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Evaluating the role of roadside vegetation in atmospheric carbon dioxide mitigation: a case study

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ABSTRACT

Urban green spaces have received little attention for climate change mitigation by way of carbon dioxide (CO_2) sequestration. The present study explores the diversity and CO_2 mitigation value of roadside tree species in Sagar city, India. Various diversity and richness indices were determined to assess the diversity structure of these discontinuous vegetations. The CO_2 mitigation value was determined by estimating biomass and carbon stock through a non-destructive method. The study area was found to include 1,130 individuals belonging to 26 families and 66 species. A higher value of diversity indices (Simpson's, 0.95 and Shannon's, 3.42) and lower Simpson's index of dominance (0.05), along with the higher value of species richness (9.25) and evenness (0.82) showed good diversity and uniform distribution of the species. The CO_2 mitigation value for the present study area was 66.62 Mg/ha, along with a total biomass value of 36.3 Mg/ha and a carbon stock of 18.15 Mg C/ha. Observations from the study show that these types of vegetations do play a substantial role in carbon sequestration. The results of this study will be useful to give an insight into the significance of these roadside trees to policymakers and the necessity for careful management of them.

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Biomass; carbon stock; CO_2 mitigation; roadside vegetation; biodiversity

Introduction

Tropical forests play a prominent role in mitigating atmospheric greenhouse gas concentrations by storing approximately half of the world's terrestrial carbon (Pati et al., 2022c; Salunkhe et al., 2014). In the recent past, anthropogenic activities such as deforestation, fossil fuel combustion, over-exploitation of resources and changes in land use are the principal causes of increasing levels of greenhouse gases, especially carbon dioxide (Mir et al., 2021; Salunkhe et al., 2014), leading to global warming and other climate-related problems. Increasing vegetation cover is one of the strategies for capturing and storing carbon dioxide in both vegetation and soil under different land use systems (Khan et al., 2020). In this context, apart from forests, urban green spaces (UGS) play a key role in improving the air quality of the area (Ashraf & Hanafiah, 2019; Nowak, 2000).

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Rapid urbanisation has resulted in a widespread conversion of vegetated areas to impervious surfaces, significantly altering the atmospheric and climatic conditions of urban areas (e.g. urban heat island effect, air pollution and increased carbon dioxide concentration) (Zhang et al., 2022). In India, urbanisation is engulfing a significant portion of peri-urban land, causing a substantial loss in green spaces (Govindarajulu, 2014). According to a recent study published by the World Resources Institute (WRI) 2019, (Bhatia et al., 2019) India has lost 1.6 million hectares of tree cover from 2001 to 2018, with 172 MT of carbon emissions during this period.

Many trees growing outside forest areas, commonly termed as trees outside forests (TOF), are not included in forest monitoring and management programmes, although they provide similar services to more conventional forests (Schnell et al., 2015; Shrestha et al., 2020). The TOF concept is defined as “trees available on lands which are not defined as a forest or other wooded land” (FAO, 2005). However, the Forest survey of India (FSI, 2011) defines TOF as “all those trees, which have attained 10 cm or more diameter at breast height, available on land which is not notified as forest”. TOF includes trees in agricultural land, plantations, wastelands, urban green space (UGS) and built-on lands, including settlements and infrastructure. In urban areas, UGS includes all the trees in private and public places (e.g. roadside trees, parks and green infrastructures). UGS symbolises the “lungs of the city” and also acts as a carbon sink for storing a significant amount of carbon as biomass by the process of photosynthesis.

India has the second-largest road network in the world after the United States (Ragula & Chandra, 2020). With the increase in population in urban areas, road networks across Indian cities are developing rapidly, and existing roads within cities are being widened to improve economic growth, employment, and education services (Solanki et al., 2016). Road construction is both an indicator of the extent of urbanisation and habitat disturbance due to the fragmentation of natural ecosystems and habitats, which in turn render native populations of species vulnerable to various threats (Jantunen et al., 2006; Rentch et al., 2005) and facilitates the introduction and spread of alien invasive species into adjoining natural communities and ecosystems (Christen & Matlack, 2006; Muzafar et al., 2019; Pauchard & Alaback, 2004).

In spite of these concerns, urban vegetation in green spaces including roadside trees harbours rich biodiversity and provides a number of ecosystem services, e.g. mitigating the “urban heat island” effect (Armson et al., 2012), providing habitat for city-dwelling flora and fauna (Goddard et al., 2010), abating air pollution (Baró et al., 2014; Kumar et al., 2019) and providing aesthetic benefits (Kardan et al., 2015; Molla & Mekonnen, 2019). In the recent past, several studies have identified the potential of urban vegetation in reducing CO_2 related warming in urban areas (McHale et al., 2007; McPherson et al., 1998). Further, under proper management, urban plantations can attain higher carbon accumulation than natural forests (Hutyra et al., 2011; Tang et al., 2016).

Road edges act as a new novel habitat for the succession of species (R. T. T. Forman et al., 2003). Generally, disturbance-tolerant and generalist species dominate the roadside vegetation, especially alien invasive species (Muzafar et al., 2019). Trees are the major components of aboveground biomass (AGB) in terrestrial ecosystems (Gibbs et al., 2007) and are critical for carbon sequestration regardless of their location. In addition, according to the results of recent studies, roadside trees are one of the major contributors to carbon sequestration in UGS (Khan et al., 2020; A. K. Singh et al., 2022). Trees growing near the roads experience less competition for resources such as light and nutrients compared to forest areas. Therefore, they are likely to sequester more carbon in comparison with nearby forest areas.

The government of India has recently adopted a National Agro-forestry Policy, 2014, to increase the tree cover of the country. In this context, the quantification of stored carbon and understanding the role of conservation in increasing carbon stores within urban areas themselves and their role in offsetting anthropogenic CO_2 emissions generated from the cities are likely to play a crucial role in policy making. Due to their discontinuous occurrence, lack of documentation and difficulty in identification through remote sensing, roadside trees have so far received little attention for their role in the current dilemma of rising carbon emissions. Considering the importance of the diverse ecological role of roadside vegetation, the present study was carried out to assess the biodiversity of trees along roadsides in Sagar township. The study also includes the estimation of CO_2 mitigation values of different roadside tree species by determining biomass and carbon stock.

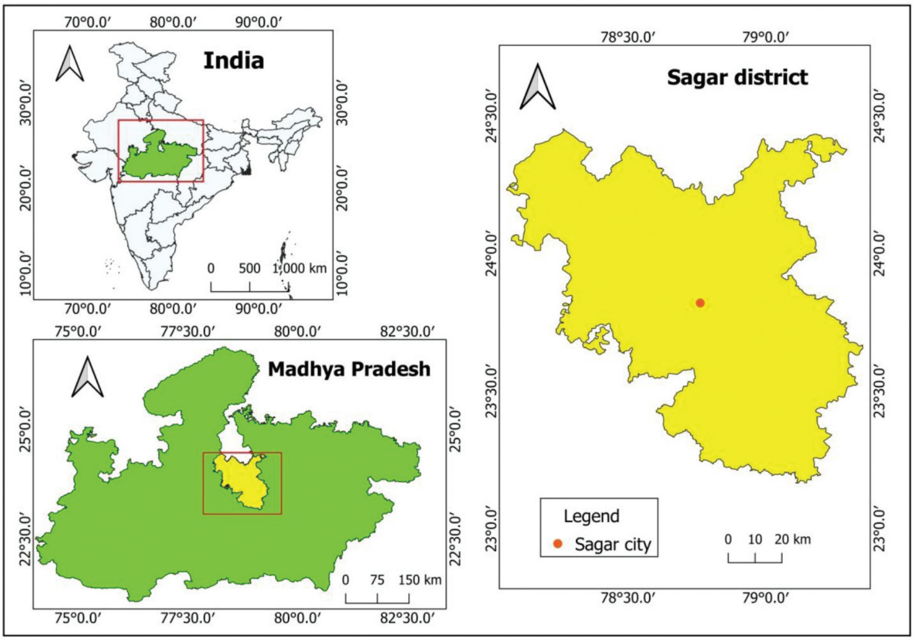
Materials and methods

Study area

The present study was carried out during 2018–19 in Sagar city (23°49′ N and 078°46′ E), Madhya Pradesh state in central India (Figure 1 A and B). It has a population of 273,296 according to the 2011 census. The topography is undulating, with several hillocks and valleys. This area is part of the lower Vindhyan range of central India and is situated at an average altitude of 420 m msl. The forests surrounding this area are classified as "tropical dry deciduous" type (Champion & Seth, 1968). The climate of the study area is monsoonal with well-defined summer, rainy and winter seasons. Summer is hot and dry, with a maximum temperature of 45 °C from April to mid-June. The rainy season begins from the month of late June up to September with an average annual rainfall of 1,187 mm. Winter is mild, with a minimum temperature of 5 °C during January. The area experiences seven to nine dry months in a year.

Field sampling

Fifty-six plots adjacent to each other, 1000 m × 10 m (length × width; 1 ha) were laid out in the study area, covering most parts of the roadside vegetation of the city (Figure 2). All the trees with girth at breast height (GBH, i.e. approximately 1.37 m from the ground) of more than 10 cm growing at a distance of 10 m on both sides of the roads were included in the sampling. For multi-stemmed individuals, bole girths were measured separately and their basal area calculated and summed. Individuals more than or equal to 30 cm GBH were considered as mature trees and individuals from 10 to < 30 cm GBH were considered as juvenile trees. GBH was measured by measuring tape, and the location of all trees was recorded using Garmin GPS device (model no. Oregon 650). Herbarium specimens of the trees were prepared and identified at the Department of Botany, Dr Harisingh Gour Central University, Sagar, with the help of the *Flora of Madhya Pradesh* (BSI, 1993, 1997, 2001).



(a)

(b)

Figure 1. (a) Study area map (b) Main roads in Sagar city, where the present study was conducted (image taken from Google Maps).

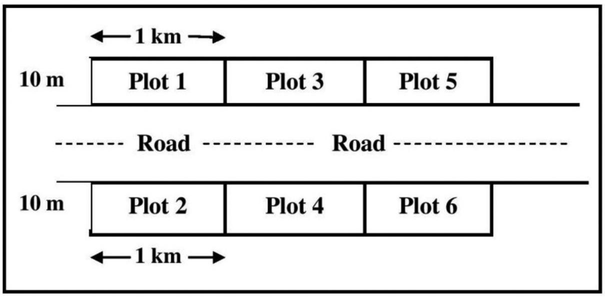


Figure 2. Schematic diagram of the field sampling method for the present study on roadside vegetation of Sagar city.

Distributional patterns of all the species were determined by the abundance to frequency ratio (A/F). Phytosociological characteristics like frequency, density, basal area and importance value index (IVI) were determined following Misra (1968) and Muller-Dombis and Ellenberg (1974). The Shannon–Wiener index of species diversity (Shannon & Weaver, 1963), Simpson's index of dominance, Simpson's index of diversity (Simpson, 1949), Margalef index of species richness (Margalef, 1958) and Pielou's index of evenness (Pielou, 1966) were used to examine the species diversity and distribution under the urban setup (Annex 1).

Biomass estimation

GBH was converted to DBH for each species and categorised into mature trees and juvenile trees. A non-destructive approach was adopted for biomass estimation. The allometric equation of Chave et al. (2005) was followed to determine the above ground biomass (AGB) of mature trees.

$$AGB = \rho \times exp\left(-0.667 + 1.784ln(D) + 0.207(ln(D))^2 - 0.0281(ln(D))^3\right)$$

Where D is the diameter and ρ is the wood-specific gravity (WSG) of tree species. Value of the WSG of different species were taken from the global wood density database of Chave et al. (2009), Zanne et al. (2009), and from earlier studies (for those species which are not available in the database).

The belowground biomass (BGB) of mature species was calculated by following the methodology of Cairns et al. (1997).

$$BGB = exp\{-1.059 + 0.884 \times ln(AGB) + 0.284\}$$

An error in biomass estimation may arise if the equations are adopted for diameter ranges outside the one used for their development (Fonseca et al., 2012). However, the use of distinct calculations for different diameter ranges and adding WSG to the allometric equations might help to reduce this error (Pati et al., 2022a). Therefore, the allometric equation used by Chaturvedi et al. (2012) was followed for AGB estimation of trees at the juvenile stage.

$$AGB = 3.344 + 0.443 \times lnD^2$$

Where D is the diameter.

Below ground biomass of the juvenile tree population was calculated by multiplying the above ground biomass value with 0.26 (IPCC, 2003).

The biomass of palm trees was calculated using the equation from Brown (1997) as follows,

$$Y = 4.5 + (7.7 \times H)$$

Where Y is biomass and H is stem height in metres

$$\text{Total biomass}(TB) = AGB + BGB$$

Total woody carbon (TWC) estimation

Total woody carbon (TWC) was determined as follows,

$$TWC = (AGB + BGB) \times 0.5$$

Where 0.5 is the conversion factor which represents that the C content is assumed to be 50% of the total biomass for tropical dry forest (IPCC, 2003).

Estimation of carbon dioxide mitigation value

The estimated carbon stock was converted into carbon dioxide mitigation value by multiplying carbon stock with 3.67 (molar ratio of carbon dioxide to carbon 44/12) as per the recommendation of IPCC (2007).

Statistical analysis

Species diversity indices were calculated using the Past 4.07 programme (version 4.07; Øyvind Hammer, Natural History Museum, University of Oslo). Other statistical analysis was performed using ORIGIN PRO 2021. Phyto-sociological data, biomass and carbon density values were used to generate a correlation matrix plot to assess the interrelationship between the studied variables. Principal Component Analysis (PCA) was performed to correlate vegetation characteristics with other studied variables. Further, the variations explained by principal components (PC) were also calculated.

Results

Enumeration of trees of ≥10 cm GBH in Sagar city's roadside vegetation shows a total of 1130 individuals belonging to 66 species and 26 families. It was observed that Fabaceae was the most represented family, with 17 identifiable plant species. The Annonaceae, Apocynaceae and Myrtaceae were followed with four identifiable plant species each. Out of 66 species, 53 were native and 13 exotic (Table 1). Amongst exotic species, *Eucalyptus alba* showed stronger colonisation with the highest number of individuals (41), highest frequency (14.29%), highest density (0.73) and second highest IVI (7.121) (Table 1). Amongst native species, *Acacia arabica* had the highest number of individuals (162) in the study site followed by *Holoptelea integrifolia* (88) and *Azadirachta indica* (82)

Table 1. Tree species encountered in sample plots laid down in the roadside vegetations of Sagar city, central India with their family, nativity, number of individuals, frequency percentage, density, abundance, abundance/frequency ratio, basal area (cm^2/ha) and IVI.

S. No.	Species name	Family	Native/ Exotic	Number of individuals in sampled plots	F %	D	A	A/F	BA in cm^2/ ha	IVI
1	*Acacia arabica*	Mimosaceae	N	162	39.29	2.89	7.36	0.187	2550.269	20.897
2	*Acacia auriculiformis*	Mimosaceae	E	1	1.79	0.02	1.00	0.560	39.93653	2.505
3	*Acacia leucophloea*	Mimosaceae	E	1	1.79	0.02	1.00	0.560	10.39333	0.912
4	*Aegle marmelos*	Rutaceae	N	3	5.36	0.05	1.00	0.187	46.26435	1.885
5	*Ailanthus excelsa*	Simaroubaceae	N	19	21.43	0.34	1.58	0.074	310.5334	5.592
6	*Albizia julibrissin*	Fabaceae	N	1	1.79	0.02	1.00	0.560	23.65929	1.627
7	*Albizia lebbeck*	Fabaceae	N	27	12.50	0.48	3.86	0.309	1159.227	6.311
8	*Albizia saman*	Fabaceae	N	28	19.64	0.50	2.55	0.130	1558.649	7.838
9	*Alstonia scholaris*	Apocynaceae	N	11	7.14	0.20	2.75	0.385	162.4279	2.571
10	*Annona squamosa*	Annonaceae	E	2	1.79	0.04	2.00	1.120	9.341589	0.691
11	*Anthocephalus cadamba*	Rubiaceae	N	3	5.36	0.05	1.00	0.187	37.05342	1.719
12	*Azadirachta indica*	Meliaceae	N	82	41.07	1.46	3.57	0.087	2569.763	14.944
13	*Bauhinia racemosa*	Fabaceae	N	5	5.36	0.09	1.67	0.311	7.427619	1.297
14	*Bauhinia variegata*	Fabaceae	N	16	5.36	0.29	5.33	0.996	127.2886	2.547
15	*Bombax malabericum*	Bombacaceae	N	22	25.00	0.39	1.57	0.063	986.9321	8.041
16	*Bougainvillea spectabilis*	Nyctaginaceae	E	2	3.57	0.04	1.00	0.280	3.389445	0.793
17	*Butea monosperma*	Fabaceae	N	56	14.29	1.00	7.00	0.490	608.9036	7.546
18	*Callistemon lanceolatus*	Myrtaceae	E	5	3.57	0.09	2.50	0.700	39.69499	1.396
19	*Cascabela thevetia*	Apocynaceae	E	2	1.79	0.04	2.00	1.120	2.87945	0.491
20	*Cassia fistula*	Fabaceae	N	1	1.79	0.02	1.00	0.560	2.010009	0.459
21	*Cassia semia*	Fabaceae	N	12	12.50	0.21	1.71	0.137	293.769	4.031
22	*Casuarina equisetifolia*	Casuarinaceae	N	1	1.79	0.02	1.00	0.560	1.781677	0.447
23	*Ceiba pentandra*	Malvaceae	E	20	8.93	0.36	4.00	0.448	1051.725	5.183
24	*Cordia dichotoma*	Boraginaceae	N	1	1.79	0.02	1.00	0.560	21.61466	1.517
25	*Cordia myxa*	Boraginaceae	N	4	5.36	0.07	1.33	0.249	75.89748	2.165
26	*Dalbergia paniculata*	Fabaceae	N	1	1.79	0.02	1.00	0.560	14.41721	1.026
27	*Dalbergia sissoo*	Fabaceae	N	70	19.64	1.25	6.36	0.324	926.0771	9.860
28	*Delonix regia*	Fabaceae	E	31	25.00	0.55	2.21	0.089	712.1288	7.311
29	*Diospyros montana*	Ebenaceae	N	1	1.79	0.02	1.00	0.560	0.801954	0.394
30	*Ehretia laevis*	Boraginaceae	N	1	1.79	0.02	1.00	0.560	0.788345	0.372
31	*Eucalyptus alba*	Myrtaceae	E	41	14.29	0.73	5.13	0.359	1007.281	7.121
32	*Ficus benghalensis*	Moraceae	N	11	16.07	0.20	1.22	0.076	1309.474	9.757
33	*Ficus glomerata*	Moraceae	N	3	5.36	0.05	1.00	0.187	67.71892	1.783
34	*Ficus religiosa*	Moraceae	N	42	37.50	0.75	2.00	0.053	5313.732	16.053
35	*Gardenia latifolia*	Rubiaceae	N	1	1.79	0.02	1.00	0.560	6.230721	0.687
36	*Gliricidia sepium*	Fabaceae	E	9	7.14	0.16	2.25	0.315	31.00392	1.958
37	*Holoptelea integrifolia*	Ulmaceae	N	88	41.07	1.57	3.83	0.093	4521.731	16.263
38	*Jacaranda mimosifolia*	Bignoniaceae	E	1	1.79	0.02	1.00	0.560	31.05784	2.026
39	*Leucaena leucocephala*	Fabaceae	E	11	10.71	0.20	1.83	0.171	80.33738	2.819
40	*Limonia acidissima*	Rutaceae	N	1	1.79	0.02	1.00	0.560	30.30596	1.986
41	*Madhuca indica*	Sapotaceae	N	4	7.14	0.07	1.00	0.140	177.2538	3.794
42	*Mangifera indica*	Anacardiaceae	N	16	14.29	0.29	2.00	0.140	1796.973	9.217
43	*Miliusa tomentosa*	Annonaceae	N	3	3.57	0.05	1.50	0.420	39.05125	1.141
44	*Millingtonia hortensis*	Bignoniaceae	N	5	5.36	0.09	1.67	0.311	267.9185	4.120

(*Continued*)

Table 1. (Continued).

S. No.	Species name	Family	Native/ Exotic	Number of individuals in sampled plots	F %	D	A	A/F	BA in cm^2/ ha	IVI
45	*Mimusops elengi*	Sapotaceae	N	4	3.57	0.07	2.00	0.560	14.13471	1.070
46	*Mitragyna parvifolia*	Rubiaceae	N	8	7.14	0.14	2.00	0.280	446.7846	3.949
47	*Peltophorum pterocarpum*	Fabaceae	N	30	5.36	0.54	10.00	1.867	597.4657	4.248
48	*Phoenix sylvestris*	Arecaceae	N	6	7.14	0.11	1.50	0.210	74.86331	2.254
49	*Phyllanthus emblica*	Phyllanthaceae	N	5	8.93	0.09	1.00	0.112	68.19228	2.490
50	*Pithecellobium dulce*	Fabaceae	E	9	12.50	0.16	1.29	0.103	157.4219	3.287
51	*Polyalthia longifolia*	Annonaceae	N	26	10.71	0.46	4.33	0.404	424.5439	4.756
52	*Polyalthia pendula*	Annonaceae	N	24	12.50	0.43	3.43	0.274	92.42087	4.139
53	*Pongamia pinnata*	Fabaceae	N	40	28.57	0.71	2.50	0.088	387.6522	8.113
54	*Psidium guajava*	Myrtaceae	N	4	3.57	0.07	2.00	0.560	3.423428	0.905
55	*Pterospermum acerifolium*	Malvaceae	N	4	5.36	0.07	1.33	0.249	63.17348	1.993
56	*Putranjiva roxburghii*	Putranjivaceae	N	1	1.79	0.02	1.00	0.560	87.58422	5.075
57	*Roystonea regia*	Arecaceae	E	41	8.93	0.73	8.20	0.918	1569.999	7.006
58	*Syzygium cumini*	Myrtaceae	N	5	8.93	0.09	1.00	0.112	258.4096	3.746
59	*Tabernaemontana divaricata*	Apocynaceae	N	1	1.79	0.02	1.00	0.560	2.143383	0.409
60	*Tamarindus indica*	Fabaceae	N	30	23.21	0.54	2.31	0.099	3897.975	13.076
61	*Tectona grandis*	Verbenaceae	N	7	10.71	0.13	1.17	0.109	139.972	3.138
62	*Terminalia arjuna*	Combretaceae	N	28	21.43	0.50	2.33	0.109	2446.857	10.341
63	*Terminalia bellirica*	Combretaceae	N	1	1.79	0.02	1.00	0.560	205.3003	11.425
64	*Thespesia populnea*	Malvaceae	N	2	3.57	0.04	1.00	0.280	2.426098	0.767
65	*Wrightia tinctoria*	Apocynaceae	N	12	3.57	0.21	6.00	1.680	104.2507	1.989
66	*Ziziphus jujuba*	Rhamnaceae	N	15	21.43	0.27	1.25	0.058	102.5024	4.728

N: Native species, E: Exotic species.

(Table 1). *Azadirachta indica* and *Holoptelea integrifolia* showed the highest frequency, whereas *Acacia arabica* and *Peltophorum pterocarpum* had the highest density and abundance, respectively. The total basal area (BA) ranged from 0.001 to 0.39 m^2/ha, being the highest in *Tamarindus indica* and the lowest in *Ehretia laevis*. IVI of different species varied from 0.372 to 20.897. It was the highest for *Acacia arabica* and the lowest for *Ehretia laevis*. Most species showed a continuous distribution pattern with an A/F ratio ranging from 0.050 to 1.86. Girth class distribution shows a reverse J-shaped curve indicating good regeneration potential (Figure 3).

Simpson's index and Shannon's index for diversity were 0.95 and 3.42, respectively, indicating good species diversity. Lower values of the dominance index indicated that a large number of species dominated the present study area rather than a few species. Further, the higher value of Margalef's index (9.246) showed higher species richness and the higher value of Pielou's index of evenness (0.816) indicates an even distribution of species within the community.

The total biomass (TB) for the vegetation along the roads was 36.3 Mg/ha, of which 30.86 Mg/ha was contributed by AGB and 5.44 Mg/ha by BGB. Native species contributed

Table 2. Tree species with their above ground biomass (AGB), below ground biomass (BGB), total biomass (TB), total woody carbon (TWC) and CO_2 mitigation value (the amount of CO_2 mitigated until the study was undertaken).

S. No.	Species name	AGB in Kg/ ha	BGB in Kg/ ha	TB in Kg/ ha	TWC stock in Kg/ ha	CO2 mitigation in Kg/ ha
1	*Acacia arabica*	1956.58	415.21	2371.79	1185.895	4352.235
2	*Acacia auriculiformis*	33.93	6.51	40.44	20.22	74.2074
3	*Acacia leucophloea*	5.21	1.24	6.45	3.225	11.83575
4	*Aegle marmelos*	48.21	9.74	57.95	28.975	106.3383
5	*Ailanthus excelsa*	148.61	27.07	175.68	87.84	322.3728
6	*Albizia julibrissin*	22.86	4.59	27.45	13.725	50.37075
7	*Albizia lebbeck*	1155.31	177.91	1333.22	666.61	2446.459
8	*Albizia saman*	1246.85	231.18	1478.03	739.015	2712.185
9	*Alstonia scholaris*	85.71	16.43	102.14	51.07	187.4269
10	*Annona squamosa*	6.49	1.51	8	4	14.68
11	*Anthocephalus cadamba*	25.31	5.69	31	15.5	56.885
12	*Azadirachta indica*	2097.35	388.84	2486.19	1243.095	4562.159
13	*Bauhinia racemosa*	3.19	0.82	4.01	2.005	7.35835
14	*Bauhinia variegata*	95.21	21.95	117.16	58.58	214.9886
15	*Bombax malabericum*	431.84	78.49	510.33	255.165	936.4556
16	*Bougainvillea spectabilis*	1.25	0.35	1.6	0.8	2.936
17	*Butea monosperma*	387.87	67.43	455.3	227.65	835.4755
18	*Callistemon lanceolatus*	37.28	8.40	45.68	22.84	83.8228
19	*Cascabela thevetia*	0.17	0.05	0.22	0.11	0.4037
20	*Cassia fistula*	1.72	0.02	1.74	0.87	3.1929
21	*Cassia semia*	304.54	59.82	364.36	182.18	668.6006
22	*Casuarina equisetifolia*	1.50	0.41	1.91	0.955	3.50485
23	*Ceiba pentandra*	365.22	75.09	440.31	220.155	807.9689
24	*Cordia dichotoma*	17.36	3.60	20.96	10.48	38.4616
25	*Cordia myxa*	29.79	6.77	36.56	18.28	67.0876
26	*Dalbergia paniculata*	11.65	2.53	14.18	7.09	26.0203
27	*Dalbergia sissoo*	816.41	172.31	988.72	494.36	1814.301
28	*Delonix regia*	378.79	82.20	460.99	230.495	845.9167
29	*Diospyros montana*	0.09	0.02	0.11	0.055	0.20185
30	*Ehretia laevis*	0.17	0.04	0.21	0.105	0.38535
31	*Eucalyptus alba*	1072.92	188.81	1261.73	630.865	2315.275
32	*Ficus benghalensis*	943.72	157.37	1101.09	550.545	2020.5
33	*Ficus glomerata*	31.03	1.93	32.96	16.48	60.4816
34	*Ficus religiosa*	2804.60	476.54	3281.14	1640.57	6020.892
35	*Gardenia latifolia*	4.23	1.03	5.26	2.63	9.6521
36	*Gliricidia sepium*	16.59	4.48	21.07	10.535	38.66345
37	*Holoptelea integrifolia*	2771.50	508.08	3279.58	1639.79	6018.029
38	*Jacaranda mimosifolia*	19.39	3.97	23.36	11.68	42.8656
39	*Leucaena leucocephala*	64.26	14.77	79.03	39.515	145.0201
40	*Limonia acidissima*	31.30	6.06	37.36	18.68	68.5556
41	*Madhuca indica*	219.70	38.04	257.74	128.87	472.9529
42	*Mangifera indica*	1498.54	245.83	1744.37	872.185	3200.919
43	*Miliusa tomentosa*	25.83	6.19	32.02	16.01	58.7567
44	*Millingtonia hortensis*	213.87	37.86	251.73	125.865	461.9246
45	*Mimusops elengi*	12.40	3.02	15.42	7.71	28.2957
46	*Mitragyna parvifolia*	356.21	63.60	419.81	209.905	770.3514
47	*Peltophorum pterocarpum*	418.60	90.67	509.27	254.635	934.5105
48	*Phoenix sylvestris*	10.79	2.91	13.7	6.85	25.1395
49	*Phyllanthus emblica*	53.76	11.60	65.36	32.68	119.9356
50	*Pithecellobium dulce*	119.73	24.53	144.26	72.13	264.7171
51	*Polyalthia longifolia*	297.19	62.56	359.75	179.875	660.1413
52	*Polyalthia pendula*	53.17	13.25	66.42	33.21	121.8807
53	*Pongamia pinnata*	261.49	69.73	331.22	165.61	607.7887
54	*Psidium guajava*	0.61	0.16	0.77	0.385	1.41295
55	*Pterospermum acerifolium*	55.75	10.55	66.3	33.15	121.6605
56	*Putranjiva roxburghii*	63.41	11.32	74.73	37.365	137.1296

(*Continued*)

Table 2. (Continued).

S. No.	Species name	AGB in Kg/ha	BGB in Kg/ha	TB in Kg/ha	TWC stock in Kg/ha	CO2 mitigation in Kg/ha
57	*Roystonea regia*	87.44	23.13	110.57	55.285	202.896
58	*Syzygium cumini*	243.14	44.78	287.92	143.96	528.3332
59	*Tabernaemontana divaricata*	0.93	0.27	1.2	0.6	2.202
60	*Tamarindus indica*	6044.72	916.03	6960.75	3480.375	12772.98
61	*Tectona grandis*	121.57	22.53	144.1	72.05	264.4235
62	*Terminalia arjuna*	2868.46	445.68	3314.14	1657.07	6081.447
63	*Terminalia bellirica*	190.69	29.95	220.64	110.32	404.8744
64	*Thespesia populnea*	1.01	0.29	1.3	0.65	2.3855
65	*Wrightia tinctoria*	99.12	19.53	118.65	59.325	217.7228
66	*Ziziphus jujuba*	70.21	15.42	85.63	42.815	157.1311

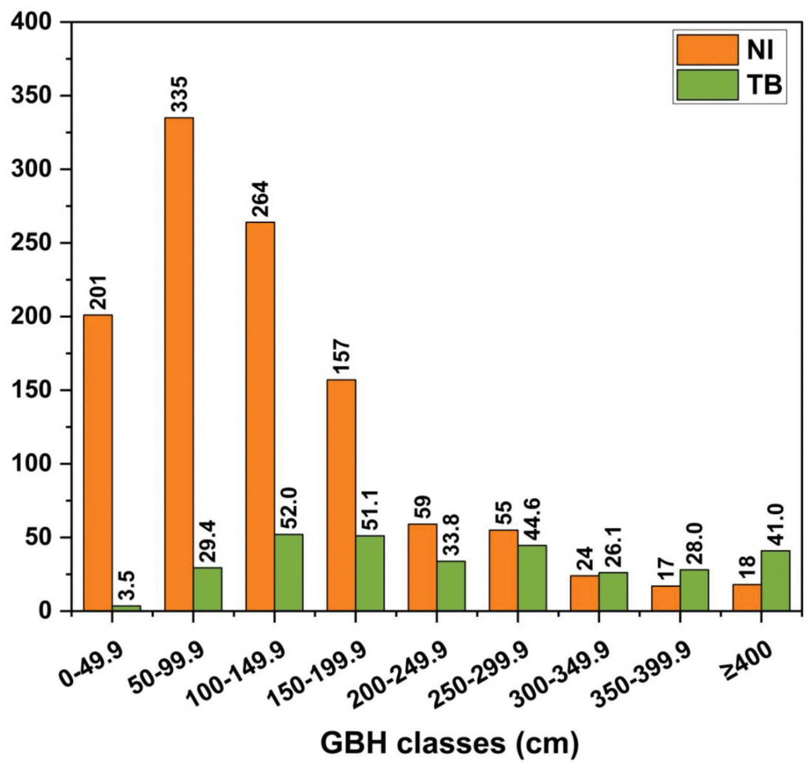


Figure 3. Number of individuals (NI) and total biomass (TB) distribution in each girth class.

92.74% to TB, whereas 7.26% was contributed by exotic species. *Tamarindus indica* made the highest contribution to total biomass with a total of 19%, followed by *Terminalia arjuna*, *Holoptelea integrifolia* and *Ficus religiosa* with 9% each (Figure 4). Girth class distribution showed a positive relationship with TB; however, there was a decline at the highest girth class owing to fewer individuals.

The total carbon storage by roadside vegetation was 18.2 Mg C/ha with a CO_2 mitigation value of 66.6 Mg/ha. Native species contributed 16.8 Mg C/ha towards carbon

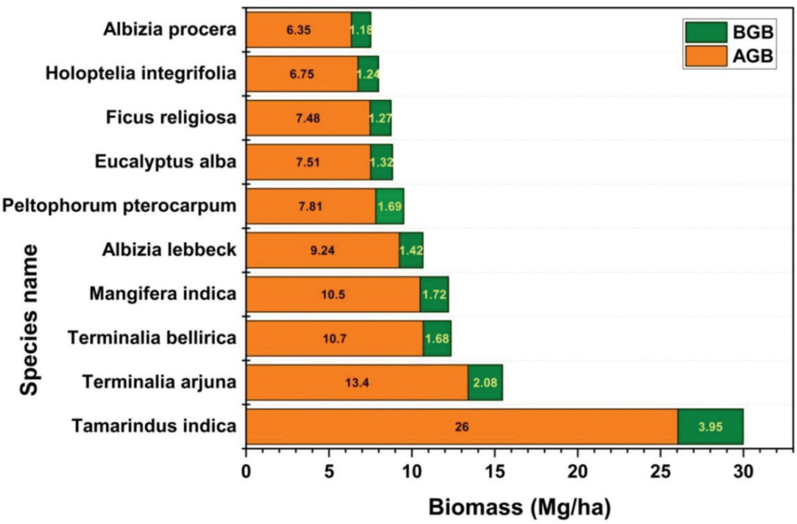


Figure 4. The 10 tree species of Sagar city with highest biomass contribution in the form of stacked above ground biomass (AGB) and below ground biomass (BGB).

stock for the present study site, while it was 1.3 Mg C/ha for exotic species. Of all species, *Tamarindus indica* contributed more to the carbon stock and CO_2 mitigation value (19%), followed by *Terminalia arjuna*, *Holoptelea integrifolia* and *Ficus religiosa* (9% each), while *Diospyros montana* (0.001%) made the least contribution Table 2. Both carbon stock and CO_2 mitigation values were higher in native tree species than in the non-natives. Out of 66 species, 10 were found to contribute 76% of the total to CO_2 mitigation.

Relationship of different vegetation attributes and studied variables

The correlation matrix analysis of basal area (BA), density (D), importance value index (IVI), number of individuals in each species (NI), above ground biomass (AGB), below ground biomass (BGB), total woody carbon (TWC) and CO_2 mitigation value showed that BA and IVI are significantly correlated with AGB, BGB, TWC and CO_2 mitigation value ($P < 0.05$). However, the tree density shows a poor relationship with these parameters ($P > 0.05$) (Figure 5).

The results of the principal component analysis (PCA) using vegetational parameters and total biomass amongst 66 species present in the studied area are depicted in Figure 6. Eigenvalue, variance, and cumulative variance of the studied species are shown in Table 3. The variations explained by the PC-1 and PC-2 account for 81.6% and 11.4%, respectively. Amongst five parameters, i.e. NI, F, IVI, BA and TB, *Acacia arabica*, *Azadirachta indica*, *Dalbergia sissoo*, *Delonix regia*, *Bombax malabericum*, *Eucalyptus alba* and *Butea monosperma* are strongly associated in terms of NI, F and IVI, whereas some of the species like *Holoptelea integrifolia*, *Tamarindus indica*, *Ficus religiosa*, *Terminalia arjuna*, *Mangifera indica*, *Ficus benghalensis*, and *Albizia saman* are significantly associated in terms of BA and TB. A significant number of species in PC-2 are clustered or overlapped (Figure 6), suggesting that these species do not make a significant contribution to all five parameters, which is also confirmed by the eigenvalue and Table 1. From Figure 6, it can also be seen that NI, F and IVI are mostly

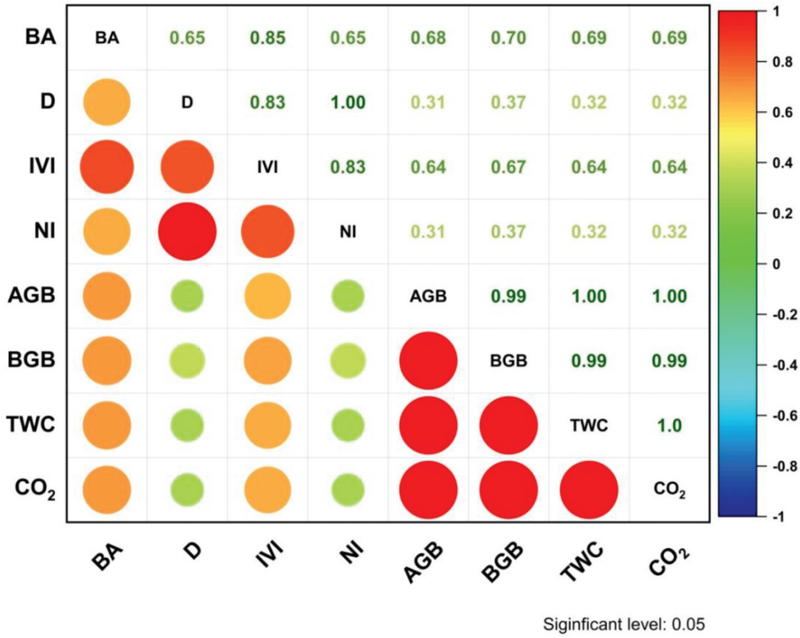


Figure 5. Correlation matrix of various structural parameters, compositional parameters, biomass, and carbon parameters. BA, basal area; D, density; IVI, importance value index; NI, number of individuals in each species; AGB, above ground biomass; BGB, below ground biomass; TWC, total woody carbon; CO_2, CO_2 mitigation value. Positive correlations are displayed in red and negative correlations in blue. Colour intensity and the size of the circle are proportional to the correlation coefficients. On the right side of the correlogram, the legend colour shows the correlation coefficients and the corresponding colour.

contributed by *Acacia arabica* and *Azadirachta indica*. On the other hand, BA and TB are highly contributed by *Tamarindus indica*, *Ficus religiosa* and *Holoptelea integrifolia*. The PCA also revealed the relationship among all the parameters undertaken for the study, where NI, F and IVI are correlated among them, whereas BA and TB are correlated with each other.

Discussion

Tree species' richness plays a vital role in tropical forest biodiversity, as they directly or indirectly sustain almost all other forms of life. Further, species diversity and richness are the two most important indicators of biodiversity (Khan et al., 2020). The roadside tree vegetation appears to be quite diverse as it consists of 1130 trees belonging to 66 species and 26 families which is higher than the reported values of roadside vegetation of other Indian cities such as Nagpur (46 species) (Lahoti et al., 2020), Varanasi (23 species) (A. K. Singh et al., 2022), Bilaspur (37 species) (Ragula & Chandra, 2020), Sylhet metropolitan city (16 species) (Deb et al., 2013) and it is lower than the reported value of Srinagar city (206 species) (Muzafar et al., 2019) and Bangalore (108 species) (Nagendra & Gopal, 2010).

Species richness and biodiversity are highly related to the structure, microclimate, edaphic characteristics, topography, and elevation (Dar et al., 2019). Further, in the

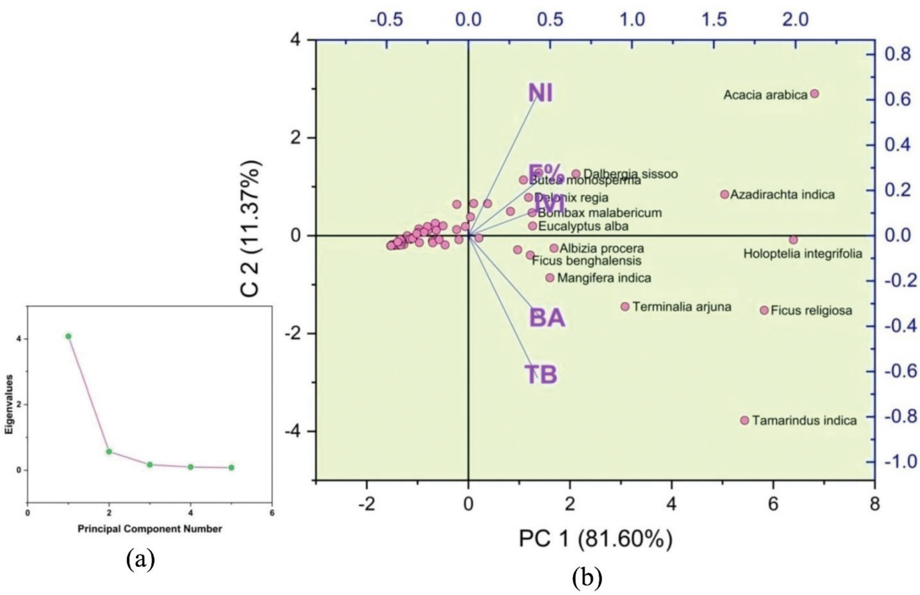


Figure 6. (a) Screen plot depicting important principal components (b) Principal component analysis: A biplot representing ordination of studied species and five variables i.e. NI, number of individuals; F%, frequency; IVI, importance value index; BA, basal area; TB, total biomass.

Table 3. Eigenvalue, variance (%) and cumulative variance of the principal components for the studied variables.

Principal components	Eigenvalue	Variance (%)	Cumulative variance
1	4.08025	81.60%	81.60%
2	0.56867	11.37%	92.98%
3	0.16988	3.40%	96.38%
4	0.09888	1.98%	98.35%
5	0.08233	1.65%	100.00%

urban setup, the availability of green spaces, amplitude of disturbance, level of urbanisation and management practice might play a crucial role in species diversity and richness. Comparatively, higher tree species' richness in our study site than Nagpur, Varanasi and Bilaspur could be due to protective and conservational attitudes and protective cultural attitudes of local communities.

Shannon's diversity index for the present study area is 3.42 which is higher than the maximum Shannon diversity value of Bangalore (2.68). Shannon's diversity index is generally at the higher end of tropical forest ecosystems ranging from 0.81 to 4.1 for the Indian subcontinent (Bhuyan et al., 2003; Parthasarathy et al., 1992; J. S. Singh et al., 1984). The values in our study (3.47) fall well within the reported range of values for tropical forests. Further, surprisingly, it is remarkably higher than the value (0.77–2.53) reported by Dar et al. (2019) from nearby tropical dry deciduous forests of Madhya Pradesh. Further, the higher value of Simpson's index of diversity (0.95), the Margalef's index of species richness (9.246), the Pielou's index of evenness (0.816) and lower value of Simpson's index of dominance

(0.05) indicated the roadside vegetation as a favourable habitat for the conservation of diversity, especially in the urban environment.

The species composition of roadside trees in the present study showed 88.3% native and 16.7% non-native species. A similar result was reported by Pati et al. (2022b) for the roadside vegetation of Dr Harisingh Gour Vishwavidyalaya, Sagar, consisting of 76.47% native and Nadal et al. (2022) for roadside plantations of Maharshi Dayanand University campus, Rohtak (23.5% exotic species and 17 native and 12 exotic species). A recent study by Tamang et al. (2019) from the institutional area of Uttar Banga Krishi Vishwavidyalaya, Cooch Behar, reported 66.3% native and 33.7% exotic flora. On the other hand, Nagendra and Gopal (2011), reported more non-native species (77 species) than native ones in the urban parks of Bangalore city, India. Further, Khan et al. (2020) reported 12.5% native and 87.5% exotic shrub species in the roadside vegetation of Ambikapur, Chhattisgarh. A similar trend was observed for the urban forests of Adama city, central Ethiopia (Koricho et al., 2020). This might be because fast-growing non-native species are introduced in cities to establish greenery in a short period of time.

Planting non-native species in urban green spaces has always been a debatable issue (Dickie et al., 2014; Sjöman et al., 2016) as they may impact ecological structure and function (Kaushik et al., 2022). Species beyond their native range are known as non-native species; however, a few may become invasive in nature and may replace native species in the future. In this regard, studies on road networks revealed that roads are sites for the establishment of exotic species and promote their invasion and spread into other areas (Angold, 1997; Khan et al., 2020; Muzafar et al., 2019; Tyser & Worley, 1992). Within the urban setup, roadsides are highly influenced by anthropogenic disturbances along with other biotic and abiotic pressures which pave the way for the establishment of exotic species. Under high disturbance pressure, roadsides not only act as corridors for the dispersal of alien species within and outside adjacent vegetation but also act as favourable niches for the establishment and naturalisation of these species (T. R. Forman & Alexander, 1998; Muzafar et al., 2019). Since the present study site includes a higher number of native species, these have significant potential to enhance and improve ecological integrity. On the other hand, it has sometimes been argued that a “native-only” approach may risk urban ecosystem resilience, particularly in countries and cities that experience extreme environmental conditions (Sjöman et al., 2016).

In the present study, we found that tree species belonging to the family Fabaceae were widespread on all plots and their tree density was higher compared to other species. A similar finding was reported for the roadside vegetation of Bilaspur city (Ragula & Chandra, 2020). This could be attributed to the fact that these trees are resilient to harsh conditions and may be due to their nitrogen-fixing potential (Ahemad & Kibret, 2014). The Fabaceae family has also been reported to be commonly used in mass afforestation initiatives across Southeast Asia (Ragula & Chandra, 2020).

In the present study, the total biomass of the roadside vegetation was 36.303 Mg/ha which was higher than the reported value for the roadside vegetation of Bilaspur city (Ragula & Chandra, 2020). This might be due to the difference in vegetational composition, soil, climatic condition and level of disturbance. Further, the biomass value is well in the range (3.99 ± 2.89–53.90 ± 11.30 Mg/ha) reported by Salunkhe et al. (2014) from the tropical dry deciduous forests of Madhya Pradesh. These results show that biomass stocking of roadside vegetations is equally important when compared to natural and semi-natural forests in the same climatic conditions.

Roadside vegetation under urban settings provides a number of benefits including carbon sequestration. The vegetation carbon stock is the product of tree density, tree species composition and basal area (Borah et al., 2015; Hu et al., 2015; Osuri et al., 2020). In our study, the maximum carbon stock per individual was contributed by the trees of higher DBH classes. The carbon stock increases with an increase in DBH, and higher DBH class trees had more carbon than a large number of small trees, as also reported by Dhyani et al. (2021), Dash et al. (2022) and Köhl et al. (2017). However, the critical role of young trees in carbon sequestration cannot be underestimated as they possess high carbon sequestration potential. The above-ground carbon stock of the trees in the present study is 15.43 Mg/ha. It is well within the global range of above-ground carbon for tropical deciduous forests of 14 to 123 Mg/ha (Murphy & Lugo, 1986). The carbon stock estimates are comparable with those reported by Salunkhe and Khare (2016) (6 to 26 Mg/ha) from the nearby forests of Sagar. Several studies also revealed that vegetation carbon density and carbon sequestration rates in urban forests might be higher than those of nearby natural forests (Davies et al., 2011; Hutyra et al., 2011). This indicates the significance of this type of vegetation for climate change mitigation and under proper management, they may play an extremely crucial role, similar to forests. The carbon stock in the present study is lower than the urban sacred grove forests of Sikkim Himalaya (76.58–156.04 Mg C/ha) (Devi et al., 2021), in the historically conserved seminary hills' urban forest Nagpur, India (31.5 Mg C/ha) (Dhyani et al., 2021), the urban green spaces in Nagpur city, India (105.2 Mg C/ha)) (Lahoti et al., 2020), the urban forest of Delhi (63.5 Mg C/ha) (Meena et al., 2019), urban forests in Shenyang, China (33.2 Mg C/ha) (Liu & Li, 2012), the urban forest of Hangzhou, China (30.3 Mg C/ha) (Zhao et al., 2010), and the urban cities in Baltimore and Atlanta, US (25.28 Mg C/ha, 35.74 Mg C/ha respectively) (Nowak & Crane, 2002). However, it is higher than for the urban city in Jersey, USA (5.0 Mg C/ha) (Nowak & Crane, 2002). The higher value of carbon storage in other UGSs is probably because the natural forests are highly protected and usually have high tree distribution and abundance which contain mature trees dependent on the age of establishment (Jaman et al., 2020).

The comparison of the carbon stock for the present study area with other roadside plantations generally shows lower values (Table 4). It is quite surprising that despite a very high diversity in the present study area, the biomass and carbon stocks are low. This could be attributed to the loss of higher DBH individuals as a result of development work and other anthropogenic disturbances, while lower DBH individuals are flourishing in a naturalistic way to restore biodiversity. Results indicate that trees in urban areas

Table 4. Carbon storage of urban street trees in different cities.

S. No	City, Country	Carbon stock (Mg C/ha)	References
1	Sagar, India	16.18	Present study
2	Beijing, China	31.9	Tang et al. (2016)
3	Daegu, Korea	24.9	Yoon et al. (2013)
4	Bangladesh	192.80	Rahman et al. (2015)
5	Dhaka city, Bangladesh	45.47–193.50	Jaman et al. (2020)
6	Port Harcourt, Nigeria	136. 15	Agbelade and Onyekwelu (2020)
7	Hawassa city, Ethiopia	167.5 ± 128.00	Feyisa et al. (2022)
8	Ilorin, Nigeria	7.82	Agbelade and Onyekwelu (2020)

have a high potential for regeneration, and open space and nutrient-rich soil add to the efficiency of young individuals. An earlier study also showed that unmanaged patches in urban areas contain more saplings and seedlings than mature trees because of active natural regeneration and the composition of species (Dhyani et al., 2021).

The present study showed that UGS might play a crucial role in combating climate change. However, rapid land-use and land-cover changes in urban areas are huge challenges for environmentalists and policymakers to create spaces to develop urban green ecosystems. The present study may support the need to increase UGS, particularly roadside trees in the growing urban sprawl in towns and cities. Understanding ecosystem service benefits (particularly carbon storing capacity and CO_2 mitigation potential) will help local authorities and urban planners acknowledge the values of these plantations and their important role in ameliorating the urban environment.

Conclusions

Urban areas with rich tree vegetation and biodiversity have considerable potential to assist the environment by storing significant amounts of carbon from the atmosphere. Further, they act as a higher carbon source compared to suburban and rural areas due to higher vehicular and industrial emissions. In order to understand the impact of climate change, quantification of carbon stock and CO_2 mitigation values for all land-use types including urban roadside vegetations are prerequisites. Results of the present study revealed that the roadside vegetation of Sagar city is quite diverse and harbours a larger number of species along with adequate richness and higher dominance of native species over exotic species. Further, we found that species belonging to the Fabaceae family were the most prevalent species throughout the roadside vegetation indicating their potential to act as a preferable choice for roadside plantations. Further, the present study showed that urban tree cover, alongside other forests (such as old-growth and secondary forests) could also play a significant role in mitigating the impact of climate change by reducing the atmospheric CO_2 as indicated by the carbon sequestration on a par with other neighbouring forest vegetation.

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Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement

Data will be made available on request.

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Annexure

Basal area (BA) and importance value index (IVI) were estimated using the following formula:

BA = πr^2

Where r is radius and r = DBH/2

IVI = Relative frequency + Relative density + Relative basal area

The formula for determination of the Shannon–Wiener index of species diversity (Shannon & Weaver, 1963), Simpson's index of dominance, Simpson's index of diversity (Simpson, 1949), Margalef index of species richness (Margalef, 1958) and Pielou's index of evenness (Pielou 1966) are as follows:

$$\text{Shannon index}(H') = \sum_{i=1'}^{s} -p_i \ln p_i$$

Where S = Number of species,

p_i = Proportion of individuals belonging to species i,

ln= Natural log

Simpson's index of dominance = $\sum_{i=1}^{s} (P_i)^2$

Simpson's index of diversity = 1– $\sum_{i=1}^{s} (P_i)^2$

Where $P_i = \frac{\text{Number of individuals in ith class}}{\text{Total number of individuals}}$

Margalef's index of species richness (R) = $\frac{S-1}{lnN}$

Where S = Total number of species in the community

N is the total number of individuals in the community

Pielou's index of evenness (e) = $\frac{H'}{\ln S}$

Where H' is the Shannon–Wiener index

S = Total number of species in the community