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Case Study

Carbon sequestration Potential assessment of urban landscape and characterization of urban trees for dust accumulation and wax content: A case study in Bengaluru city, India

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Abstract

Urban trees provide many ecosystem services, such as climate stabilization through carbon sequestration, air quality improvement and biodiversity conservation. As a result, trees store a considerable amount of carbon in their structures, and annual growth increases the carbon stored in the structure. This study investigates the diversity and carbon sequestration in tree that are grown in different landscapes of cities such as residential areas, avenue trees, parks, industrial areas and around the lake in one of the wards of Bengaluru city. In the present study, 44 tree species belonging to 23 families were found. The total carbon content accumulated by the trees in the study area is 505 tons and total CO_2 sequestered is 1852 tons which is equal to removal of CO_2 emission from 5,60,000 bikes on average runs per day. Out of the six species studied, the highest carbon sequestration was found in Peltophorum pterocarpum and the lowest was found in Michelia champaca. This study also analysed the variation in pattern of dust accumulation and wax content on leaves of different tree species in different seasons. Dust is an air contaminant in urban areas that often exceeds limit values, creating serious problems due to its harmful effects on health. Planting trees and shrubs as air filters is one way to enhance air quality in these regions. Among plant species, the highest dust accumulation, irrespective of seasons was noticed in Tabebuia rosea and the highest wax content was seen in Peltophorum pterocarpum. Thus, maintaining trees in urban areas help in conserving biodiversity and ameliorating climate.

Keywords: Landscape, Urban tree, Carbon stock, Dust accumulation, Wax content, Tree diversity.

Introduction

India is one of the fast growing economies in the world. The economic progress of the country has seen a wide range of developmental activities especially centred towards the cities. This has led to large scale urbanization, leading to considerable reduction of green cover due to reduction of agricultural land and forest cover. Such land scape changes can have serious implications on the local environment and human health in the long run. These land use changes create imbalances in the natural ecosystem and contribute to global climate change[1]. Further, global climate change is predicted to have serious implications, especially in tropical countries in terms of uncertainties of rainfall and other natural perturbations that severely affect food security as well as health. The repercussions of which is evident in recent years with prolonged dry spells, heat waves, increased frequency of floods and droughts among others.

The decline in the quality of urban ecosystems is a major concern for urban planners and managers. Environmental issues which include air and water pressure and pollutants are extra rampant in city areas, which currently results in 78 per cent of worldwide carbon emissions, also accounts nearly 60 per cent of water usage for domestic consumption[2]. In 1950, the sector emitted approximately 6 gigatonnes (Gt) of CO_2. By 1990, the cost had nearly quadrupled, attainingextra than 22 Gt. And the worldwide emission of CO_2in addition reached 36.44 Gt in 2019. Asia becomes the biggest emitter, accounting for 56% (20.24 Gt) of world CO_2 emissions[3]. It is consequently crucial to take steps to redecorate the city ecosystems to deal with those environmental issues and to preserve healthy air, water and different environment offerings wanted for wholesome city living. In the urbanization process, constructed up regions replace the floral cover and increased growth of vehicular movement. These activities are probable to increase the discharge of pollution and greenhouse gases, ensuing in extended atmospheric temperature, reduced air quality and increased degrees of stress for trees[4]. Trees work as primary CO_2 sink which helps in capture of carbon from the atmosphere and also stores the carbon in the form of biomass[5]. Carbon is used in the growth process while releasing oxygen to the air through photosynthesis. Conservation and recuperation of city inexperienced areas comprising “urban trees” is consequently a crucial method in enhancing the environmental exceptional of city areas.

Urban trees refer to trees that are present within the built environment and in the residential areas, parks, and along the avenues, industrial areas *etc*., which give to green space in the urban regions. Their impact on urban ecosystem is very crucial as they provide many important ecosystem services to urban inhabitants, such as change in climate mitigation through carbon sequestration and also improvement of air quality by fighting against air pollution, giving birth to oxygen, noise abatement, conservation of biodiversity, mitigating the Urban Heat Island effect, maintaining microclimate of surrounding areas, soil stabilization, ground water recharge, preventing soil erosion and mitigation. Tree canopy with wider crown area helps in providing cool effect by shading the ground surface and helps in maintaining the microclimate with the use of leaves through transpiration[6]. Several studies have claimed that green cover in urban ecosystem plays a crucial role in mitigating the global carbon footprint. Tree vegetation not only sequester carbon directly contributing to a reduction in atmospheric CO_2 concentration, but also affect the carbon balance indirectly, through their effects on the maintain or regulating environmental quality. Changes in biosphere productivity, impact on atmospheric composition most noticeably on CO_2, also on other gases such as NO, which leads to further impacts on climate. Trees in the urban ecosystem have known ecological functions by sequestering carbon from the atmosphere and fighting against automobile pollution. The net carbon reduction by urban tree planting can be up to 18 kg carbon dioxide per year per tree, which is equal to the benefits provided by three to five trees in forest which has similar growth and health[7].

Dust in the surrounding atmosphere in most cases influences Earth's temperature by scattering and soaking up shortwave to long wave radiation, which influences the floor temperature directly. Atmosphere dust modifies the exchange of radiation through absorption and scattering of both incoming solar radiation and outgoing terrestrial radiation[8]. It not only affects the surface temperature but also, the existence on Earth, through its diverse direction and oblique interactions with living and non-living components. Dust impacts the primary process of rainfall through its indirect and direct regulation, therefore regulating the hydrological cycle and the monsoon systems, which has an impact on the distribution of water resources and agricultural productivity, which ultimately results in global climate change. Trees are one of the natural systems which can be effectively used for monitoring air pollutants like particulate matter or dust. In general, exposed areas of trees, especially leaves act as regular absorbers of dust. Vegetative leaves have been regarded as natural filters as they absorb huge quantities of dust from the atmosphere. Therefore, urban air quality can be improved by planting trees in the urban ecosystem. However, the variation of dust deposition in different trees are maybe due to leaf wax content and different morphological characters such as leaf size, tree height, leaf structure and texture, presence or absence of hairs, *etc*. Stomatal frequencies are also related to dust collecting capacity of plants on the upper and lower surfaces of the leaf [9].

Trees in urban area are largely affected by anthropogenic activities and also natural stresses that may lead to the degradation of urban forest and life span of trees will be reduced when compared to in rural areas or natural stands. Although estimates vary with land use system, life span of trees in city or town areas is relatively less. One of the important stressors of urban trees is air pollution, which has a negative impact on tree health. Urban pollution especially dust reduces tree development and the extent of tree growth reduction may also depends on the type of tree species, particulate concentration and distribution of pollutants and climatic factors. In this background, present study is an attempt to assess the diversity of tree species among different landscapes in the urban areas and their contribution towards ameliorating the urban environment and conservation of biodiversity.

Materials and methods

In order to study the above factors on a pilot basis, the study was conducted in five different landscapes of Ward number four (Yelahanka New town), Bangalore, Karnataka, India. In this region of Bengaluru city, five different landscapes, namely; Avenue Trees, Residential Area, Industrial area, Lake and park were studied. Two kilometre stretch of each of the landscapes was sampled, while in the case of a lake, the entire lake was assessed and three parks were enumerated which cover a length of two kilometres. Trees present in these landscapes were identified to their species level and carbon stocks were assessed. The tree species found common in all the landscape were studied for carbon stock, dust accumulation and wax content.

Tree height Measurement and diameter at breast height (DBH): Tree height and DBH is important factor to estimate biomass of trees, non-destructive method was used to identify the biomass. DBH is determined by measuring tree Girth at Breast Height (GBH), roughly 1.4 meter above the ground. The girth of trees present in urban landscapes was measured directly by measuring tape[10]. The height of every tree was measured by Blume-Leiss Model BL6 Altimeter.

Measurement of above ground biomass (AGB) of trees: The AGB of tree includes whole tree comprising of complete shoot, fruits, branches, flowers, and leaves. AGB is calculated using the following formula[11].

$$AGB\ (kg) = Tree\ Volume\ (m^3) \times wood\ density\ Kg/m^3$$

$$V = \pi r^2 H$$

Where V= volume of the cylindrical shaped tree in m^3, r = radius of the tree in meter, H = Height of the tree in meter, Radius of the tree is calculated from GBH of tree. The wood densities were obtained from the website www.worldagroforestycentre.org. Wood density was derived from Global wood density database. The standard average density of 0.6 gm / cm is used wherever the density value is not available for tree species.

Estimation of Carbon: In tree or any vegetative species 50 per cent of its biomass is considered as carbon *i.e.,* Carbon Storage =Biomass x 50% or Biomass/2 (kg/tree)[12].

Determination of the carbon dioxide (CO_2) sequestered in the tree: CO_2 is composed of one molecule of carbon and two molecules of oxygen. The atomic weight of carbon is 12.001115, the atomic weight of oxygen is 15.9994, the weight of CO_2 is C+2xO=43.999915, the ratio of CO_2 to C is 43.999915/12.001115=3.6663. Hence, to determine the carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.6663.

Plant material and sample collection: Leaf samples were collected from 6 tree species which were commonly found in all the five landscape *i.e. Bauhinia purpurea, Michelia champaca, Pongamia pinnata, Peltophorum pterocarpum, Swietenia mahagoni* and *Tabebuia rosea*. All are common trees species in Bengaluru and widely used in urban areas. First leaf samples were collected on 12 February 2022, considered as non-rainy day and second leaf samples were collected on 2 June 2022, considered as rainy day. Both the samples were collected from the same location (13.0944^0 N, 77.5952^0E) subjected to heavy traffic load in both the season. Individual leaf samples were collected in the polythene bag without disturbing the leaves and brought to laboratory for the estimation of dust and wax content.

Dust accumulation by leaf: In the present study fully matured leaves of the selected tree species from different landscape were taken randomly at different heights. The surfaces of the leaves were cleaned with clean brush and identification marks were put on the samples. The leaves subjected for 24 hours for dust accumulation which was collected in the pre weighed butter paper bags with the help of fine brush[13]. The amount of dust accumulated on leaves was weighed on top pan electronic balance (Sortorious, ALC-210.4, and USA) and calculated by using the equation:

$W = (W_2-W_1)/A$

Where; W is dust content (µg), W_1 is initial weight of butter paper bag, W_2 is final weight of butter paper bag with dust, A is total area of the leaf (cm^2).

Measurement of Leaf area: Ten leaves from each plant were collected at random and leaf area was measured with Leaf area meter (Model- 3100 C, LI-COR, Lincoln, USA). The average leaf area was expressed as cm^2 and average of all 10 leaves gives the leaf area of the species.

Measurement of leaves wax content: Wax removal was done by dipping the leaves in chloroform. The duration for which the leaves were immersed in the chloroform was standardized for each species as 15 seconds as the maximum wax content was released compared to other time duration expressed in $\mu g/cm^2$.

Procedure: Empty petriplates are washed cleanly without any other residues and kept for oven drying. These empty petriplates were weighed on an electronic balance and replicated 5 times for each species. Sufficient chloroform is added to the petriplates so as to completely immerse the leaf. The leaves of known leaf area after cleaning were cut into pieces and dipped in the petriplates containing chloroform. Every sample leaves were dipped for 15 seconds which results in dissolve of epicuticular wax to in the chloroform. Then petriplates are kept undisturbed overnight for evaporation to take place in a dust free condition. After ensuring the complete drying of the petriplates and no residue of chloroform left, the petriplate were weighed using an electronic balance (Sortorious, ALC-210.4, USA). The difference in the weight of the empty petriplate and the petriplate with the wax was considered as wax content.

Statistical tool: Single factor ANOVA is used to know the significant differences of Carbon stock at different landscapes. It is carried out in MS Excel 2010.

Results and discussion

Tree Diversity: Tree diversity in Industrial area, Avenue Trees, Residential Area, Lake and Parks of the study area are conferred in Table-1. There were 44 tree species found in the study area belonging to 23 different families. Out of the 44 species highest numbers of species were found in Parks (40) followed by industrial area (27), avenue trees (25), and Lake area (18) and the least number of species (16) were found in residential area (Figure-1). The numbers of trees found in different landscapes are 206, 336, 378, 143, and 291 km^{-1} in Industrial area, lake, avenue trees, Residential area and Parks respectively (Table-1). Trees planted as avenue trees recorded the highest number of trees.

Out of 206 trees in Industrial area, the highest number of trees belonged to *S. companulata* (51) followed by *P. pinnata* (47), *P. pterocarpum* (16), and *G. robusta* (10) and one each from *A. scholaris*, *C. lanceolatus*, *D. sissoo*, and *F. benghalensis* species. In case of lakes, a total of 336 trees came from 18 different trees species among which 114 trees were of *H. Lagenicaulis* and 110 trees belonged to *P. pinnata* while least number is found that of *F. benghalensis*, (1). Similarly in avenue trees, the highest numbers of trees found were that of *P. pinnata* (163) followed by *P. pterocarpum* (48), *B. purpurea* (40), *S. mahagoni* (28) and *M. champaca* (24). Residential area had least number of trees compared to all other landscapes, in which the highest number of trees found were of *B. purpurea* (24) and *T.rosea* (24) followed by *P. pinnata* (23), *P. pterocarpum* (17) and *C. guianensis* (16) and least number were seen in the species *A. indica* (1), *M. calabura* (1), *T. argentea* (1) and *T. catappa* (1). Similarly in the parks, out of the total 291 trees recorded, the highest number of trees were that of *P.*

pinnata (27) followed by *G. robusta* (26), *D. Regia* (21), *A. indica* (19), and *L. flosreginae* (19). The least number of trees found were *A. columnaris* (1), *F. religiosa* (1), *A. lebbeck* (2), *F. benghalensis* (2), and *S. saman* (2). Among the five landscapes studied, 30 per cent of the tree population was found among the avenue trees, 25 per cent were found in the lake ecosystem, 21 per cent in the parks, 15 per cent in industrial area and 10 per cent in residential area. The type of species as well as the tree density varied across the landscapes. *P. pinnata* is found to be the most dominant species, which constitutes about 27 per cent of the total population from all the five landscapes studied. This could be due to the following reasons; *P. pinnata* is leguminous in nature and has the ability to assimilate atmospheric nitrogen and thus it helps in not only reducing the nutrient deficiency but also helps in reducing the NO_2 emission (which is a greenhouse gas) that comes from inorganic fertilizer application[14]. A higher population is indicative of a higher survival rate and therefore suggests that it has higher stress tolerance[15]. The morphological features of *P. pinnata* such as moderate height, medium sized leaflet and lush green canopy make them suitable for growing in cities across the landscapes and also it is also easy to manage[16]. Availability of planting materials is also another factor. *P. pinnata* is the preferred tree species to increase the production of tree born oil seeds to promote bio-fuel manufacturing.

Table-1: List of tree species and their distribution in five urban landscapes.

Sl. No	Name of the species	Family	Number of Individuals per kilometre					Total
			Industrial area	Lake	Avenue trees	Residential area	Parks	
1	*Albizia lebbeck*	Fabaceae	3	-	4	-	2	9
2	*Alstonia scholaris*	Apocynaceae	1	-	-	-	7	8
3	*Anthocephalus cadamba*	Rubiaceae	-	-	1	-	-	1
4	*Araucaria columnaris*	Araucariaceae	-	-	-	-	1	1
5	*Artocarpus heterophyllus*	Moraceae	-	5	3	-	6	14
6	*Azadirachta indica*	Meliaceae	3	-	3	1	19	26
7	*Bauhinia purpurea*	Fabaceae	7	5	40	24	15	91
8	*Bixa orellana*	Bixaceae	-	-	-	-	6	6
9	*Callistemon lanceolatus*	Myrtaceae	1	-	2	-	5	8
10	*Cassia spectabilis*	Fabaceae	5	-	-	2	-	7
11	*Cocco snucifera*	Aracaceae	0	6	6	-	4	16
12	*Couroupita guianensis*	Lecythidaceae	1	-	-	16	5	22
13	*Dalbergia sissoo*	Fabaceae	1	-	-	-	5	6
14	*Delonix regia*	Fabaceae	2	-	1	-	21	24
15	*Eucalyptus globulus*	Myrtaceae	-	12	-	-	-	12
16	*Ficus benghalensis*	Moraceae	1	1	-	-	2	4
17	*Ficus racemosa*	Moraceae	-	5	2	-	3	10
18	*Ficus religiosa*	Moraceae	-	2	-	-	1	3
19	*Grevillea robusta*	Proteaceae	10	-	2	-	26	38
20	*Hyophorbe lagenicaulis*	Aracaceae	-	114	-	-	3	117
21	*Jacaranda mimosifolia*	Bignoniaceae	-	-	1	2	9	12
22	*Kigelia pinnata*	Bignoniaceae	1	2	-	-	12	15
23	*Lagerstroemia flos reginae*	Lithraceae	9	-	-	-	19	28
24	*Mangifera indica*	Anacardiaceae	-	-	3	-	4	7
25	*Michelia champaca*	Magniliaceae	3	3	24	13	7	50

26	*Millingtonia hortensis*	Bignoniaceae	1	-	2	-	5	8
27	*Muntingia calabura*	Muntingiaceae	7	3	0	1	5	16
28	*Peltophorum pterocarpum*	Caesalpiniaceae	16	3	48	17	7	91
29	*Phyllanthus emblica*	Phyllanthaceae	-	-	-	-	3	3
30	*Plumeria alba*	Apocynaceae	3	48	-	-	4	55
31	*Polyalthia longifolia*	Annonaceae	-	-	3	-	11	14
32	*Pongamia pinnata*	Fabaceae	47	110	163	23	27	370
33	*Samanea saman*	Fabaceae	1	-	3	2	2	8
34	*Santalum album*	Santalaceae	-	-	-	-	3	3
35	*Saraca asoca*	Fabaceae	6	-	5	-	5	16
36	*Schefflera actinophylla*	Araliaceae	-	-	-	-	5	5
37	*Spathodea companulata*	Bignoniaceae	51	-	2	4	7	64
38	*Swietenia mahagoni*	Meliaceae	5	3	28	5	5	46
39	*Syzygium cumini*	Myrtaceae	5	6	-	-	4	15
40	*Tabebuia argentea*	Bignoniaceae	-	-	1	1	-	2
41	*Tabebuia rosea*	Bignoniaceae	4	2	11	24	5	46
42	*Tectona grandis*	Lamiaceae	4	-	1	-	-	5
43	*Terminalia catappa*	Combretaceae	-	6	-	1	3	10
44	*Thespesia populnea*	Malvaceae	8	-	19	7	8	42
Total			206	336	378	143	291	1354

Carbon sequestration: The total amount of carbon stocked in five landscapes varied from 155 tons km^{-1} in industrial area, followed by 143 tons km^{-1} in avenue trees, 121 tons km^{-1} in parks, 61 tons km^{-1} in residential area and the least 26 tons km^{-1} was found in the trees around the lake. From these five ecosystems, a total of 505 tons of carbon is stored in the standing biomass of trees, which is equal to 1852 tons of carbon dioxide sequestered from the atmosphere over years (Table-2). Trees present in the study area proved the ability to remove 1852 tons CO_2 from the atmosphere which is equal to removal of CO_2 produced by 5,60,000 bikes that runs on city on an average per day[17]. Industrial area contributed for the highest carbon sequestration compared to all other landscapes. The numbers of trees present were relatively less, however, higher carbon sequestration was found because of better growth noticed in Industrial area. The tree species *S. Companulata* had greater girth class and contributed more biomass which resulted in more sequestration of carbon and also the presence of greater number of trees (Table-1). *S. companulata* is often grown as an ornamental tree. It is a fast growing tree which survives even in unfavourable conditions. Hence, the tree has an ability to survive in Industrial area. Similarly, avenue trees dominated by *P. pterocarpum,* sequestered highest carbon after trees in Industrial area in (Table-1). *P. pterocarpum* is a large tree that has a dense spreading crown and the flowers remain a natural golden yellow colour even after falling and also as they dry. Thus this tree species may be used as shading purpose in addition to its usage as an important ornamental street and avenue tree.

The least amount of carbon sequestered was from the Lake landscape. It could be due to low tree diversity and the presence of lower number of large sized trees. Trees that can be planted in this ecosystem should have the ability to tolerate high soil moisture content and even flooding and such characters are generally present in all trees. This could be the reason for reduced diversity of tree species here[18]. Irrespective of tree count, industrial area showed higher carbon sequestration as compared to lake, avenue trees and parks where tree count was higher. It clearly indicates that carbon sequestration is greatly influenced by the biomass produced by the trees. Evaluation of biomass of tree provides information on the structure and functional attributes of trees. The bigger the size and structure, greater will be the biomass. Nearly 50 per cent of dry biomass comprises of carbon, biomass estimation explains the total amount of carbon that may be removed by trees[19]. Estimating the biomass in trees is the first step in carbon accounting as the biomass is the primary indication of carbon sequestration.

Table-2: Carbon stock estimation and CO_2 in the above ground biomass of standing trees in all five landscapes.

Land use system	Number of trees	Carbon (tons)/km	CO_2 (tons) /km
Industrial Area	206	155	568
Allalasandra lake	336	26	95
Avenue trees	378	143	524
Residential area	143	61	222
Parks	291	121	444
Total	1354	505	1852

There is no significant difference between the landscapes.

Table-3: Carbon stock and CO_2 in the standing six tree species found commonly in all five landscapes.

Tree species	Tree count	Average DBH in meter	Average height in meter	Above ground biomass in ton	Carbon in ton/ tree	CO_2 Sequestered in ton/tree
Bauhinia purpurea	91	0.78	8.54	59	27	97
Michelia champaca	50	0.71	11.68	12	6	23
Pongamia pinnata	370	0.68	8.45	139	64	229
Peltophorum pterocarpum	91	1.54	15.11	196	88	324
Swietenia mahagoni	46	1.19	14.87	66	33	120
Tabebuia rosea	46	1.28	13.18	78	39	143

Out of the six species studied, the highest carbon sequestration was found in the species *Peltophorum pterocarpum* (324 tons per tree) followed by *Pongamia pinnata* (229 tons per tree) and the lowest was found in *Michelia champaca* (23 tons per tree). The average DBH varied from 1.54 m in *P.pterocarpum* followed by 1.28 m in *T. rosea,* 1.19 m in *S. mahagoni,* 0.78 m in *B. purpurea,* 0.71 m in *M. champaca* and least was seen in *P. pinnata* is 0.68 m. The mean height of the tree varied from 15.11 m in *P. pterocarpum* followed by 14.87m in *S. mahagoni,* 13.18 m in *T. rosea,* 11.68 m in *M. champaca,* 8.54 m in *B. purpurea* and least was seen in *P. pinnata* is 8.45 m (Table-3). *P. pinnata* and *T. rosea* had highest and lowest tree count respectively.

P.pterocarpum helped in storing 88 tons of carbon and removing 324 tons of carbon dioxide from the atmosphere, which is the highest compared to all other species. In this table it is clear that the tree count of *P.pterocarpum* is less compared to *P. pinnata* but it helped in removing more carbon dioxide from the atmosphere. This is because of the greater girth size *P.pterocarpum* (Table-3). The greater in DBH and height, which proves carbon sequestration, is greatly influenced by the size of the tree species. Higher biomass will be contributed by the higher girth class individuals and the higher carbon sequestration is the resultant of higher biomass[20]. The increase in carbon storage in standing trees increases with increase in tree diameter, which clearly indicates the cost of preserving and saving mature and old large trees to retain the carbon sequestered in the urban ecosystem where it remains for centuries unless it is disturbed either naturally or anthropogenically. As the trees grow into larger size and the growth attain large stature, the girth at breast height results in a constant addition to the tree's total carbon stores, likewise small-diameter trees also contribute in adding carbon in trees but it must effectively speed up to size before the girth at breast height results in significant carbon gains.

Dust accumulation: The perusal of data revealed that accumulation of dust on leaves varied in different species, in different days (Figure-2). Among plant species, highest dust accumulation was noticed in *T. rosea* (141 µg cm^{-2}) followed *M. champaca* (140 µg cm^{-2}), *S. mahagoni* (127 µg cm^{-2}), *P.pterocarpum* (84 µg cm^{-2}), *B. purpurea* (82 µg cm^{-2}) whereas, lowest was recorded in *P. pinnata* (64 µg cm^{-2}) during the non-rainy days. In the rainy days highest dust accumulation was noticed in *T. rosea* (98 µg cm^{-2}) followed *M. champaca* (95 µg cm^{-2}), *S. mahagoni* (92 µg cm^{-2}), *B. purpurea* (57 µg cm^{-2}), *P.pterocarpum* (39 µg cm^{-2}) whereas, lowest was recorded in *P. pinnata* (38 µg cm^{-2}). The seasons of the year were found to influence the dust load on the leaves of the selected species. Irrespective of the species, the highest dust deposition was on non-rainy days followed by rainy days.

Table-4: Characteristics of selected plants at study site.

Tree species	Avg. Leaf area (cm^2)	Leaf shape
Bauhinia purpurea	48.32	Ovate
Michelia champaca	45.95	Elliptic to lanceolate
Pongamia pinnata	38.33	ovate elliptical
Peltophorum pterocarpum	47.98	oblong
Swietenia mahagoni	50.35	Lanceolate; ovate
Tabebuia rosea	51.85	Oblong to elliptic

The present study shows that there is variation in the pattern of dust accumulation on leaves of different trees in different seasons. Atmospheric dust accumulation varies with structure, geometry, height, size of petiole, presence/ absence of hairs and presence of wax on leaf surface of selected plants[21]. Among plant species, the highest dust accumulation, irrespective of seasons, was noticed in *T. rosea*, compared to other species, and this may be ascribed to medium rough leaf surface, Oblong to elliptic shape, leaf persistence is semi evergreen, where dust retention will be for longer the period and more leaf area may be one of the main reason to have highest dust accumulation compared to other species (Table-4). Wax content in the leaf may also play a major role in holding of dust. Whereas, the lowest dust load on *P. pinnata* may be due to surface smoothness and waxy coating on the leaves. Similar conclusions were drawn based on studies conducted with *Plantago* species with smooth leaf surfaces, which had smaller accumulation of dust[22]. As of the present study, *P. pinnata* had less leaf area and this might be another main reason for lower dust retention. Relatively, less dust accumulation on leaves of *M. champaca* may be due to an elliptical shape with flat surface at the midrib of the leaf and in leaves of *S. mahagoni* it may be due to leaflets that are shiny and lance-shaped. These findings are in conformity and reported that the effect of dust accumulation as per the leaf characteristic of plants[23]. The results of this study showed that the dust-retained capacities of the six sampled tree species decreased in the following order: *T. rosea* > *M. champaca* > *S. mahagoni* > *P. pterocarpum* > *B. purpurea* > *P. pinnata*. The seasons of the year were found to significantly influence the dust load on the leaves of the selected species. Irrespective of the species, the highest dust deposition was in the month of February (winter) and the lowest noticed in the June (rainy) season. This is in agreement with the findings while studying seasonal variation of leaf dust accumulation and pigment content in plant species exposed to the urban environment reported the highest dust accumulation in winter followed by summer and rainy season also revealed seasonal variation of dust accumulation in vegetation near the national highway at Sambalpur in Orissa, India[24,25]. The two seasons for study were also found to have significant influence on leaf dust accumulation on different species under study. Therefore, trees showing a highest removal of dust are very precious for phytoremediation in urban land use system.

The studied species also differed in the amount of wax on leaves. Among the tree species, the highest wax content was noticed in *P.pterocarpum* (268 µg cm^{-2}) followed *P. pinnata* (195 µg cm^{-2}), *M. champaca* (179 µg cm^{-2}), *B. purpurea* (123 µg cm^{-2}), *T. rosea* (74 µg cm^{-2}) , whereas, *S. mahagoni* (52 µg cm^{-2}) recorded the lowest wax content (Figure 4). With respect to dust and wax content studied on selected species, *P.pterocarpum* showed the highest wax content. However, this was no much impact in the amount of dust, which in the case of *P.pterocarpum* dust was almost 30 percent lower than the amount of wax (Figure-2). The wax content in other species is also not reflected in the amount of dust[26]. In their case, the amount of in-wax PM (wPM) was also almost 30 per cent lower than the amount of surface PM (sPM), despite the larger amount of wax on leaves. When compared to present study wax content did not show any direct effect in the dust accumulation. The results of this study show that the wax content of the six sampled tree species decreased in the following order: *P. pterocarpum*> *P. pinnata* >*M. champaca*> *B. purpurea*> *T. rosea* >*S. mahagoni* .Wax content on leaves might have helped in accumulation of little amount of dust. It would appear that as regards immobilising dust in waxes, the chemical properties, structure and roughness of the wax may be more important than wax amount or layer thickness[27]. The deposition of dust on waxes causes the pollutants to be immobilised, at least for some time, meaning that during this time people can breathe cleaner air. So, the quality of air around us is important for prevention and should control air pollution like dust in atmosphere[28].

Conclusion

Cities are centres of economic growth and development. Urban areas now account for almost half of India's gross domestic product, but rapid urbanization is leading to land-use change, habitat loss, biodiversity loss, climate change, and pollution both inside and outside cities and is a major driver of global change. Bangalore is popularly known as garden city of India and is one of the rapidly growing cities of India. In the past few decades, city has significantly grown. It is important to take measures to maintain a healthy and clean environment along with the developmental changes. Present study is an effort to assess the benefits derived from the trees planted in major landscapes in one of the new extensions of Bengaluru city. Carbon is one of the major components of all cellular life forms;

trees effectively utilize carbon as a building material to form trunks, roots, complete tree. Urban trees provide many benefits such as climate stabilization through carbon sequestration, air quality improvement, biodiversity conservation, among others. Trees store a huge amount of carbon in their trunk and structures, and over a time its growth increases the carbon stored within the structure. This study investigates the carbon sequestration tree species grow along the different landscapes of industrial area, residential area, road-side, parks and around the lake in Ward no. 4 Yelahanka of Bengaluru, Karnataka, India. In the present study, 44 tree species belonging to 23 families with 1354 trees were found. Among the five landscapes studied, highest tree population is found in the avenue trees. *Pongamia pinnata* is most dominant tree species. Out of total six species studied, the highest carbon sequestration was found in the species *Peltophorum pterocarpum,* 324 tons and the lowest was found in *Michelia champaca,* 23 tons per tree. This study also showed the variation in pattern of dust accumulation on leaves of different tree species in different seasons and also studied the wax content on leaves of different tree species. Among plant species, the highest dust accumulation, irrespective of seasons was noticed in *Tabebuia rosea* and the highest wax content was seen in *Peltophorum pterocarpum.*

Urban trees in the study area helped in removing carbon dioxide from the atmosphere in addition to removing dust, which is an important air pollutant. With these environmental and social benefits realized from urban tree planting, it is imperative to rationalize tree planting in cities with the city expansion so as to achieve the sustainable, healthy and aesthetic environment. Growing trees in urban areas can be used as a cost effective method of reducing carbon dioxide in the atmosphere and a mitigation measure for global climate change.

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Abbreviations: CO_2- Carbon Dioxide; DBH- Diameter at Breast Height; AGB- Above Ground Biomass; NO_2- Nitrogen Dioxide; NO- Nitrogen Oxide.

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