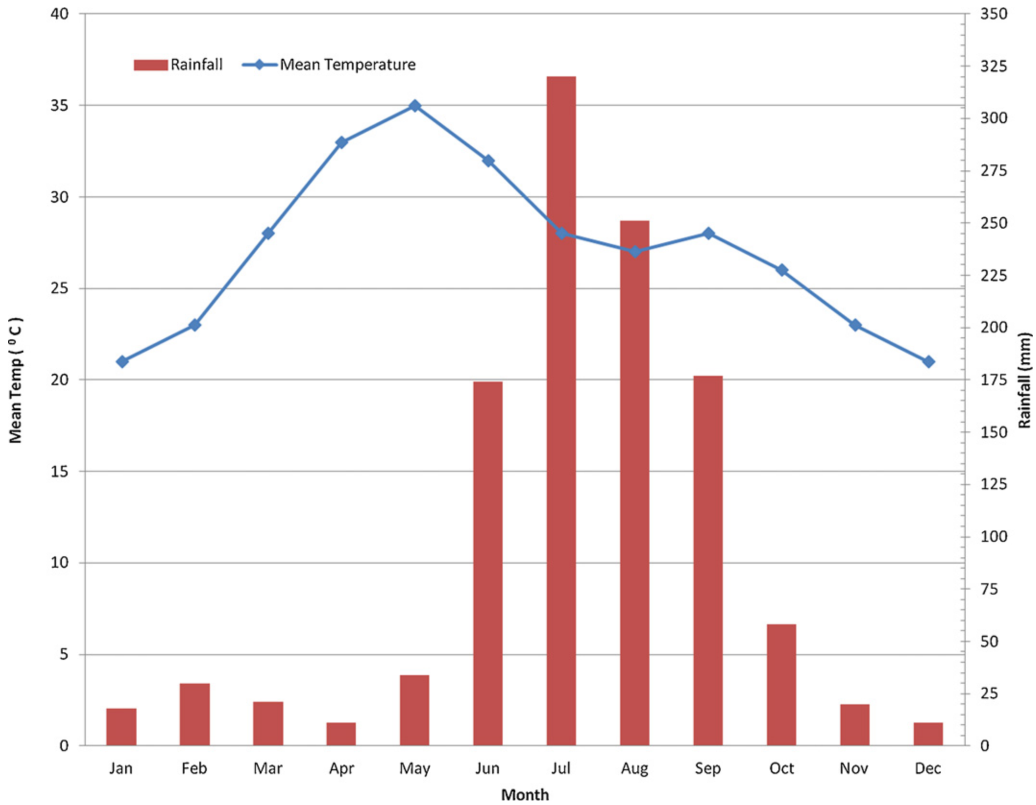

Fig. 2. Climate of Nagpur city, India.

'Zero Mile' City. Nagpur's relatively clean environment well developed infrastructure, connectivity, etc. is helping the accelerated development. It is also called the 'Garden City of Maharashtra' and is appropriate to and worthy of being the 'Gateway to the Central Indian Forests'. It is also the second capital of Maharashtra with municipal area 220.8 km^2, situated at latitude 21°9′N and 79°6′E with the average elevation of 303 m above sea level. Climate of the city in general is semi-arid with uni-modal monsoon. The average annual rainfall (based on 30 years data) is about 1161.5 mm. The winter (November to February) in general is mild. Mean temperature during summer gradually increases from 28 (March) to 35 °C (May). After onset of monsoon in June mean temperature declines to 32 °C (Fig. 2). On the other hand, the coldest time of year in Nagpur is in December when it is 21 °C on average, but could get down to 12 °C. Geologically, Nagpur city lies at the origin (vertex) of a 'V' shaped Nag River Basin with its vertex at the edge (key point) of Deccan Trap Plateau and arms spread eastward in the alluvia and soil structure up to the Wainganga river. 'Nagpur' city derives its name from the Nag River. Plant wealth of the district can be grouped into three main types: Hill Forest, Savannah and Pond vegetation along with some minor groupings such as Riverine, Wasteland plants and Weeds. The Nagpur district is quite rich and varied in its plant composition. According to Flora of Nagpur District (Ugemuge, 1986) there are 1136 plant species which fall under 679 genera and 142 families. In addition to the natural flora of the district, there are large numbers of plants found either in cultivation or introduced for various purposes at one time or other which have now been naturalized in the area.

Two dominant soils, Very Deep Soils on Piedmont Alluvial Plain and Shallow to Medium soils on Plateau and Escarpments have been recognized as covering the present city limits. More than 81 per cent area is under the very deep soils and less than 19 per cent under the shallow to medium soils (Soils of Nagpur District, 1990).

Materials and methods

A floristic study was designed to evaluate the vegetation in Nagpur's city forests, gardens, avenue plantations and other locations. The random field study was conducted during January 2009–January 2010. The size and number of quadrates were determined by species area curve method (Mishra, 1968). The size of quadrates was 30 m × 30 m for dense patches of tree vegetation. According to the dense to sparse vegetation the plotting of quadrates ranges from 30 to 60 per hectare. Transect method of sampling (stratified, random distributed) was used for avenue plantations. The woody plant species with ≥31.5 cm CBH (circumference at breast height) was considered as trees following Ralhan et al. (1982). The vegetation data were quantitatively analyzed for abundance, density, and frequency following Curtis and McIntosh (1950). Quadrate data was pooled for plots to estimate density, frequency, total basal area, and relative values of density, frequency, total basal area (Mishra, 1968; Muller-Dombois and Ellenberg, 1974). Importance value index (IVI) was calculated by summing up the relative values of density (RD), frequency (RF), and total basal area (TBA) (Curtis, 1959). The ratio of abundance to frequency was determined to evoke the distribution patterns. The identification and authentication was done with reference to the pertinent literature viz., different regional and national flora viz. Flora of Nagpur District (Ugemuge, 1986), Flora of Maharashtra State Vol. I (Singh and Karthikeyan, 2000), and Flora of Maharashtra State Vol. II (Singh et al., 2001). The herbarium facilities at Department of Botany; RTM Nagpur University, Nagpur were utilized. The information was correlated with tree canopy percentage of each zone of the city (Galvin and Bleil, 2004).

To compile data on the existing land use pattern of the city, remote sensing data (Fig. 3) was collected for Nagpur area situated between 21°13′N longitude and 79°6′E latitude. The satellite data was acquired from the IRS P6 (RESOURCESAT-1) Scene (Path

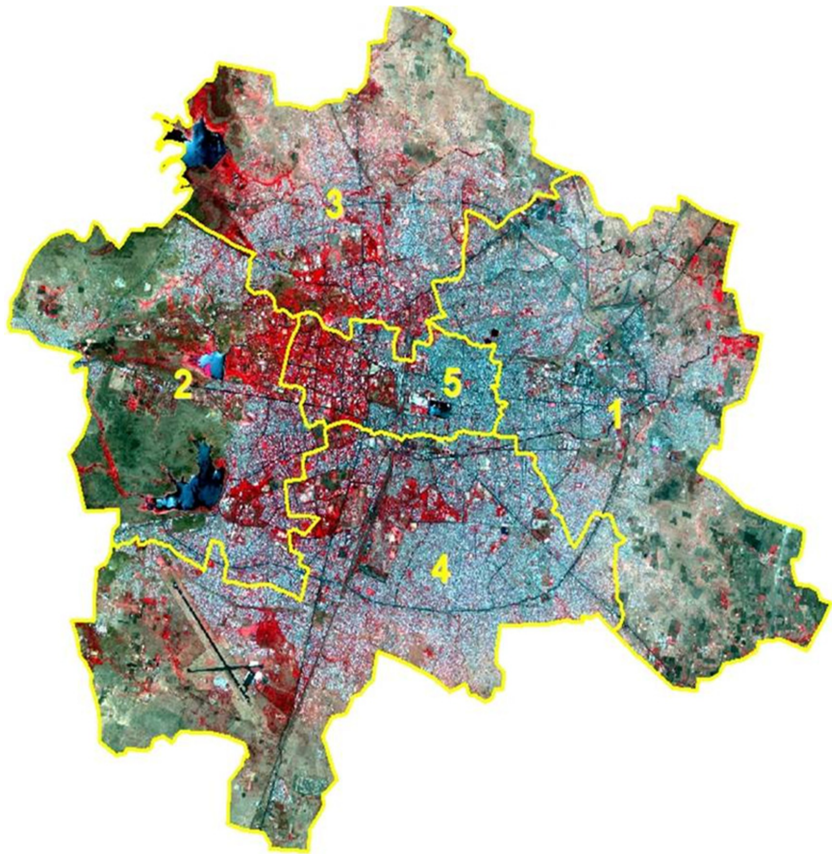

Fig. 3. False Colour Composite (FCC) of satellite data for Nagpur city, India.

99, Row 57 Year September 2010) and the collateral data were used from reference map, Survey of India Toposheets 55 O/4 and 55 K/16. Resources at employs Linear Imaging Self Scanner (LISS 4) operating in three spectral bands in the visible and Very Near Infrared Region (VNIR), with 5.8 m spatial resolution Supervised classification method was used for image analysis in 'Geomatica ver. 10' to differentiate land use classes such as forests, cultivated land, habitation, open spaces, water bodies and plantation. The city was divided into five zones demarcated by Nagpur Municipal Corporation for study.

The city master plan (Fig. 4) was obtained from Nagpur Improvement Trust and digitized. Information on pollution and water table were collected from various agencies like National Environmental Research Institute (NEERI) and Nagpur Municipal Corporation (NMC), and data on human interaction was collected through field visits. The air quality data is monitored daily by NEERI at 6 different locations in the city and annual average is reported. The data reported here pertains to the period 2005–2008. Similarly water table data is collected in the month of May and October (pre and post monsoon) by Vishveshwaraiyya National Institute of Technology, Nagpur every year. The data is recorded for representative wells in each zone.

Results

Human population data are provided in Table 1. From the image analysis, it was observed that the city has nearly 18% area under forests and plantation/parks, 17% under cultivation and 2% under water bodies. Open spaces account for 22% area (Table 2). The city on an average has 31 m^2 green spaces per person (forest, plantation and cultivation included). These numbers put Nagpur ahead of Bangalore, Delhi and Jaipur (Fig. 1). However, the green space estimated by Chaudhry et al. (2011) is based on 2001 population data. The West and North zone have relatively more green space, with the East zone has the poorest forest cover, but has 13.53 km^2 land under cultivation. Lack of stringent regulations seem to have converted all the cultivated area into built up area with the result that the zone has greater area under forest than the cultivated area and in general least green space (13 m^2/person). In master plan of the city, spaces are marked for development of parks, playgrounds and recreational activities. Most of the open spaces currently harbour natural vegetation. But such spaces are lacking in the Central zone which is reflected in the per capita green cover numbers. The Central zone is most densely populated with less forest area (2.09 km^2). This is the oldest part of the city where business establishments, commercial activities are concentrated.

The East zone has major area under cultivation because of the irrigation facilities along the banks of Nag river. The West zone has the highest forest cover because of the fact that settlement in this zone occurred by clearing forests and attempts were made to preserve the trees and forest cover. More changes are expected in South zone because the MIHAN project is being implemented in this zone and the effects on land use, population, etc. will be known only after 4–5 years.

The Master Plan (Fig. 4) of the city covers an area of nearly 245 km^2 and has zonings for 12 kinds of land utilization. More than 24% of the area has been earmarked for the category "No Development except Agriculture". These are regions on the fringes of the city and on the western side consist of catchment areas of the three lakes (Fig. 4), which are essential for water supply to the city. Nearly 39% of the land has been kept for residential utilization while public institutions like Government offices have been allotted 10.6% of the land. Significant areas (6.7% of the land) have been

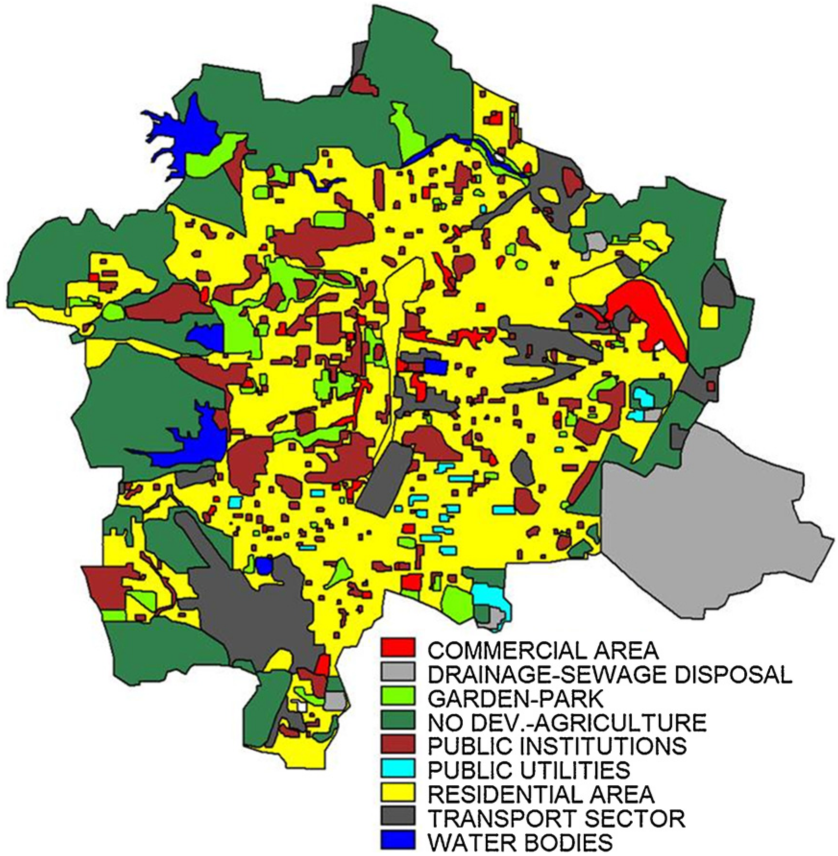

Fig. 4. City plan map of Nagpur, India.

Source: Nagpur Improvement Trust.

Table 1
Zone-wise population of Nagpur city, India.

Zone	Zone number	Area (km^2)	Population	Population density (persons/km^2)	Per cent population in the zone
East	1	59.53	665,103	11,172	28
West	2	42.24	334,635	7923	14
North	3	43.09	398,667	9251	17
South	4	64.52	662,110	10,262	27
Central	5	11.43	337,484	29,519	14
	Total	220.82	2,398,000	68,127	100

Table 2
Zone-wise land use in Nagpur city, India.

Class/land use	Area (km^2) under different land uses in city zones					
	East	West	North	South	Central	Total
Forest	0.9	6.78	5.38	4.59	2.09	19.74
Open land	13.72	14.78	8.63	12.13	0.25	49.51
Cultivation	13.53	3.88	8.93	9.51	1	36.85
Plantation	2.95	4.41	3.63	6.55	1.27	18.82
Habitation	28.13	10.85	15.39	31.49	6.57	92.42
Water bodies	0.31	1.53	1.13	0.25	0.26	3.48
Total	59.53	42.24	43.09	64.52	11.43	220.82
Green space	17.38	15.07	17.94	20.65	4.36	75.41
Per capita green space m^2	26	45	45	31	13	31

left for cattle and dairy development in the eastern part of the town; most of this land is presently under agriculture and has very fertile soils.

Natural vegetation

The natural vegetation of the city is very diverse. The frequency of species, families and genera was checked at district versus city level (Table 3). During the floristic survey, 124 different trees species belonging to 38 families were observed which indicated that the city has diversity of different tree flora. The East zone comprises low vegetation (Fig. 5) while thick vegetation occurs in west zone. The North zone has well diversified forest cover because of Gorewada park where the south and central zone meet. The zone wise distribution of the taxonomic structure of woody species is given in Table 4.

Comparison between taxonomical features of the city and district (Table 3) shows that the city has a well diversified vegetation

Table 3
Taxonomical features of vegetation in Nagpur city and district, India.

	Dicotyledons		Monocotyledons		Trees canopy	
	Number	%	Number	%	Number	%
NagpurDistrict						
Families	115	80.99	27	19.01	51	35.92
Genera	528	77.76	151	22.23	138	20.32
Species	841	74.03	295	25.95	188	16.55
Nagpur city						
Families	92	81.08	19	17.12	38	34.23
Genera	349	80.05	87	19.95	101	23.17
Species	512	78.77	138	21.23	124	19.08

District data source: Ugemuge (1986).

with almost equal number of families, genera, and species that found in the district.

Cassia siamea, *Acacia lecophloea*, *Azadirachta indica*, and *Mimosa leucocephala*, *Dalbergia sissoo*, *Hardwickia binnata*, *Butea monosperma*, *Albizzia lebbeck* are tree species that are widely distributed dominantly across the city. Deciduous trees are often mixed with thorny orthophyllous shrubs. Tree elements are mixed with shrubs and climbers. In the city, 26 species of microphyllus trees belonging to 9 families were documented. Majority of microphyllus trees are from family Mimosaceae and Caesalpiniaceae. They are natural i.e. wild rather than cultivated or planted and in accordance with the climatic condition of the city (high temperature, dry air, intense light). The city is also covered with open seasonal sclerophyllous species i.e. with thorny outgrowths, short grass meadows with a few shrubs, and scattered trees. The meadows are broken up at various places by rivers, rivulets and streams. In such areas tree vegetation is not prominent. However, very few scattered trees and a few shrubs and climbers are encountered. The probable reason for the lack of dense vegetation in this region appears to be soil composition.

Garden trees

Ornamental trees are generally planted in the gardens and parks. Nagpur has more than 94 public gardens. Although there are no private gardens, residential houses have a lot of plantings. Civic bodies like Nagpur Improvement Trust (N.I.T.) and NMC have developed 50 gardens across the city. These gardens occupy in all 0.73 km^2 in all. Besides these, Panjabrao Deshmukh Agricultural University has three gardens, namely Satpuda Botanical garden, Maharajbagh garden and Telenkheri garden. State forest department has conserved and developed a garden on Seminary Hill (named Japanese garden).

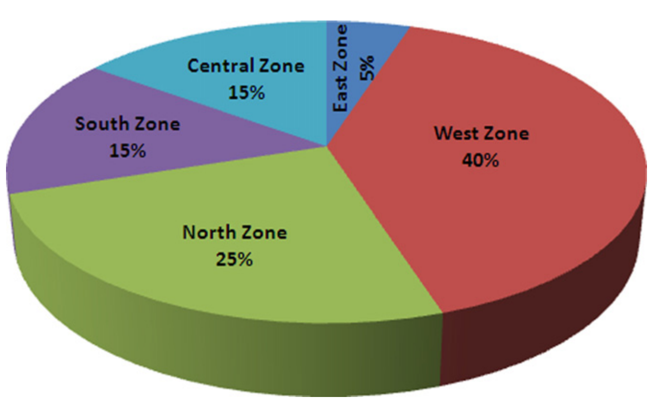

Fig. 5. Per cent tree canopy cover-Nagpur Zonal abundance.

Table 4
Zone wise comparison of major woody elements in Nagpur city, India.

Zones	Per cent canopy cover	Dominant tree species
East	5%	*Dalbergia sissoo*, *Delonix regia*, *Acacia lecophloea*, *Azadirachta indica*, *Mimosa leucocephala*, *Mangifera indica*, *Pithocoelobium dulce*, *Cassia siamea*, *Pongamia pinnata*
West	40%	*Acacia nilotica*, *Acacia lecophloea*, *Polyalthia longifolia*, *Mimosa leucocephala*, *Cassia siamea*, *Dalbergia sissoo*, *Kigellia pinnata*, *Grewia hirsuta*, *Phoenix sylvestris*, *Tectona grandis*, *Mangifera indica*, *Ailanthus excelsa*, *Azadirachta indica*, *Pongamia pinnata*, *Butea monosperma*, *Eucalyptus* sps., *Pithocoelobium dulce*, *Bauhinia racemosa*, *Randia dumeratum*, *Ceroscoides* sp., *Mitragyna parvifolia*, *Putranjeeva roxhburgii*, *Ailstonia scholaris*, *Zizyphus jujuba*, *Z. oenoplea*, *Delonix regia*, *Cassia fistula*, *Erythrina variegata*, *Bombax ceiba*,
North	25%	*Mimosa leucocephala*, *Cassia siamea*, *Eucalyptus* sps., *Acacia nilotica*, *Acacia lecophloea*, *Azadirachta indica*, *Hardwickia binnata*, *Gmelina arborea*, *Acacia catechu*, *Buchanania lanzan*, *Phoenix sylvestris*, *Bauhinia racemosa*, *Cassia fistula*, *Dalbergia sissoo*, *Delonix regia*, *Termanalia arjuna*, *Cleistanthus collinus*, *Albizzia procera*, *Anogeissus latifolia*, *Butea monosperma*, *Pterocarpus marsupium*, *Pongamia pinnata*, *Pithocoelobium dulce*, *Ziziphus glaberrima*, *Neolamarkia kadamba*, *Gardenia resinifera*, *Mitragyna parviflora*, *Morinda citrussifolia*, *Randia dumeratum*, *Ceroscoides* sp., *Santalum album*, *Grewia hrisuta*, *Grewia tilifolia*, *Tectona grandis*, *Soymida febrifusa*, *Erythrina variegata*, *Bombax ceiba*,
South	15%	*Acacia lecophloea*, *Cassia siamea*, *Azadirachta indica*, *Eucalyptus* sps., *Pongamia pinnata*, *Butea monosperma*, *Tectona grandis*
Central	15%	*Acacia lecophloea*, *Cassia siamea*, *Azadirachta indica*, *Delonix regia*

Different plant species planted along the city's roads are:

(1) *Main roads:* Trees are planted 10–20 m away from the centre of road; *D. sissoo* is the most common species along these roads. *C. siamea*, *A. lebbeck*, *A. indica*, *H. binnata*, etc. are also planted.
(2) *Link roads*: These are very narrow roads not exceeding 12 m width. Trees generally planted on such roads are *Delonix regia*, *C. siamea*, *Cassia fistula*, *A. lebbeck*, *Acacia nilotica*, *A. indica*, *H. binnata*, *Pithocoellobium dulce*.

Roadside trees are generally planted for shade by N.I.T. and NMC. A total of 28 different types of trees used for their bioasthetic value are found. The majority of the trees are from the *Caesalpiniaceae* and *Mimosaceae* families.

According to the survey conducted by Nagpur Municipal corporation in 2011, the city has 1.765 million trees in total.

Other benefits of urban forestry in Nagpur

A small survey was carried for the collection of data from the residents along the borders of city. It was estimated that nearly 3% of the population depended on forest for fuelwood collection, medicinal plants collection, livestock grazing and other types of utilization of forest resources. It was also noted that in peri-urban

Table 5
Comparative ambient air quality in major cities of India (2008).

	Major air pollutant concentration (µg/m^3)		
	Sulphur dioxide (SO_2)	Nitrogen dioxide (NO_2)	Respirable Suspended Particulate Matter
National standard	80	80	100
Chennai (Adyar)[a]	7	12	94
Delhi (BSZM)	7	10	133
Mumbai (Sion)	35	103	293
Nagpur (Sadar)	6	18	53

Data source: CPCB (2009).
[a] Places in parenthesis indicate the area of sampling in the city.

areas like Gorewada region, Seminary Hills areas, University Campus area, Dabha area, Khapri, Dighori, indigenous peoples around the forest areas of Nagpur city depend to varying degrees on forests like trees are a source of their livelihoods; not just for food but also for fuel, for livestock grazing and for medicine. The bark, seeds, leaves and flowers of some trees like neem are also a source of natural medicine for the urban poor.

Tree transpiration and tree canopies affect air temperature, radiation absorption and heat storage, wind speed, relative humidity, turbulence, surface albedo, surface roughness and consequently the evolution of the mixing-layer height. These changes in local meteorology can alter pollution concentrations in urban areas (Nowak et al., 1998). The ambient air quality of the major cities of India in comparison with the Nagpur city (Table 5) shows that it is quite good as indicated by relatively low contents of RSPM. National Ambient Air Quality Standards (2009) for cities in India stipulate SO_2, NO_2 and Respirable Suspended Particulate Matters (RSPM) content in air to be less than or equal to 80, 80 and 100 µg/m^3, respectively. Detailed study in the major five zones demonstrates the value of urban forestry in arresting pollution as evidenced by relatively poor air quality in North (Sadar) and East (Itwari) zones in comparison with the West (Civil lines), Central (RBI) and South (NEERI) zones where green cover is decisively more (Table 6 and Fig. 6). In the commercial area the CO_2 level is highest (366 ppm), probably partly because of lowest vegetation and vehicular pollution.

Biodiversity of green space is also an important dimension. Nagpur city has a relatively diverse vegetation comprising about 750 species of both dicotyledons and monocotyledons out of which 124 species are of trees. Higher density as well as higher biodiversity of vegetation enables the plants to absorb larger amount of CO_2 from the atmosphere thereby maintaining its concentration at lowest possible concentration (Chaudhari et al., 2007). In comparison, a study on urban forests in Bangalore city in India (Sudha and Ravindranath, 2000) identified 374 species in the different land-use categories. Species richness was found highest in parks (291 species), followed by residential areas (164), institutions (126), and temples (107). Although, density of street trees in Bangalore is lower than many other Asian cities, the species diversity is high (Nagendra and Gopal, 2010). From the perspective of biodiversity, the golden rule is: the larger the urban forests, the richer the biodiversity, i.e. the number of plants and animals species often

Table 6
Zone wise ambient air quality in Nagpur city, India (2008).

	Major air pollutant concentration (µg/m^3)								
	Sulphur di-oxide (SO_2)			Nitrogen di-oxide (NO_2)			Respirable Suspended Particulate Matter		
National Standard	80			80			100		
Zoneand location	Min	Max	Average	Min	Max	Average	Min	Max	Average
East (Itwari)[a]	6.39	18.93	12.66	25.4	49.86	37.63	76	115	95.5
West (Civil lines)	5	13	7.89	17	47	27.84	33	87	55.89
North (Sadar)	6	12	9.29	18	46	33.57	52	98	74.71
South (NEERI)	7	11	9	17	58	37.5	32	85	58.5
Central (RBI)	4.96	15	9.98	18.25	35	26.63	30	81	55.5

Data source: NEERI (2008).
[a] Places in parenthesis indicate spot of sampling.

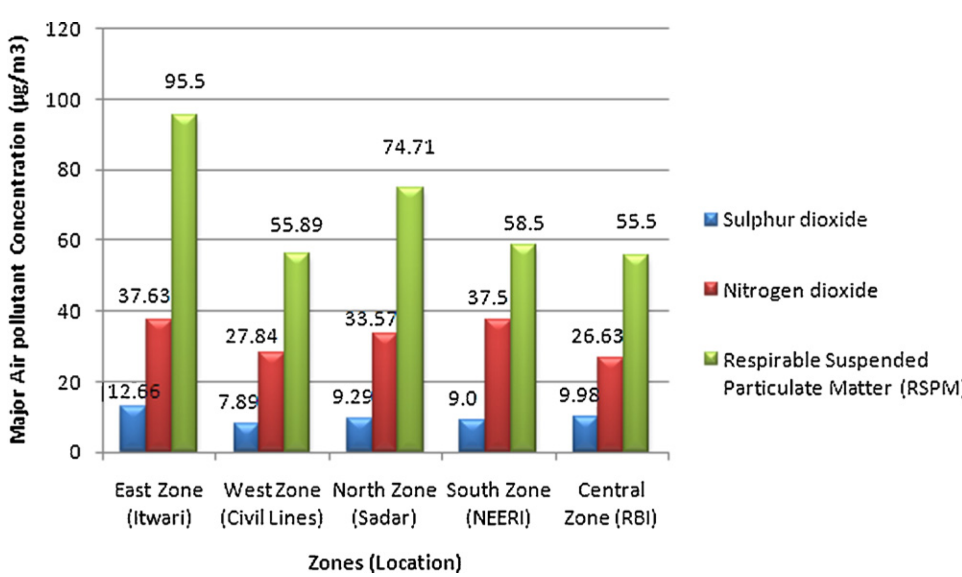

Fig. 6. Zone-wise ambient air quality in Nagpur city during 2005–08.
Data source: National Environmental Engineering Research Institute, Nagpur.

increases with increasing size of urban green spaces. Thus, maintaining larger green spaces with high structural diversity might have helped Nagpur city in maintaining a high plant diversity.

This study's findings should be adequate to initiate a systematic urban green space development programme in Nagpur to facilitate its development as a world-class city. However, we recognize that urban forests in India are not very well studied where species selection, planting methods, pollution control, carbon storage; energy/soil/water conservation aspects are concerned. Research that quantifies the spatial extent, species diversity across different urban land use, growth and mortality, urban tree biomass, diameter distribution of urban trees across various species, present carbon storage and rate of carbon sequestration by urban trees and urban forest, pollution mitigation potential, and hydrological functions of urban forests is urgently required. The findings will also be interesting to revisit after 4–5 years as the city is expected to peak in terms of population growth and most of the land uses would have occurred to alter the urban landscape for decades to come. Such an analysis will provide definite strategies as development continues in other tier II cities of India and by extension in Asia.

Discussion and conclusions

According to the Asian green cities index report (Siemens, 2011), Indian cities (22 cities) on an average have 17 m^2/person green space. Wang et al. (2007) report that developed countries tend to adopt a general standard of green space of 20 m^2 per person. Based on these reports, it could be concluded that Nagpur has a rather good green space provision. The current rules and regulations of the state and city governments impose stringent conditions prior to approval of change in land use from forest/plantations to other purpose. Relatively easy rules govern change of land use from agriculture to non-agriculture uses like residential or industrial development. Thus the civic bodies need to guard the green space in East zone where there is no forest but substantial area is under cultivation and hence vulnerable to unregulated land use change. The loss of green cover in Central zone serves as an example in this regard. The city in general has reasonably good biodiversity of tree species. Lower biodiversity as concerns avenue trees could be attributed to the priority accorded to providing a 'green rib' as early as possible rather than adding beauty and colour to Nagpur. For obvious reasons, choice of species for avenue plantation needs to be revised to include maximum possible viable species.

Although current data shows that Nagpur city has relatively greater per capita green space. The green spaces are however not well distributed. Arguments are made for revising rules governing land use changes especially from agriculture to residential or other purpose within city limits. It is recommended to expand the choice of species for avenue plantation and guard against the fast occurring changes in south zone.

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