

Tree density and canopy cover in the urban areas in Gujarat, India

H. S. Singh

Total tree enumeration, a first initiative of its kind in India, was done in 2011 in all urban areas in Gujarat. The enumeration data were analysed to find out tree cover and density, tree cover per inhabitant and carbon store in the urban areas. About 6.55 million trees grow in 167 urban areas (municipal corporations and municipalities) with average tree density of 18.9 trees/ha. Thirty-four cities and towns have adequate tree cover with tree density above 30 trees/ha and the rest have low tree cover. The canopy cover (53.9%) and tree density (152 trees/ha) in Gandhinagar, the capital city of Gujarat, are the highest in India; thus Gandhinagar may be listed amongst the greenest cities in the world. The status of tree cover in small and medium cities in the background of growing urbanization has also been discussed. Need for adequate number of trees as environment infrastructure in the urban areas to address growing environmental issues, has been highlighted. The tree canopy cover in some of the urban areas in India and other countries has been discussed to develop a norm of minimum tree cover in the urban areas in India.

Keywords: Green cover, tree cover, urban forestry, urban trees.

A century ago, just about one-tenth of the global population was living in the cities, which now exceeds 50% (ref. 1). In the context of rapid urbanization and growing environment problems, there is a need of social awareness campaign for the governance of urban systems that counters the menace of defacement of patches of tree cover and sensitizes the issues of environment – green space, hygiene, sanitation and solid waste management. Such governance is now essential in the cities and towns in developing countries such as India where urbanization is at an unprecedented rate.

Trees in city forests and woodlands, parks and gardens, schools, hospitals, institutional compounds or on the streets in the urban landscape improve air and water quality; reduce pollution and suspended particle matter; bring cooling effect and save energy; provide biodiversity richness and recreational and educational benefits and bring positive impact on human health and social life². In other words, trees are major environment capital assets and infrastructure in cities that require care and maintenance. The Green India Mission (GIM), one of the missions under India's National Action Plan on Climate Change (NAPCC), has recognized these roles of urban trees and has aimed to enhance tree cover in the urban and peri-urban areas in over 200,000 ha in a decade³.

Immense environmental, ecological and economic benefits from urban forest have been documented in some countries. Urban land in USA currently occupies about 28 million hectare (m ha) which stores approximately 704 million tonnes (mt) of carbon in trees with an estimated annual net carbon sequestration of around 22.8 mt. Besides directly storing carbon, urban trees also reduce carbon dioxide emissions by cooling ambient air and allowing residents to minimize annual heating and cooling and remove particulate matter and other pollutants⁴. Similar assessment has been done for some cities in Asia, such as those in China and Japan to strengthen urban forestry activities. Carbon sequestration and release of oxygen, important functions of the trees, are related to the tree species, their dimension and age. For example, the large healthy trees remove more air pollution and carbon annually than small trees.

Strategic urban planning using a green infrastructure approach focuses on how to identify the lands to grow trees and the rest of lands to accommodate development, in order to help communities balance environmental and urban growth. The sustainable urban development concept with adequate tree cover addresses the need of planners to adopt a green infrastructure approach and presents the technical means to incorporate trees into planning. This also guides communities to develop urban forestry programmes to capture the social and environmental benefits of trees. In this approach, the urban forestry professionals learn the interface with the urban planning process to maximize green infrastructure and reduce grey

H. S. Singh is in Social Forestry Division, Sector 10A, Aranya Bhavan, Gandhinagar 382 010, India. e-mail: hss.ifs@gmail.com



Figure 1. Map of districts and major cities in Gujarat.

infrastructure costs. Climate change is one of the few issues that influence the assessments and actions of governments and citizens. Principles and practices of ecological landscaping fit well with concerns about the effects of climate change. To know the status of tree cover and also design urban forestry programmes, tree survey and enumeration, the first such exercise in India, was planned in all urban areas in Gujarat. The objectives of the exercise were to estimate the number of trees and status of tree cover in the urban areas; to gather baseline information to monitor trend of tree cover; to find out the preferences of tree species; to assess changes in tree cover in future; to assess carbon store and also scope of carbon sequestration, and to develop plans for improving tree cover in the cities and towns.

The study areas

Gujarat in the western part of India is one of the major states out of 28 states and 7 Union Territories in India. The tree enumeration and survey have been done in all urban areas in Gujarat in 2011, which cover about 1.77% of the state's geographical area against about 3% of earth's urbanized terrestrial surface in the world¹. There are eight Municipal Corporations – major cities, each of them surrounded by the buffer zone of villages under the Urban Development Authority (Figure 1). Also, there are

159 medium and small cities/towns, which are known by different municipalities in Gujarat. Total tree counting was done in all these cities and towns, which cover a total area of 345,762 ha. Villages under Urban Area Development Authorities around the eight municipal corporations were also included to estimate tree cover. Compared to other parts of India, the urbanization in Gujarat is relatively fast. The urban population in Gujarat has increased from 28.1% in 1971 to 42.6% (25.7 million) of the state's total of 60.3 million in 2011. With the present trend, forecasts suggest that, by 2021, about 35 million people constituting nearly half of the state population would be residing in the urban Gujarat (Urban Department, Gujarat, 2011).

Methodology

The State Government has established a Social Forestry Division in each district, except Dangs district under the Social Forestry Wing of the Gujarat Forest Department to implement programmes of tree plantation outside the forest areas. Also, every taluka (administrative unit under a district) in Gujarat has social forestry organization. The Social Forestry Wing of the Department decided to conduct total tree counting in all municipal corporations and municipalities in the state for proper planning of urban forestry. The areas under Urban Development Authorities

of the Municipal Corporations were also included in this exercise. Within the boundaries of municipal corporations (mahanagar palikas) and municipalities (nagar palikas), all trees standing in parks and gardens; compounds of schools, colleges and institutions; along streets and roads; cantonment area; forest lands; individual premises and any other such areas were counted in different diameter classes. In the areas under Urban Development Authority – peripheral areas of the major cities, tree counting was done in randomly selected villages (about 11% of total villages) and the data were projected to estimate the tree population. The enumerations of trees were done from September to December 2011, and verification of counting was done in December 2011 and January 2012. The Additional Principal Chief Conservator of Forest, Social Forestry, Gujarat, had planned and coordinated the urban tree census at the state level. The counting in cities at district level was organized and conducted by the Deputy Conservator of Forests in charge of the district whereas Assistant Conservator of Forest and Range Forest Officers coordinated and conducted tree counting in the municipalities. The teams for each urban area consisting of foresters, forest guards, members of NGOs, students and members of urban bodies were constituted, and they were guided and trained about the methodology to count and measure the girth of the trees above 10 cm at breast height (GBH; girth at breast height). About 2160 forest staff, employees of municipal corporations, students and member of NGOs worked to count trees. Labourers were also employed to help the staff. In this tree census, tree stems of each species were counted in the 11 girth (GBH) classes (10–30 cm, 30⁺–45 cm, 45⁺–60 cm, 60⁺–75, 75⁺–90 cm, 90⁺–120 cm, 120⁺–150 cm, 150⁺–200 cm, 200⁺–250 cm, 250⁺–300 cm and above 300 cm).

Tree cover in Gandhinagar, the capital city of Gujarat, was also assessed using remote sensing data (IRS-P6: LISS III FCC) of November 2011. The false colour composites (FCC) of IRS-P6 and LISS IV have been enlarged using an optical instrument PROCOM II and visual analysis has been done for delineation of tree-cover classes based on image interpretation key. The interpretation was done on a 1 : 50,000 scale.

Results and discussion

Initiatives in Gujarat

The first planned urban afforestation in Gujarat was done in Gandhinagar, after a decision of the Government to develop a barren area as the state capital. The Forest Department was the first to step in to start tree plantation in a planned manner in mid-1960s. From 1971 to 2011, a total of about 3.50 million seedlings were planted⁵.

Van Mahotsav (tree plantation festival) is celebrated every year in all towns and cities of Gujarat. In 2005, the

Gujarat Urban Development Mission (GUDM) of the Urban Department and Forest Department initiated a new tree plantation scheme (Nagar Nandan Van Yojana) in 129 urban areas in 2005–06 to plant 834,000 tall seedlings and also to distribute about 633,000 seedlings to the people. This programme helped improve tree cover in several towns. Subsequently, this plan was extended to other towns. The Urban Department also implemented plantation schemes separately to improve greenery in the cities. Tree plantation in campaign mode was also carried out in some cities such as Ahmedabad, Surat and Vadodara. Through notification of the Gujarat Urban Development Department in November 2009, the Government emphasized Urban Green Plan to improve tree cover. The provision for creation of cultural forests, oxygen park, green guard, etc. has been made to involve people, NGOs and civic society to plant trees in the open space. The Urban Authorities are advised to earmark certain per cent of the budget for raising trees.

In 2004, Gujarat initiated another programme to establish cultural forests (Sanskritic Van) near urban and sub-urban centres during celebration of state-level Van Mahotsav. Since then, a total of nine such forests have been created in and around cities and towns till 2012. The Urban Authorities have also replicated such forests at other sites.

Tree cover in the municipal corporation areas

The results of tree cover and tree population in Gandhinagar helped to develop an equation between tree cover and number of trees, which has been applied to estimate tree cover. A study based on remote sensing data has estimated 3075 ha of tree cover (dense + open) in Gandhinagar, which is equivalent to 8.67 lakh trees (both estimates are for 2011) and 53.9% of geographical area. Thus about 282 trees, distributed in the different girth classes, may be equivalent to 1 ha of tree cover in this area. The calculations regarding tree cover in the cities presented in this article are based on this equation⁵. Overall, Gandhinagar, Bhavnagar and Vadodara may be called as green cities of Gujarat having tree densities higher than the average density of the eight municipal corporations. Other municipal corporations – Surat, Ahmedabad, Rajkot and Jamnagar have tree densities below average (Table 1). Junagadh has less tree density within the municipal corporation boundaries, but dense forest in a large area adjoining the city, but beyond the boundaries of the municipal corporation, improves environmental status.

Trees cover in the areas of Urban Development Authorities

Villages around the major cities – municipal corporations have been included in the Urban Development Zone under the Urban Development Authority, but they are not

Table 1. Tree population in municipal corporation areas – eight major cities in Gujarat

Municipal corporations (major cities)	Human population	Geographical area (ha)	Number of trees (above 10 cm GBH)	Tree cover (ha)	Tree cover/inhabitant (m ²)	Tree density/ha	Tree cover percentage of geographical area
Ahmedabad	5,570,590	46,985	617,090	2,188	3.9	13.1	4.66
Surat	4,462,000	39,549	333,970	1,184	2.7	8.4	3.00
Vadodara	1,666,700	16,264	747,190	2,650	15.9	45.9	16.29
Gandhinagar	208,300	5,700	866,670	3,075	147.6	152.0	53.90
Rajkot	1,287,000	10,400	137,520	488	3.8	13.2	4.69
Bhavnagar	593,770	5,320	475,950	2,106	35.5	89.46	21.35
Junagadh	320,250	5,670	76,690	272	8.5	13.5	4.80
Jamnagar	529,310	3,434	45,880	1,877	3.1	13.4	4.74
Total	14,637,920	133,322	3,300,960	13,840	9.5	24.8	8.78

Table 2. Estimate of trees and tree cover in the area of Urban Development Authorities

Urban Development Authority	Number of villages	Area (ha)	Total number of trees	Tree density/ha
AUDA (Ahmedabad Urban Development Authority)	67	59,375	79,5470	13.40
RUDA (Rajkot Urban Development Authority)	54	56,224	16,6410	2.96
VUDA (Vadodara Urban Development Authority)	98	55,200	1814,360	32.87
SUDA (Surat Urban Development Authority)	94	32,651	464,510	14.23
BADA (Bhavnagar Urban Development Authority)	15	13,147	180,910	13.76
JUDA (Junagadh Urban Development Authority)	40	30,722	369,780	12.04
JADA (Jamnagar Urban Development Authority)	26	24,142	308,390	12.77
GUDA (Gandhinagar Urban Development Authority)	39	38,800	2260,100	58.25
Total	433	310,261	6,359,930	20.50

a part of the city till date. Urbanization in these villages is fast, and some of them have turned into sub-urban areas and are integrating fast with the municipal corporations. The tree populations in the areas of eight Urban Development Authorities have been estimated (Table 2).

Tree cover in the villages around Gandhinagar and Vadodara is good, and it is poor in the area of Rajkot Development Authority. In Gujarat, it is difficult to increase tree cover beyond a certain limit in the municipal corporation areas due to non-availability of space. This can be compensated by increasing tree cover in the sub-urban areas under the respective Urban Development Authorities. A large number of lakes/ponds in the villages around the municipal corporation areas should be preserved and their status should be improved by planting suitable trees like *Ficus sp.*, *Azadirachta indica*, *Syzizium cumini*, *Manilkara hexendra*, *Mangifera indica* and *Acacia nilotica*.

Average tree density in Anand district, one of the greenest districts, is over 68.4 trees/ha, although there is no forest area in the district. Rural non-forest areas in Nadiad, Mehsana and Gandhinagar have an average tree density above 50 trees/ha (ref. 6). It is possible to achieve this level of tree cover under intensive agro-forestry and horticulture programmes in the villages around the municipal corporations.

Tree cover in municipalities (nagar palikas)

Geographical area of 159 municipalities in Gujarat is about 212,440 ha. A total of 3,244,160 trees having GBH

above 10 cm were counted in these municipalities with average tree density of about 15.27 trees/ha and tree cover of about 5.4% of geographical area. Of the 159 municipalities, 8 have high tree density above 50 trees/ha, 23 municipalities have moderate tree density between 30 and 50 trees/ha, 58 have tree density between 10 and 30 trees/ha and the remaining 70 municipalities have very poor tree cover – below 10 trees/ha.

The salient findings of the tree counting and survey in the municipal corporations and municipalities are as follows (Table 3).

(i) Eight municipal corporations support about 3.30 million trees, whereas 159 municipalities have 3.24 million trees. Thus, about 6.55 million trees grow in cities and towns in Gujarat. Average tree cover in the eight municipal corporations is 8.78% of geographical area, and the average tree density and tree cover per inhabitant are 24.8 trees/ha and 9.5 m² respectively, which is below the average in the developed countries.

(ii) Before establishment of Gandhinagar in late 1960s, the present area of the capital city was barren and dusty with poor tree cover. Afforestation programme during the last four decades is noteworthy, as Gandhinagar is now the greenest city in India in terms of tree density.

(iii) Amongst all major cities in India, tree density is highest in Gandhinagar^{5,7}. The green cover in Bhavnagar and Vadodara is comparable with the major green cities in India. Among the eight major cities, five – Surat, Rajkot, Jamnagar, Junagadh and Ahmedabad have inadequate tree cover. Victoria Park (202 ha) in Bhavnagar

Table 3. Summary of tree cover in the urban areas

Description	Total of eight municipal corporations	Total of 159 municipalities	Total of 167 urban areas
Area (ha)	133,322	212,440	345,762
Human population	14,637,920	11,062,100	25,700,000
Tree population	3,300,980	3,244,160	6,545,140
Average tree density (trees/ha)	24.76	15.27	18.93
Tree cover (ha)	13,840	11,504	25,344
Per cent of total area under tree cover	8.78	5.42	7.33
Tree cover per inhabitant (m ² /inhabitant)	8.8	10.6	9.5

and Indroda Park (450 ha) in Gandhinagar have dense tree cover. Similarly, a large palace compound, gardens and compound of the Railway Staff College in Vadodara have dense tree groves. These are the main reasons for adequate tree cover in the three cities. Surat is an old city with concentration of buildings and human population. Space for growing is less within the municipal corporation area. As a result, tree density is poor. Other cities have environmental limitation. But the villages in the area of Urban Development Authorities provide scope for earmarking lands for tree plantation to cover this gap.

(iv) The municipalities in Gujarat have average tree density of 15.3 trees/ha, which is below the average tree density in rural areas (16.2 trees/ha) in Gujarat⁶. The average tree cover in the municipalities is about 5.4% of their total geographical area. Some of the municipalities have good tree cover with density above 50 trees/ha. About half of the total municipalities have poor tree cover and 70 of them have tree density below 10 trees/ha. Of them, 27 municipalities have poor tree cover – tree, with tree density below 5 trees/ha. Five municipalities have tree density below 2 trees/ha.

(v) Size of trees in Ahmedabad city was relatively large. In eight municipal corporations – major cities, about 61.8% trees belonged to 10–60 cm girth (GBH) class, whereas 30.3% trees had girth between 60 and 120 cm, 6.6% between 120 and 200 cm and about 1.3% trees had girth above 200 cm. About 4435 giant trees in the major cities had girth (GBH) above 300 cm.

(vi) In Gujarat, about 268 million trees outside forest (TOF) have growing stock of 118.0 million m³ (refs 6 and 7). On an average one tree in Gujarat may store about 207 kg carbon against India's average of 208 kg carbon/tree (refs 6–8) and has been estimated about 7.86 kg carbon/tree/year for the trees in India, although it depends on size and species of trees. The carbon stored in the tree cover in the urban areas (municipal corporations and municipalities) of Gujarat is about 1.3 mt and the present annual carbon sequestration rate is about 49,500 carbon ton, which may increase substantially if tree cover improves as planned by the state.

Tree species

Two hundred and thirty-five tree species, including exotic trees were recorded in urban areas of Gujarat. Maximum

of 226 tree species were encountered in Gandhinagar. The main tree species in the order of their decreasing number in the eight major cities are – neem (*Azadirachta indica*), *Prosopis chilensis*, deshi babool (*A. nilotica*), amaltas or garmalo (*Casia fistula*), asopalav and pendula (*Polyalthia longifolia* and *Polyalthia pendula*), peltrofurum (*Peltroforum ferruginieum*), kasid (*Casia siamia*), Gulmohar (*Delonix regia*), sirus (*Albizia lebbbeck*), kanji (*Holoptelea integrifolia*), saptarni (*Alstonia scholaris*), *Eucalyptus* sp., sharu (*Casuarina equisetifolia*), pipado (*Ficus tsila*), ardusa (*Ailanthus excelsa*) and mango (*M. indica*). Gorad (*Acacia senegal*) is dominant in the forests of Victoria Park and Indroda Park. The number of *Ficus* species – banyan (*Ficus benghalensis*), pipad (*Ficus tsila*) and peepal (*Ficus religiosa*) is also good, but their presence in all cities is felt due to their size. Neem is the most dominant tree in towns and cities in North Gujarat, Saurashtra and Kachchh. The number of *asopalav* (*Polyalthia* sp.), a species planted in gardens and compounds, is also high. Population of grazing-resistant trees like *Prosopis*, kasid, amaltas, saptaparni and kanji is increasing due to their success in plantation.

The green cities

In India, Gandhinagar, Bangalore, Chandigarh, New Delhi, Guwahati, Dehradun, Bhubaneswar and Shillong are a few cities which have relatively good tree cover and natural environment⁹. FSI⁷ has estimated 11.9% of the geographical area under tree and forest cover in Delhi and 14.9% in Chandigarh, although green space (tree cover + parks and garden, grass cover in play ground, grass cover in open space, etc.) is high. A good tree crown cover has also been estimated in Bangalore. The tree cover in Gandhinagar (53.9%) is highest amongst all cities in India. Bhavnagar and Vadodara have good tree cover (above 15% of geographical area and tree density more than 30 trees/ha), comparable with the medium green cities in the world.

The average tree cover in the 20 main metropolitan areas in USA has been estimated to be about 27.1% of the geographical area⁴. The average tree crown coverage was 26.74% in the urban and sub-urban areas in cities of Japan¹⁰. Average woodland cover has been estimated as about 18.5% of the geographical area within municipal limits of 26 large European cities (average tree cover –

104 m²/inhabitant)^{1,9}. In 439 cities in China, the overall green space was 380,000 ha or 20.1% of the urban area in 1991. Subsequently, the green cover in these cities increased to 23.0% (6.52 m²/inhabitant) by 2000 and then to 32.5% at the end of 2006, and the country is at target to achieve the green cover^{11,12}. There is no authentic information that ranks the green cities of the world, but the tree cover in Gandhinagar is at par with that in Atlanta – city which has the highest tree density in USA⁴. Atlanta has the reputation of being called the ‘city in a forest’ due to its abundance of trees, unique among major cities in USA. Similarly, Gandhinagar can be called as ‘city in a man-made forest’.

Conclusion

Urban areas, dotted with lakes, tree groves and surrounded by villages had less threat of abrupt rise in temperature during summer, but the situation is changing fast in all fronts – rise in concentration of greenhouse gases, global rise in temperature and local increase in temperature due to expansion of concrete jungles. In several big cities like Ahmedabad, the surrounding satellite areas are growing at an unprecedented rate and they are gradually merging with the big cities. The expanding concrete jungle is changing the landscape. There is a possibility of development of hot island temperature in the concrete jungle within the large urban landscape in which possibility of abrupt rise in temperature during extreme summer, beyond the tolerance of human beings, in the absence of adequate tree cover is not ruled out. Thus, maintaining adequate tree and green cover has become unavoidable in the urban areas for better life of its citizens.

Urban forests or tree groves in the urban areas are threatened by urbanization and their protection is only possible when their true values are accounted for properly to counter the forces of urbanization. True values include energy conservation, urban heat island reduction, storm water run-off, air pollution reduction, particulate pollution reduction, noise and glare control, carbon sequestration, urban recreation/enjoyment and environmental security. There is need to develop a method to account for these benefits so that it becomes compulsory for planners to maintain such norms of tree cover. Although higher norms of tree cover have been advocated in developed countries, it may not be possible in highly populated countries like India to achieve such norms of tree cover. As appears in the analysis of tree cover in the urban areas in Gujarat and also norms indicated in other studies, a norm of 15% of total geographical area under tree cover or average tree density of 30 trees/ha should be a minimum realistic target for urban planners. In addition to scattered trees, a city should be dotted with big patches of

forest or tree groves, allowing them to function as pollution sink. Also, the planning of urban forestry to achieve this norm should be linked with planning in the energy, water supply, urban infrastructure, development of new housing society, waste disposal and reclamation sites. Existing patches of natural and man-made urban forests like Victoria Park in Bhavnagar and Indroda Park in Gandhinagar should be preserved and enriched. Open space in the city – institutional areas, societies and parks, along streets and reclamation areas should be planted with suitable tree species. River banks should be made green and they should be transformed into recreation sites by improving tree cover. Establishment of urban areas should be permitted after approval of tree plantation plan to achieve the norms. Lakes and ponds in and around the urban areas should be preserved and developed by planting trees such as *Ficus* sp., amla (*Tamarindus indica*), mango, jamun, neem and other avenue trees to attract urban people and also birds. This article also provides information on how to monitor tree cover, and helps in developing guidelines for urban forestry.

1. Singh, V. S., Pandey, D. N. and Chaudhary, P., Urban forest and open green spaces – lesson for Jaipur. Occasional Paper No. 1/2010. Rajasthan State Pollution Control Board, Rajasthan, 2010.
2. Rowantree, R. A. and Nowak, D. J., Quantifying the role of urban forests in removing atmospheric carbon dioxide. *J. Arboricult.*, 1991, **17**, 269–275.
3. Anon., Green India Mission. Ministry of Environment and Forests, New Delhi, 2011.
4. Nowak, D. J., Hoehn III, R. E., Crane, D. E., Stevens, J. C. and Walton, J. T., Assessing urban forest effects and values, Washington, DC's urban forest. Resource Bulletin NRS-1. US Department of Agriculture, Forest Service, Northern Research Station, Pennsylvania, 2006, p. 24.
5. Anon., Tree cover in Gandhinagar capital city area using remote sensing technique. Internal report, Gandhinagar, Gujarat, 2011.
6. Anon., Tree wealth of the non-forest areas of Gujarat – tree census in non-forest area – 2009. Gujarat Forest Department, 2009, pp. 56–67.
7. FSI, India State of Forest Report. The Forest Survey of India, Dehradun, 2011.
8. Kishwan, J., Pandey, R. and Dadhwal, V. K., India's forest and tree cover: contribution as a carbon sink. Technical Report. Indian Council of Forestry Research and Education, Dehradun, 2009.
9. Chaudhary, P. and Tewari, V. P., Urban forestry in India: development and research scenario. *Interdiscip. Environ. Rev.*, 2011, **12**, 80–93.
10. Anon., A study on counting method for urban tree cover area using natural vegetation data. *J. Jpn. Inst. Lands. Archit.*, 2003, **66**, 859–862.
11. Wang, X.-J., Analysis of problems in urban green space system planning in China. *J. For. Res.*, 2009, **20**, 79–82.
12. Yang, J., McBride, J., Zhou, J. and Sun, Z., The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry and Urban Greening*, Elsevier, 2004, vol. 3, pp. 65–78.

Received 2 September 2012; revised accepted 21 February 2013