Urbanisation and greening of Indian cities: Problems, practices, and policies

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Abstract

Introduction

Sustainability of the Indian economic growth remains largely threatened due to the adverse impact of climate change (Prime Minister's Council on Climate Change—India). While India struggles with increase in carbon emissions and seasonal anomalies, limited availability of domestic finance confines avenues of environmental amelioration. Simultaneously, high population growth and lack of public participation constrain the effectiveness of policy initiatives. The urban population growth of 31.8 % during 2001–2011 stands in stark contrast to the simultaneous national population growth of 17.6 % (Census of India 2011). Rapid urbanisation and widespread urban sprawl have depleted green cover and increased urban vulnerability to climate change. Transformation of Southwest Indian Subcontinent Monsoon, increased severity in seasonal fluctuations, and frequent temperature anomalies remain major concerns. Furthermore, deterioration in air quality, generation of urban heat islands (UHIs), and acute water shortage worsen the living conditions. Paediatric susceptibility to respiratory diseases and vulnerability of pavement dwellers to seasonal severity have escalated tremendously in cities. The summer heat wave of 2015 claimed around 2330 lives (CNN 2015). Therefore, a study of the climate change in urban India, and exploration of economically viable avenues for its amelioration assumes urgent importance, and remains an issue of global concern.

India is currently confronted with the emergence of more than 35 cities having million-plus population (Ministry Of Home Affairs, India 2011), and is further estimated to house 14 % of the world's urban population by 2025 (McKinsey & Company 2010). Delhi, which presently houses 22.7 million residents, is the world's second most populous urban agglomeration, while Mumbai and Kolkata which rank 7th and 10th accommodate 19.7 million and 14.4 million residents, respectively. Bangalore, Chennai, and Hyderabad are expected to exceed the 10 million population threshold by 2025 (UN-DESA 2012). Emergence of urban clusters and their expansion consumes significant proportions of agricultural land and substantially impacts biological diversity.

Population growth is intrinsically linked to increased demand for energy. The compounded annual growth rate of total installed capacity for electricity generation in India during 1971–2012 stood at 6.58 % (Ministry of Statistics & Program

Implementation 2013). The building industry consumes 40 % of the national electricity consumption and is estimated to increase up to 76 % by 2040 (Centre for Science & Environment, New Delhi, India 2014). The domestic sector accounted for 22 % of the total electricity sales in 2011–2012 (Ministry of Statistics & Program Implementation 2013). Excess of domestic energy consumption may be eliminated through energy friendly practices. Around 3000–5000 kWh of energy can be saved through implementation of energy efficient measures primarily aimed at reducing building cooling needs (NHB 2015).

Increase in population has adversely affected the green cover in urban India—Chennai and Mumbai have a meagre 0.46 m^2 (Srivathsan 2013) and 0.12 m^2 (FAO 1998) of green space per capita, respectively, as compared to the UN recommended standard of 9 m^2 of green space per capita (Table 1). The shrinking of residential gardens adds to environmental degradation. Significant decrement in the area of residential gardens has been observed in Kozhikode during 2000–2010. The quantum of decrease was 2.43 m^2 for the low-income group, 14.16 m^2 for the middle-income group, and 47.35 m^2 for the high-income group (Gangopadhyay and Balooni 2012). The observed change in lifestyle at the expense of garden space indicates devaluation of urban green cover.

Table 1

Summary of UHI intensity in selected Indian cities with major contributing factors

City	UHI range		Climate	% Decadal decrement in global solar radiation	Per capita green space (m^2/inhabitant)	Identified hot spots	Major contributing factors
	Summer	Winter					
New Delhi	2.0–5.0 °C	6.0, 4–7 °C	Humid sub-tropical	3.4	21.52	Commercial, residential, mixed-use areas, and traffic	High population density High density of road network High amount of

City	UHI range		Climate	% Decadal decrement in global solar radiation	Per capita green space (m^2/inhabitant)	Identified hot spots	Major contributing factors
	Summer	Winter					
						intersections	traffic flow
Pune	2–3.1 °C	9, 10 °C	Hot semi-arid	1.5	1.4	Village nuclei and industrial sectors	Increase in population by 10 times in 20th century Modification from "bicycle city" to "motorbike city" Disproportionate increase in building heights as compared to street width Influence of katabatic wind
Visakhapatnam	2.5 °C	4.0 °C	Tropical wet and dry climate	3.9	0.18	Central and southern business district	Increase in industrialisation and urbanisation. Reclamation of

City	UHI range		Climate	% Decadal decrement in global solar radiation	Per capita green space (m^2/inhabitant)	Identified hot spots	Major contributing factors
	Summer	Winter					
							tidal swamp for port-based industries, replacement of agricultural villages by the establishment of steel plant, and replacement of fishing villages by Gangavaram port.
Chennai	2.48 °C	3.35, 4.0 °C	Tropical wet and dry climate	1.7	0.46	Concrete surfaces, runways, high traffic load	Large areas of exposed hard concrete surfaces, runways, bus parking bays High traffic

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Source Mohan et al. (2009, 2012), Deosthali (2000), Padmanabhamurthy (1990/1991), Pandey et al. (2012), Devi (2006), Rao et al. (2003), Government of India 2015a, b, Alphabetical List of Towns and Their Population, McKinsey Global Institute (2010), Vanum and Hadgu (2012), Sarma and

Sainath (1990/1991), Devdas and Lilly Rose (2009), Srivasthsan (2013), Chaudhry et al. (2011), and Attri and Tyagi (2010)

Population growth and the consequent urban expansion, increase in anthropogenic emissions, and reduced potential for evaporative cooling increment the net heat stored in urban environment and lead to UHIs. Augmentation of transport linkages (Fig. 1) has increased the road density to an average of 1.42 km/km^2 of land (Ministry of Road Transport & Highways 2012), thereby increasing the proportion of thermally active surface layers, which actively contribute to intensification of UHIs.

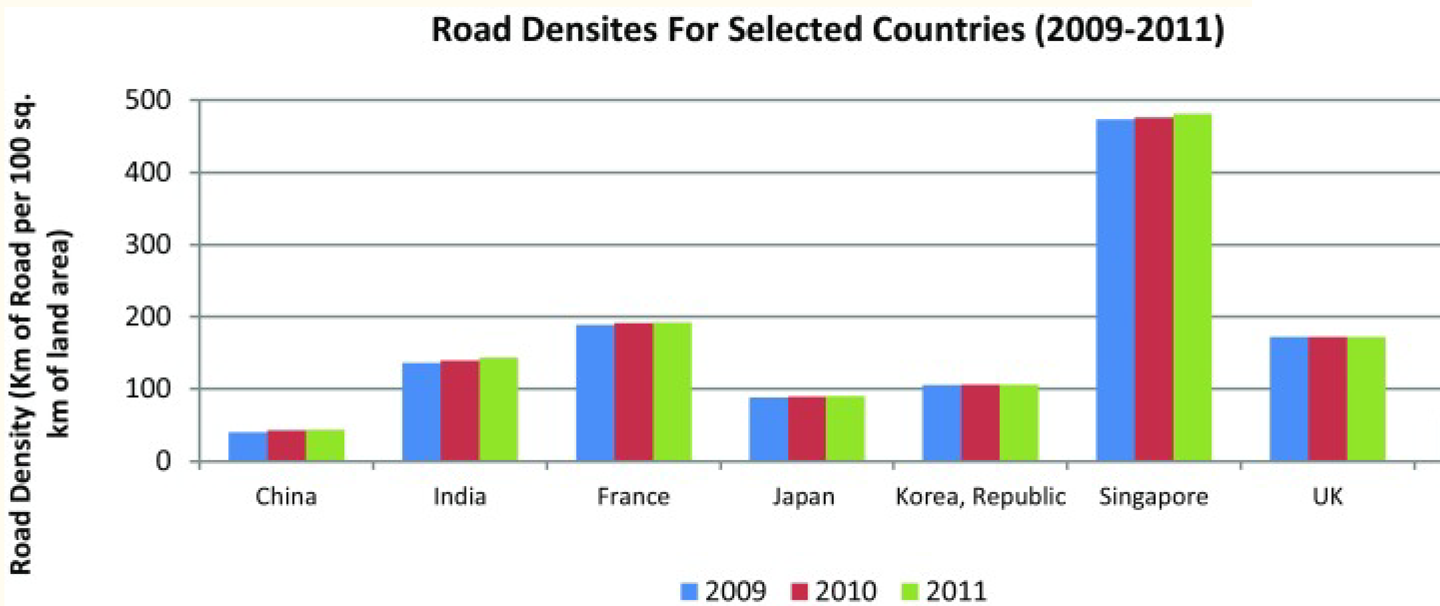

Fig. 1

Road densities for selected countries 2009–2011 *Source* Compiled using data obtained from World Bank (2014)

Table 2 provides a summary of previous research on the climatic role of greenery in urban India. It is observed that little research has been devoted to explore the passive cooling potential of urban greenery in India. This study therefore, aims to highlight the typical environmental problems arising in Indian cities due to the impact of climate change, and explores the scope of climatic amelioration through urban greening. The first objective is to study the after effects of urbanisation which are categorised into UHIs, heat stress-induced health hazards, and increase in carbon emissions. Four metropolises (New Delhi, Pune, Chennai, and Visakhapatnam), with million-plus population have been analysed to identify the prominent practices contributing to urban heating. The second objective is to study the cooling effect of urban greening through the provision of roof gardens, use of tree shade, and cooling of paved surfaces. The third objective is to propose planning guidelines for urban greening in India. Indian bye-laws and practices related to urban greening at the national level and those implemented in the studied metropolises have been enumerated, and compared with the practices followed in Singapore, London, New York, and Sydney. Comparative analysis is attempted through classification of the greening initiatives into four approach-based categories, i.e. preservation, maintenance, growth and development, and level of public participation. The generated observations have been utilised to recommend planning guidelines and policies that are expected to help in consolidating natural sustainability of Indian cities, and other emerging economies.

Table 2

Summary of published research on climatic role of urban greenery in India

Reference	City	Objective
Chaturvedi et al. (2013)	Nagpur	Study the percentage of land cover under forestry, diversity in vegetation species, and their effect on urban air quality
Vailshery et al. (2013)	Bangalore	Road segments with and without trees were studied to assess the effect of trees on urban environment
Jaganmohan et al. (2012)	Bangalore	Study the diversity, density, and distribution of greenery in domestic gardens
Gangopadhyay and Balooni (2012)	Kozhikode	Relate the technological infusion in different economic classes of the society with changes in home gardens
Dongre (2011)	Thane	Review the progress of social forestry and analyse the reasons for its success

Reference	City	Objective
Singh et al. (2010)	Jaipur	Lessons from green cities are used to emphasise the need for greening of Jaipur and provide strategies for connecting science to decision making for enhancement of urban resilience and human well being
Chaudhry and Tewari (2010)	Chandigarh	Zonal Travel Cost Method is used to study the recreational value of urban parks and gardens in attracting domestic tourists
Dwivedi et al. (2009)	Bhopal	Estimate the level of disturbance faced and ecological services rendered by the Kerwa Forest Area located near Bhopal
Alexandri and Jones (2008)	Mumbai	Study the cooling effect of roof gardens and green walls on building envelope
Chaudhry et al. (2007)	Chandigarh	Study the non-market economic valuation of environmental amenities using Contingent Valuation Method.
Sudha and Ravindranath (2000)	Bangalore	Study species composition in different land use categories and the change in vegetation cover

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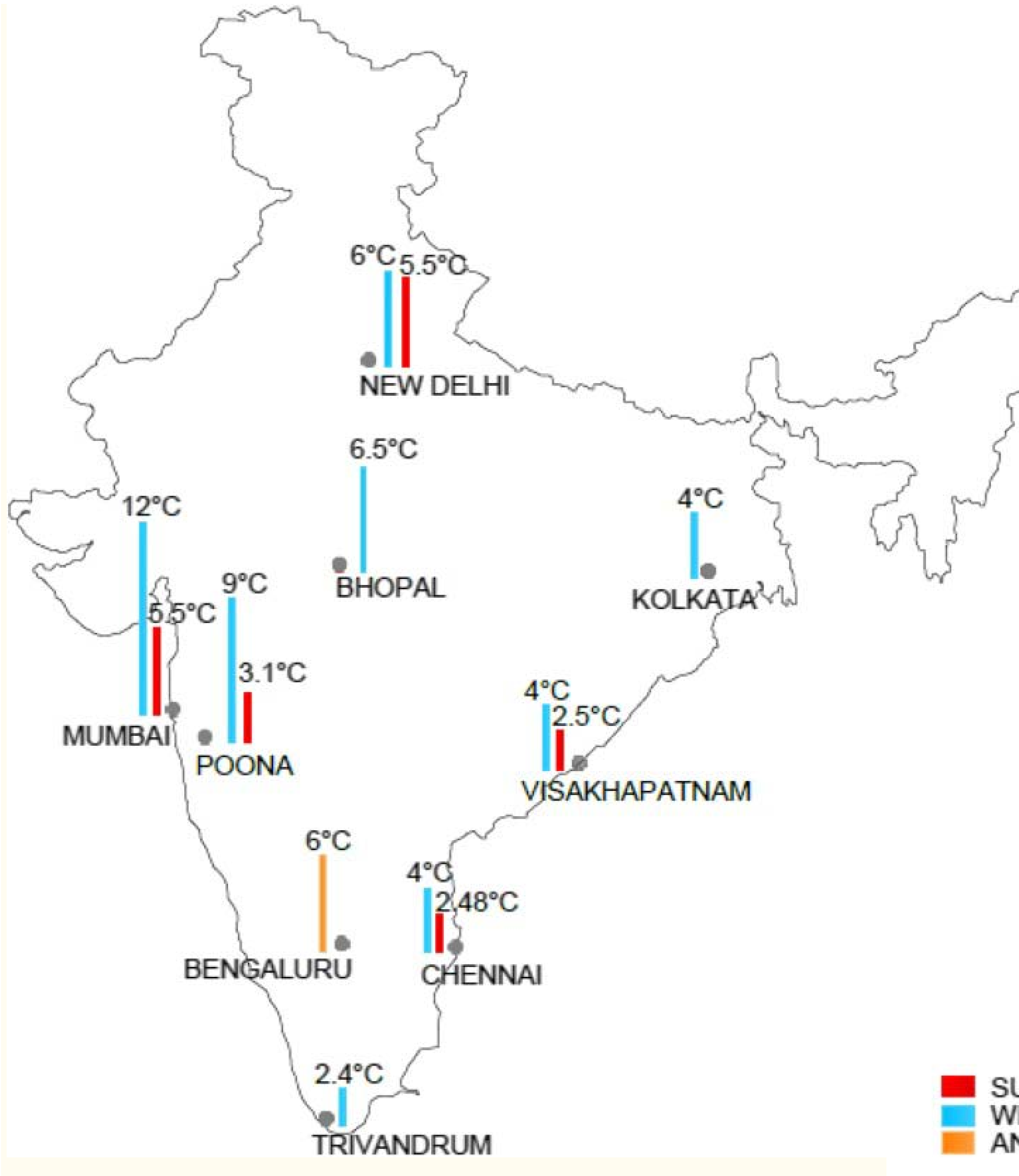
Urban heat islands

Urban sprawl and unplanned growth of Indian cities pose significant threat to the local climate. Previous research from various sources have been utilised to study the UHIs in the selected cities of New Delhi, Pune, Chennai, and Visakhapatnam. Table 1 provides a summary of the UHIs and enumerates the contributing factors.

While the inland cities of Pune, Bhopal, and New Delhi remain intensely heated, the cooling effect of sea restricts increase of temperature in the coastal cities of Chennai, Trivandrum, and Visakhapatnam (Fig. 2). In contrast, the seaward city of Mumbai witnesses highest winter and summer heat island intensities, which may be due to the prominent escalation in atmospheric pollution and high population density.



6°C
5.5°C
NEW DELHI
6.5°C
BHOPAL
4°C
KOLKATA
12°C
5.5°C
MUMBAI
9°C
3.1°C
POONA
4°C
2.5°C
VISAKHAPATNAM
6°C
BENGALURU
4°C
2.48°C
CHENNAI
2.4°C
TRIVANDRUM
SU
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AN

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Fig. 2

Observed intensities (°C) of UHIs in Indian Cities. *Source* Devdas and Lilly Rose (2009), Deosthali (2000), Mohan et al. (2009), Devi (2006), Gopinath et al. (2014), Ansar et al. (2012), and Padmanabhamurty (1990/1991)

Heat stress-induced health hazards

Warmer neighbourhoods increase the vulnerability of residents to heat exposure (Harlan et al. 2006). Heat waves aggravate thermal discomfort in heat islands, often culminating in health issues. Heat stroke, heat exhaustion, infectious diseases, and cardiovascular and respiratory problems aggravate during summer seasons (Harlan et al. 2006). The population group most susceptible to these harmful effects comprises the poor, the physically weak, and the elderly (CDC 2015). More than 21 % of the Indian population lives below the poverty line (Reserve Bank of India 2013), and remains extremely vulnerable to health hazards. Out of the ninety-three heat waves recorded in Visakhapatnam between 1951 and 2000, 31 were classified as “severe”, and may lead to aggressive behaviour and heat-related deaths (Devi 2006). The number of casualties due to heat waves has increased from 1900 in 2003 (Harlan et al. 2006) to 2330 in 2015 (CNN 2015). Noticeably, most of the affected belonged to the labour class (The Times of India 2015), thus exposing the increased vulnerability of the poor to heat stress.

Increase in atmospheric pollution and carbon emissions

Analysis of the decadal global solar radiation recorded at eleven Indian cities shows a statistically significant decreasing trend (Table 1). This has been attributed to cloud cover, and change in atmospheric aerosol load due to industrial smoke release and biomass burning. Although the trend subsided in North America, China, and Europe after the 1990s, it still continues in India (Attri and Tyagi 2010).

In 2011, EPA identified India and Russia as the fourth largest contributors to the global CO_2 emissions due to fossil fuel combustion, cement manufacturing, and gas flaring (EPA 2015). In 2003, the construction sector in India accounted for maximum CO_2 emissions (22 %), while the transportation industry (road transport, aviation, and shipping) contributed to 12.9 % of the national CO_2 emissions (Parikh et al. 2009). In 2007, 87 % of the total CO_2 emissions from the transport industry were attributed to road transport (MoEF 2010). Hyderabad witnessed a reduction in the content of black carbon, particulate matter, CO, and ozone by about 57 %, 60 %, 40 %, and 50 %, respectively, during a weeklong nationwide truck strike (Sharma et al. 2010). Rapid urbanisation has enhanced living standards leading to increased vehicle ownership pattern (Fig. 3). Increased number of vehicles per capita in Chandigarh has forced the concentration of Respirable Suspended Particulate Matter (RSPM) beyond the permissible levels (Chaudhry et al. 2013).

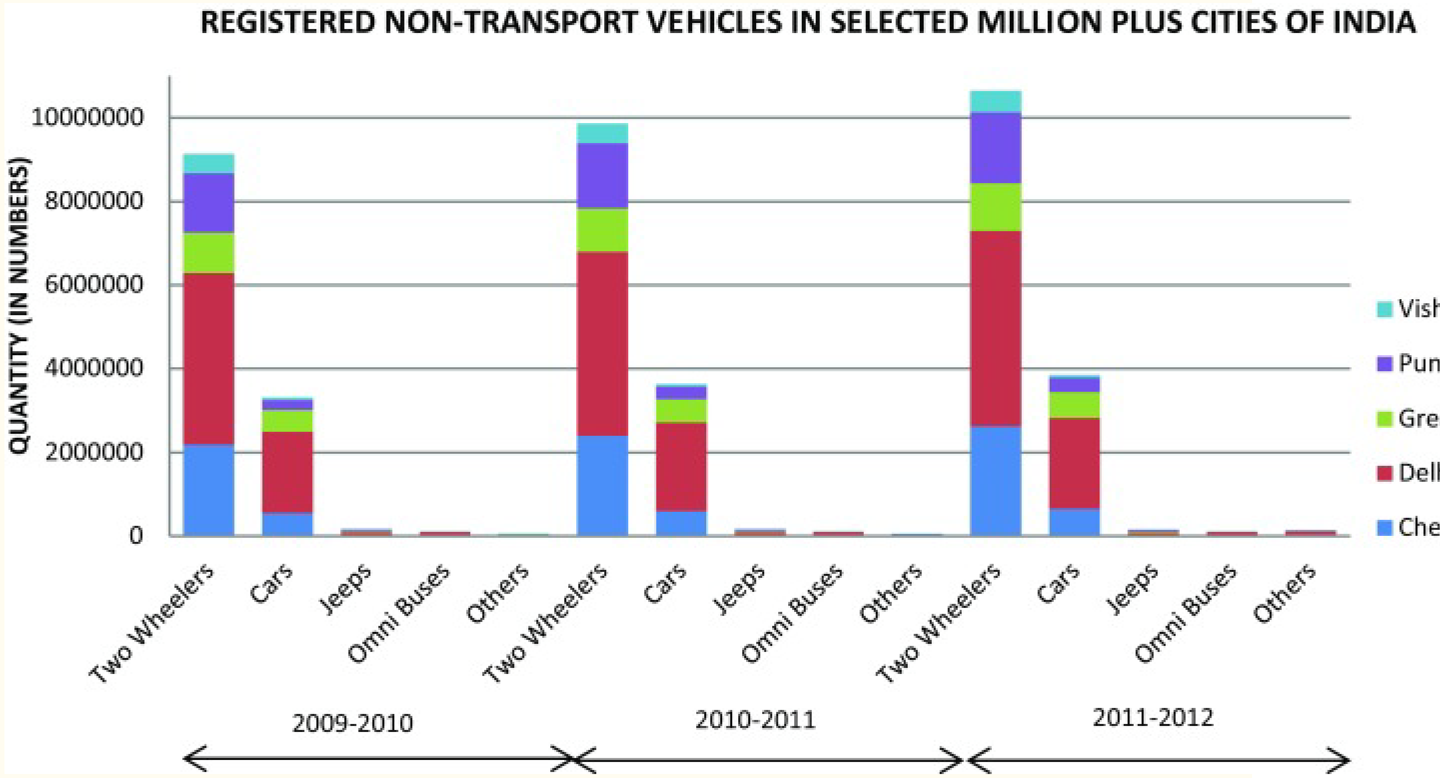

Fig. 3

Registered non-transport vehicles in selected Indian cities with million-plus population *Source* Compiled using data obtained from Ministry of Road Transport & Highways, India (2012, 2013)

Generation of volatile organic compounds like benzene, toluene, and methylene chloride leads to photochemical oxidation thereby increasing concentration of ozone and occurrence of smog (Srivastava et al. 2006; Atkinson 2000). Air quality in Mumbai is plagued with vehicular emissions, resulting in significantly pronounced concentration of benzene (Srivastava et al. 2006). Lucknow suffers from PM10 concentrations exceeding permissible standards by a factor of 1.3–3.2 (Kisku et al. 2013). Lower concentrations of particulate matter are generally observed during the monsoons due to washing out of soluble pollutants—the PM2.5 concentration reportedly reduced from 300 to 180 µg m^3 in Delhi (Pandey et al. 2012). Conversely, higher concentrations are reported during winters due to inversion and stable environment. Wind usually helps in flushing of pollutants, but perpendicular orientation of major roadways has resulted in the generation of “islands of pollution” in Pune (Deosthali 2000). In the absence of wind, aerosols get trapped in the lower atmospheric boundary layer and diminish the incoming solar radiation leading to reduced daytime surface temperatures (Pandey et al. 2012). Dimming of incoming solar radiation due to “Asian Brown Clouds” observed over the Indian Subcontinent (Ramanathan et al. 2005), and a decrease of 13.6 ± 1.4 W/m^2 per 0.1 increase in the aerosol optical depth during the pre-monsoon period over Delhi (Singh et al. 2005) justify the aforementioned observation. It should be noted that, “a negative forcing (and hence cooling) in the lower atmospheric levels may be coupled with a positive forcing (and hence warming) in the upper atmospheric levels”, thus affecting the local weather (Pandey et al. 2012).

Effect of vegetation on atmospheric pollution

Vegetation helps in the removal of atmospheric pollutants through the absorption of gaseous pollutants like SO_2, NO_2, O_3, and CO_2 primarily into the leaf stomata (Nowak 1994), dry deposition of suspended particulate emissions like PM10 (Akbari et al. 2001), bioaccumulation of heavy metal air pollution like soot, soil dust, fuel oil particles, coal ash particles, and particles from industrial emissions (Kocic et al. 2014), and daytime photosynthetic assimilation of CO_2. The green city of Nagpur (green space of 31 m^2 per capita) enjoys a healthy quality of air with concentrations of SO_2 (6 $\mu g/m^3$), NO_2 (18 $\mu g/m^3$), and RSPM (53 $\mu g/m^3$) contained well within the permissible limits of 80, 80, and 100 $\mu g\ m^3$, respectively (Chaturvedi et al. 2013). Street trees have been observed to reduce levels of suspended particulate matter and contributed to 65 % reduction in SO_2 levels in Bangalore (Vailshery et al. 2013). High swathes of green cover in Gandhinagar (green space of 160 m^2 per capita) (Sustainability Outlook 2012), and Chandigarh (green space of 55 m^2 per capita) (Chaudhry et al. 2013), appear to reduce SO_2 and NO_x concentrations. Interestingly, though Gandhinagar is a major SO_2 and NO_x emitting district in India (Garg et al. 2001), concentrations of SO_2 (3–37 $\mu g/m^3$) and NO_x (5–34 $\mu g/m^3$) remain within permissible limits around the Gandhinagar Thermal Power Plant (Padmavathi et al. 2015). Apart from filtering air pollutants and abating noise pollution, trees and green spaces aid in regulation of thermal comfort through the passive cooling of environment.

Go to:

Vegetation induced cooling

Trees and vegetative elements serve as cooling apparatus, and help to reject heat through cooling of roofs, cooling of paved surfaces, and provision of shade.

Cooling of roofs

Roofs can be cooled through the provision of roof gardens, use of reflective coating on roofs (Akbari et al. 2001; Coutts et al. 2013), provision of thin water film for evaporative cooling, and use of movable canvas or inverted earthen pots for provision of shade (Nayak et al. 1982).

Roof gardens increase the proportion of green areas and ameliorate UHIs through thermal pacification. They minimise monetary expenditure on storm water runoff management by serving as readily available media for water retention (Weiler and Scholz-Barth 2009). They render ecological utility by filtering airborne pollutants (Santamouris et al. 2011), and enhance aesthetic appeal through provision of vegetative living spaces (Weiler and Scholz-Barth 2009), breaking the monotony of concrete jungles. The soil medium insulates the roof while the vegetative layer intercepts radiation; the total system accounts for evaporative cooling. The reduction in the building cooling load and the consequent savings in energy depend on the thickness of soil, and the type and density of vegetative cover. Wong et al. (2003) observed the annual energy consumption for a hypothetical commercial building in Singapore to decrease by 5 % on changing the vegetative cover from turfs to shrubs. However, it should be noted that limited soil water content constrains the cooling potential of green roofs (Coutts et al. 2013).

In tropical climates, building roofs assume critical role in intense heat exchange during noon (Taha et al. 1988). Deosthali (2000) propounds that disproportionate increase in building heights as compared to street width further increases the importance of roofs in thermal exchange. Few studies suggest roof gardens to be undesirable during winters due to heat loss (Nayak et al. 1982; Bansal et al. 1992). However, Santamouris et al. (2011) opines that increase in heating loads is less significant than cooling energy savings. He attributes the increase in heating demands due to cool (reflective) roofs to lower solar altitudes, overcast skies, and lesser duration of sunshine hours. Nayak et al. (1982) observed roofs in Delhi with 90 % shading and heat transfer coefficient of 5.7 W/m^2 °C to provide thermal performance comparable to roof gardens. Further research is required to clarify the role of roof gardens/cool roofs in composite climates such as Delhi.

Cooling of surfaces

Vegetative growth ensures a pervious ground cover with potential for evaporative cooling. Trees shade pavements and building envelope besides reducing longwave heat gain by maintaining lower surface temperatures (Huang et al. 1987). Since road networks occupy considerable land area, avenue trees and roadside greening help to reduce ambient temperatures. A reduction of 9.26 °C in surface temperature of parking lots has been observed in Nagoya, Japan, through plantation consisting of 70 % grass and 30 % trees (Onishi et al. 2010).

Depletion and transformation of the natural landscape is a major drawback of excessive urbanisation. While decline in urban open spaces and wetlands has resulted in loss of drainage network and ground water tables in Bangalore (Sudhira et al. 2004), reclamation of tidal swamp and fishing villages for port-based industries in Visakhapatnam has led to temperature increases of 2 °C (Ramachandra and Kumar 2010) and 4 °C (Devi 2006) in Bangalore and Visakhapatnam, respectively (Table 1). Around 40 % of the mangrove area on the western coast of India has been lost to urban development, or has been converted into agricultural land (Upadhyay et al. 2002). The eastern port city of Kolkata has a green space of 2 m^2 per capita (SIEMENS 2014) highlighting an acute shortage of green cover.

Use of tree shade

Trees render direct cooling of the microclimate through shading, evapotranspiration, and carbon sequestration. They, simultaneously induce indirect cooling of the environment through reduced demand for cooling energy, thus lowering carbon emissions from power plants (Akbari et al. 2001).

Trees serve as natural evaporative coolers—in the presence of sufficient quantity of water, a single tree can provide an air-conditioning efficiency of 20 kW by transpiring about 400 l of water daily (Pokorny 2001). Strong cooling potential has been observed in urban parks where evapotranspiration is assisted with wind flow (Huang et al. 1987). Since the effectiveness of evaporative cooling from trees is highly dependent on the availability of ground water, the savings in energy often get reduced due to increase in irrigation water costs in hot-arid climates (McPherson et al. 1989). During drier periods, the rate of evapotranspiration decreases due to reduced soil moisture content (Yu and Hien 2006), and also due to the self-regulatory mechanism of stoma (Oke 1987). Reduced potential for evapotranspiration is anticipated in the future due to climate change, water shortage, and heat waves (Yu and Hien 2006), making it imperative to maximise the utility of tree shade for efficient passive cooling.

Referring to simulation studies conducted on 10 cities in USA (Taha et al. 1996), Akbari et al. (2001) report trees to reduce ambient temperature by 0.3–3 °C at 2 p.m. A row of Kaizuka hort trees planted along the west wall of a building in Fukuoka, Japan, intercepted 95 % of the insolation, thus providing natural cooling against the afternoon sun (Hoyano 1988). The savings associated with trees are highly climate dependent, and have been estimated to amount up to $200 per tree (Akbari et al. 2001). Little research has been conducted on the energy saving potential of trees in India and needs to be explored.

The lack of space required for accommodating a fully grown tree in densely developed Indian cities can be overcome by using green walls. Plant cover on wall acts as a layer of insulation and reduces the transmission of heat to indoors. This entails innovative strategies for ease of implementation and maintenance. The energy conservation potential of a green wall is directly proportional to the amount of surface area covered—reduction of 33% in surface absorption coefficient value of wall has been observed (Kontoleon and Eumorfopoulou 2010). Use of free-standing green walls can be explored in humid climates to avoid weakening of building structures due to dampness.

Heavy urbanisation in India has drastically reduced the quantum of green cover. Interestingly, though the tree cover in Delhi increased from 6.61 % in 2003 to 8.29 % in 2009 (Government of National Capital Territory of Delhi, India 2014a), the city has witnessed considerable rise in urban temperatures (Mohan et al. 2012). Thus, a general increase in the urban green cover may prove insufficient in achieving the desired cooling effect, and therefore, makes it imperative to focus on the greening of built spaces, and on the maintenance of balance between green cover and built-up area. The subsequent section reviews and analyses greening practices in Indian cities, and recommends guidelines for urban afforestation.

Go to:

urban greening policies in India and global best practices

The National Forest Policy of India aims to ensure that a minimum of one-third of the total land area of the country remains under forest or tree cover. It encourages planting of trees alongside roads, railway lines, rivers, streams, and canals. Raising of "green belts" has been recommended in urban/industrial areas and in arid tracts (Ministry of Environment & Forests, India 1988). Table 3 provides a summary of the major government initiatives towards forest and tree management.

Table 3

Major initiatives towards forest management

Initiatives by Indian Government	Objectives
National Green Tribunal Act, 2010	Provides for establishment of a National Green tribunal for effective and expeditious disposal of cases related to environment protection including enforcement of any legal right relating to environment

Initiatives by Indian Government	**Objectives**
National Action Plan for Climate Change, 2008	National Mission for Green India with a view to launch a national mission to enhance ecosystem services including afforestation of 10 million hectares of land
Environmental Impact Assessment (EIA) Notification, 2006	To identify, examine, assess, and evaluate the likely and probable impacts of a proposed project on the environment. It makes prior environmental clearance mandatory for the development activities listed in the notification
National Environment Policy, 2006	Intended as a guide to regulatory reforms and environmental projects, review and enactment of legislation by Government bodies. It seeks to stimulate partnership of different stakeholders to strengthen environmental management
Biological Diversity Act, 2002	Conserve biological resources and associated knowledge and facilitate access to them in a sustainable manner
National Afforestation and Eco-Development Board established in 1992	Promotes afforestation, tree planting, ecological restoration, and eco-development activities
Environmental Protection Act, 1986	Provides for protection of the environment which is inclusive of water, air, land, and the inter-relationship existing between the environment, human beings, and living creatures

Initiatives by Indian Government	Objectives
Forest Conservation Act, 1980	Provides for regulating diversion of forest land for non-forestry purpose in different states of India
Wildlife Protection Act, 1972	Control poaching, smuggling, and illegal trade in wildlife and its derivates. Protection of the listed species of flora and fauna. Establishment of ecologically important protection areas
Indian Forest Act, 1927	Consolidate the law relating to forests, the transit of forest-produce, and the duty leviable on timber and other forest-produce

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Source MoEFCC-India, Forest Conservation (2014), MoEF-India (2006), The Environment (Protection) Act (1986), MoEF-India (2013–2014), Prime Ministers Council on Climate Change-India (2008), Ministry of Law & Justice- India (2010), MoEF-India, National Environment Policy (2006), MoEFCC-India (2002, 2014), MoEF-India, Wildlife (Protection) Act (1972), MoEF-India (2013), MoEF-India (2006), The Environment Impact Assessment (EIS) Notification (2006), Ministry of Law-India, 1927, Ministry of Law & Justice- India (2010), MoEFCC-India, Forest Conservation, (2014), MoEFCC-India (2014), Ministry of Environment—Forest & Climate Change, Government of India (2014), MoEFCC-India (1980)

A number of measures have been initiated at the national level to maintain natural heritage, check soil erosion, and denudation, but an imbalance is observed between the built and natural cover in cities. While the National Forest Policy stresses on the greening of arid and industrial tracts, adequate greening of private lands has not been emphasised. Further, the rapid pace of development since early 1990s has extended urbanisation beyond the carrying capacity of cites. Table 4 provides a summary of the existing greening bye-laws in the selected cities of New Delhi, Pune, Chennai, and Visakhapatnam. Based on the comparisons drawn with global best practices, planning guidelines are recommended for Indian cities.

Table 4

Greening practices in India and global best practices

City/country	Initiatives pertaining to				Observations
	Preservation	**Maintenance**	**Growth & development**	**Public participation**	
New Delhi, India	The Delhi Preservation of Trees Act, 1994 Establishment of Tree Authority including Tree Officer for preservation, development, and maintenance of trees Need of permission from Tree officer prior to felling/cutting/removal/disposal of tree Establishment of Tree Help line where information can be given about illegal felling of trees	Provision for recovery of expenditure from people who fail to plant trees as per directive or from owners who fail to protect trees from danger. In lieu of permission for removal of tree, compensatory planting of 10 trees to be done Selection of trees and plants to be made keeping in mind distinctive avenue development, round the year	More than a million trees planted under the City Plants a Million Tree Campaign by the government in 2011 Roundabouts, road sides, and central verges identified for tree plantation	The Green Leap Delhi initiative by the Department of Environment started in 2011 provided for distribution of free seeds/saplings The Tree Ambulance service by New Delhi Municipal Corporation provides emergency help to residents to	Initiation of urban afforestation Steps taken to encourage public participation Lack of stress on greening of private buildings

City/country	Initiatives pertaining to				Observations
	Preservation	**Maintenance**	**Growth & development**	**Public participation**	
		flowering in parks, and shade requirements		save trees	
Pune, India	The Maharashtra (Urban Areas) protection and Preservation of Trees Act, 1975 No tree can be felled without written permission from Tree Authority		NGO-Tree Public Foundation has planted 50 000 trees	Pune Municipal Corporation provides advertisement rights to public and private agencies in return for development and maintenance of landscaping of road medians, traffic islands etc.	Tree plantation programs initiated by NGOs. Lack of public participation and maintenance work

City/country	Initiatives pertaining to				Observations
	Preservation	Maintenance	Growth & development	Public participation	
Visakhapatnam, India	No restriction on felling of trees on private lands In case of Tree Patta, felling can be done at the end of rotation period when the Divisional forest officer authorises it		12 major parks proposed involving investment of Rs 14 crores The Umar Alisha Rural Development Trust is working on the planting of 1 million trees through a time span of 5 years		No restriction on felling of trees on private lands Thrust on development of parks Little existing green cover necessitates strict planning guidelines
Chennai, India	Tamil Nadu Tree Protection Act No tree can be felled without permission of District Committee		Tree plantation schemes initiated by government-		Efforts towards urban afforestation Initiation of

City/country	Initiatives pertaining to				Observations
	Preservation	Maintenance	Growth & development	Public participation	
	Species marked as "royal trees" cannot be felled even on private lands without the permission of Chief Conservator of forests.		6 400 000 saplings in 2012 6 500 000 saplings in 2013		tree census
Singapore	Mandatory provision of planting verges along public roads and private properties	Carefully laid out guidelines for tree species to be planned along roads with recommendations for spacing	15% Increase in roadside greenery from 1999 to 2010	Encourage roof gardens	Holistic maintenance of greenery in cityscape.
Sydney, Australia	Vision to promote and support biodiversity	Support liveable green network of streets by– Planting trees in unused road spaces Replace paving	Aim for increase in city's urban forestry to- 50% by 2030 75% by 2075	Promote green roofs and green walls on new building developments.	Provision of grants program Replacement of paving with trees and green

City/country	Initiatives pertaining to				Observations
	Preservation	Maintenance	Growth & development	Public participation	
		with trees and landscape plantings		Explore provision of grants program for residents and businesses to maintain large canopy trees on their property.	elements
London, UK	Stress on promotion of accessibility to green areas	Maximisation of urban greening through planting of trees and soft landscaping where applicable Principle of “right place, right tree”	Planting of two million trees by 2025		Location specific tree plantation
New York	Well-developed Tree Census		Million Tree	Tree	Stress on

City/country	Initiatives pertaining to				Observations
	Preservation	**Maintenance**	**Growth & development**	**Public participation**	
City, USA	providing details of city trees inclusive of species richness, age, diameter at breast height, canopy cover, and condition of trees		Initiative	giveaways to volunteers Mulchfest used for recycling holiday trees and nourishing city plantings. TreesCount 2015 by the New York City Department of Parks and Recreation aims at mapping street trees and engages locals through voluntary	public participation

City/country	Initiatives pertaining to				Observations
	Preservation	**Maintenance**	**Growth & development**	**Public participation**	
				participation	

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Source Government of India-Planning Commission (2014), Government of National Capital Territory of Delhi (2014b), Times of India (2014b), GVMC (2015), PMC (2014), Times of India and Madaan (2013), Sinha (2013), DDA (2015), Government of NCT of Delhi (2015), Tree Delhi (2015), Hindu (2013), Greater London Authority (2011), City of Sydney (2012), National Parks Board-Singapore (2009), About Million Trees NYC (2014), Tan et al. (2013), Peper et al. (2007), New York City Department of Parks & Recreation (2015)

Inferences

Government bodies in urban India tend to focus more on preservation of existing greenery than on afforestation. New Delhi has initiated exceptional efforts for the preservation, maintenance, and growth of trees. Government backed initiatives like the Green Leap Delhi and Tree Ambulance inculcate care for trees, and encourage public participation. While tree planting programs have been recently initiated in Chennai, care and maintenance of saplings to ensure their survival and health are required. Although NGO's have initiated afforestation programs in Pune, its green space of 1.4 m^2 per capita necessitates stronger actions. Visakhapatnam recently suffered huge loss of green cover due to the cyclonic storm of Hudhud in 2014, and is in an acute need of afforestation.

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Policy and planning recommendations

1. Lack of afforestation programs is a major drawback of Indian cities. Urbanisation should be complemented with afforestation targeting specific increment in tree count.
    a. Performance-based incentive programs encourage competition and result in better output. The Garden Cities of China and Tree City USA

(Chaudhry et al. 2011) serve as precedents with established guidelines for better environmental performance.

b. Since low-income residents tend to live in dense neighbourhoods, special care should be taken to ensure provision of green walls and green/cool roofs. Such measures will prove crucial in the cooling of microclimate and compensating for dearth of material resources.

2. Road traffic is a major source of pollution in India. Impetus should be given to greening of transport corridors to reduce atmospheric pollution.

   a. The high density of Indian roadways can be utilised as green corridors for attenuating atmospheric pollution, and inducing uniform cooling.

      - (i) Evergreens should be selected for roadways to minimise accidents due to leaf shedding from deciduous varieties. This should be backed with guidelines for choice of tree species and tree spacing as observed in Singapore.

      - (ii) Special care should be taken to ensure complete visibility at traffic intersections and rotaries.

   b. In keeping with the National Forest Policy, trees should be planted and maintained along railway lines, canals, and streams. Green belts should be raised in derelict lands.

   c. Incorporation of permeable pavements such as grassed footpaths and greening of parking lots will help to decrease the proportion of paved areas, aid in storm water retention, and reduce surface heating.

3. Significant reduction in atmospheric pollutant levels in Hyderabad during a truck strike period highlights the need for lesser polluting modes of transport. Public transport and use of CNG-based vehicles should be promoted to reduce mobile emissions from private vehicles.

   a. Car pooling and use of public transport like metro rail should be encouraged.

   b. Weekly days can be designated as no-personal-vehicle-day, whereby only public transport would remain functional.

   c. Implementation of stringent rules aimed at regulating vehicular life, such as the banning of commercial vehicles older than 15 years in Delhi (Times of India 2014a), will help to overcome the lack of public support.

4. The observed trend of shrinking residential gardens needs to be checked.
   a. Strict enforcement of bye-laws regulating the size of home gardens, and imposition of penalty for disregard to public laws will help to instill discipline among locals.
   b. The high percentage of flat-roofed buildings in India provides ample scope for development of roof gardens. The added benefit of rain water harvesting and storm water runoff collection could be amalgamated to solve acute water shortage in cities.
   c. Since people remain more amenable to monetary benefits, tax abatements can be provided for maintenance of roof gardens, box plantations, and green terraces.
5. Public participation is a prerequisite for the success of any urban development program and is significantly missing in India.
   a. Emulating New York's afforestation program, the youth should be educated and engaged in voluntary activities of plantation, care, and maintenance of tree saplings.
   b. Tree giveaways will help to instill a sense of responsibility towards protection of the natural environment.
   c. Minimum threshold values for green cover per plot ratio should be designated in residential areas. Since wealthier neighbourhoods tend to have more plantable area, while low-income residents tend to live in denser neighbourhoods with lower possible stewardship (Troy et al. 2007), the minimum green cover per built-up area should consider economic stratification.
   d. Large-scale industrial projects can make use of carbon-credit projects.
6. Transport corridors and industrial belts are major contributors to air pollution. Extensive green cover in Gandhinagar helps to maintain pollutant concentrations within permissible limits. The recent Smart City initiative by the Indian Government promoting development of urban green spaces can be coupled with strategic landscaping to optimise benefits of greening programs.
   a. Presence of greenbelts around islands of pollution such as industrial zones reduces spread of pollutants. Use of strategic parameters such as

pollution attenuation factor in Kirumambakkam industrial estate of Pondicherry (Khan and Abbasi 2000) can be explored.

b. Government database should provide information about choice of tree species as per climatic requirements to ensure maximum efficiency at minimum cost.

c. The policy of "right place, right tree" as observed in London provides technical support towards intelligent greening of cities.

d. The greening strategy should be climate driven, and responsive to site demands. This entails potential to explore the intra-city site variations for growth of varied variety of flora (Jim 2012). This will help to reduce stereotype, and stimulate creativity among the locals.

e. Identification of "champion trees", i.e. trees of ecological importance due to species richness or physical attributes (Jim 2012), and policies for their preservation will help to sustain species variety and richness.

7. Lack of tree databank providing detailed assessment of the physical, economical, and ecological value of city flora undermines probable afforestation of Indian cities.

   a. Tree census should be initiated and must include a study of the physical attributes of trees, such as species variety, richness, health, age etc. The Chennai civic body's recent initiative to undertake tree census (Energy Alternatives India 2014), and the Indian Environment Ministry's recent proposal to conduct national level tree census (Aggarwal 2015) are welcome changes.

   b. Tree census should generate information about the ecological value of species. The findings can be used to educate residents about the intangible benefits of trees.

   c. Study on increase in property value due to the vegetative presence will provide an assessment of the economic value of city flora, and help to convince residents about the monetary benefits emanating from maintenance and development of green areas. Recent studies investigating the impact of environmental amenities on real estate prices in Mumbai (Gupta and Mythili 2010), and Chandigarh (Chaudhry et al. 2013), serve as noteworthy examples.

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Conclusion

Increased impact of climate change is a major threat to Indian economic growth. Imbalance between built and natural spaces is deteriorating the thermal environment of Indian cities. Lack of technical data and scientific awareness amongst city dwellers has resulted in devaluation of green cover.

Although efforts have been taken at the national level to protect tree cover, urban afforestation is prominently lacking. Savings of more than 3000 kWh of domestic energy consumption are estimated with implementation of energy friendly practices primarily aimed at passive cooling of residential constructions. Information should be made available to people guiding them about planting choices. Since India exhibits a mix of climatic characteristics ranging from hot and dry to cold and cloudy, the greening strategy should be reflective of the local climatic conditions.

People remain more amenable to monetary gains, therefore, tax reductions and incentives for maintenance of green spaces would help to ensure adequate contribution to urban green cover from residential and commercial neighbourhoods. The greening efforts need to be complemented with minimised use of private vehicles for amelioration of air pollution.

Conflicting reports on probable outcome of roof gardens in composite climates warrant investigation and future research. Detailed study on the carbon sequestering potential of urban greenery in India is needed. Studies can be initiated to quantify the impact of environmental amenities on property prices.

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