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Assessment and Valuation of Climate Regulation Ecosystem Service Benefits from Semi-arid, Urban Forest Ecosystem: Findings from Delhi Ridge Forest

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ABSTRACT

Urban forests provide many ecosystem services that significantly enhance urban centres' sustainability and city residents' well-being. They play a vital role in capturing carbon dioxide and facilitating its long-term storage through biomass and soil, thereby contributing to climate regulation. The Delhi Ridge forest is a key urban forest ecosystem that substantially benefits the surrounding communities. In this study, we assessed the vegetation carbon stocks (VCS), soil organic carbon (SOC) stocks, and total carbon stocks (TCS) across four segments of the Delhi Ridge using non-destructive biomass assessment methods. Our findings indicated that the VCS, SOC stocks (up to a 10 cm depth), and TCS for the entire Delhi Ridge are 47.72, 25.77, and 73.48 Mg C ha^{-1}, respectively. In contrast to traditional assessments of carbon stocks, we approached this analysis from a monetary perspective. By linking the climate regulation benefits of the Delhi Ridge to the social cost of carbon in India, we found that the CO_2 equivalent for the entire Delhi Ridge amounts to 269.44 Mg ha^{-1}, offering climate damage prevention benefits valued at US$23,171.48 ha^{-1}. These results are intended to enhance stakeholders' understanding of the intangible climate regulation benefits that arise from the Delhi Ridge and to support policymakers in formulating targeted, climate-resilient strategies for the city.

Key words: Urban forests, Climate Regulation, Regulating Ecosystem Services, Delhi Ridge, CO_2 equivalent, Carbon pools

INTRODUCTION

Ecosystem services are intrinsically linked to human well-being (Read et al. 2025). Tropical forests provide diverse ecosystem services, including fuelwood, fodder, and medicinal plants, as well as essential processes such as soil formation, habitat provision, climate regulation, flood management, and cultural benefits (Chopra et al. 2022). In today's context, anthropogenic activities, particularly burning fossil fuels, have led to increased atmospheric CO_2 concentrations. Growing evidence indicates that this elevated carbon load significantly impacts the global climate system, resulting in extreme weather events (Anonymous 2018).

One of the crucial regulating ecosystem services forests offers is climate control through carbon sequestration. Tropical forests account for 60% of the world's photosynthesis, capturing 72 Pg C yr^{-1} (Beer et al. 2010). As a result, these forests are integral to the climate mitigation strategies embraced by various nations. Moreover, the global community has come to recognize the vital role of forests in achieving the United Nations Sustainable Development Goals (UNSDGs), particularly Goal 13 (Climate Action) and Goal 15 (Life on Land).

Numerous studies have consistently highlighted forests' crucial role in the global carbon cycle and carbon sequestration (Chang et al. 2017, Lun et al. 2018, Mitchard 2018, Chu et al. 2019, Lin and Ge 2019, Tagesson et al. 2020). The volume of forest biomass indicates the amount of carbon dioxide that forests extract from the atmosphere during various physiological processes (Brown et al. 1996). Most carbon is stored in aboveground biomass, which encompasses leaves, stems, and trunks, while belowground biomass, including root systems, holds comparatively less carbon. Additionally, tropical forests sequester significant amounts of carbon in their soils as organic matter (Houghton 2005). Several factors influence the quantity of biomass and carbon storage within forests, such as altitude, latitude, canopy cover, age, and ecological processes (Pan et al. 2013, Pandey et al. 2014). Accurately estimating biomass on national, regional, and local levels and quantifying its spatial and temporal variability can serve as a valuable resource for policymakers in developing and implementing climate-resilient strategies (Salunkhe et al. 2018).

In recent years, there has been a notable increase in studies in India aimed at understanding the carbon dynamics of tropical forests (Chaturvedi et al. 2012, Salunkhe and Khare 2016). Biomass estimation encompasses both direct and indirect methods. Direct methods involve harvesting the entire plant and using the dry weight of various plant parts to calculate biomass. In contrast, indirect methods are non-destructive and utilize various plant variables, such as diameter at breast height (DBH) and height (H), to estimate tree biomass (Chave et al. 2005, Brahma et al. 2018). Biomass estimation methods and equations have been developed for efficient quantification (Ravindranath and Ostwald 2008; Chavan and Rasal 2010; Vashum and Jayakumar 2012; Nath et al. 2019). Moreover, remote sensing and GIS technologies have increasingly been applied in studies of biomass estimation (Bijalwan et al. 2010, Choudhary et al. 2017, Pandey et al. 2019, Ramachandra and Bharath 2020).

With an unprecedented rate of urbanization, Delhi has emerged as one of the fastest-growing urban conglomerates in the world (Naikoo et al. 2020). Infrastructure development has received a policy impetus to accommodate the ever-increasing influx of people from surrounding areas. However, the rapid infrastructure expansion comes at a significant cost, with forests and natural areas often being the first to be sacrificed for urban growth. The Delhi Ridge harbours the remnants of semi-arid tropical thorn forests, providing numerous ecosystem services to nearby communities, including air pollution control, temperature regulation, biodiversity habitat, carbon sequestration, groundwater recharge, and psycho-sociological benefits. Although the 32 km-long Delhi Ridge is legally protected, the past three decades have seen an increase in built-up areas surrounding the Ridge, as well as encroachments within the protected forest, leading to heightened anthropogenic pressure on this already fragile urban forest ecosystem (Chopra et al. 2022a). In light of the escalating threat posed by climate change, it is crucial to sustainable policies for the long-term management of urban green spaces. Recent scholarly attention has focused on the carbon stock estimation of Delhi Ridge has witnessed some scholarly limelight (Meena et al. 2019, Tomar and Baishya 2020). Recent scholarly attention has focused on the carbon stock estimation of Delhi Ridge (Meena et al. 2019, Tomar and Baishya 2020). However, assessing the monetary value associated with these carbon stocks is equally important to encourage and inform policymakers and stakeholders. This study aims to (a) quantify the carbon stocks of the entire Delhi Ridge and (b) evaluate these carbon stocks in monetary terms, thereby facilitating effective communication of the climate regulation ecosystem service benefits derived from the Delhi Ridge Forest to various stakeholders in a more accessible manner.

MATERIAL AND METHODS

Study area

The study was conducted in Delhi, the capital city of India, situated between 28°22'' to 28°24'28°24' N and 76°48'' to 77°23'77°23' E. This city lies within the subtropical zone and experiences hot, dry summers. A significant portion of its annual rainfall, totalling 762.3 mm, occurs during the monsoon season, which typically lasts from late June until September (IMD). Delhi Ridge (Fig. 1), an extension of the Aravalli hill ranges, is one of the city's two prominent geographical features alongside the River Yamuna. Due to increasing population pressure, Delhi Ridge is divided into four segments: Northern Ridge, Central Ridge, South Central Ridge, and Southern Ridge. Among these, the Northern Ridge is the smallest, while the Southern Ridge is the largest. The total area of Delhi Ridge spans 7,777 hectares. Various segments of the Ridge are managed by several government agencies, which include the Department of Forest National Capital Region of Delhi, the Delhi Development Authority (D.D.A.), Delhi Biodiversity Foundation, Central Public Works Department (C.P.W.D.), the Army, and the Municipal Corporation of Delhi (M.C.D.).

Delhi Ridge is characterized by dry tropical thorn forests (Champion and Seth, 1968), primarily dominated by species such as *Acacia leucophloea*, *Acacia senegal*, *Anogeissus pendula*, *Diospyros montana*, *Balanites aegyptiaca*, *Acacia catechu*, *Acacia modesta*, *Wrightia tinctoria*, and *Butea monosperma*. However, the entire forest ecosystem

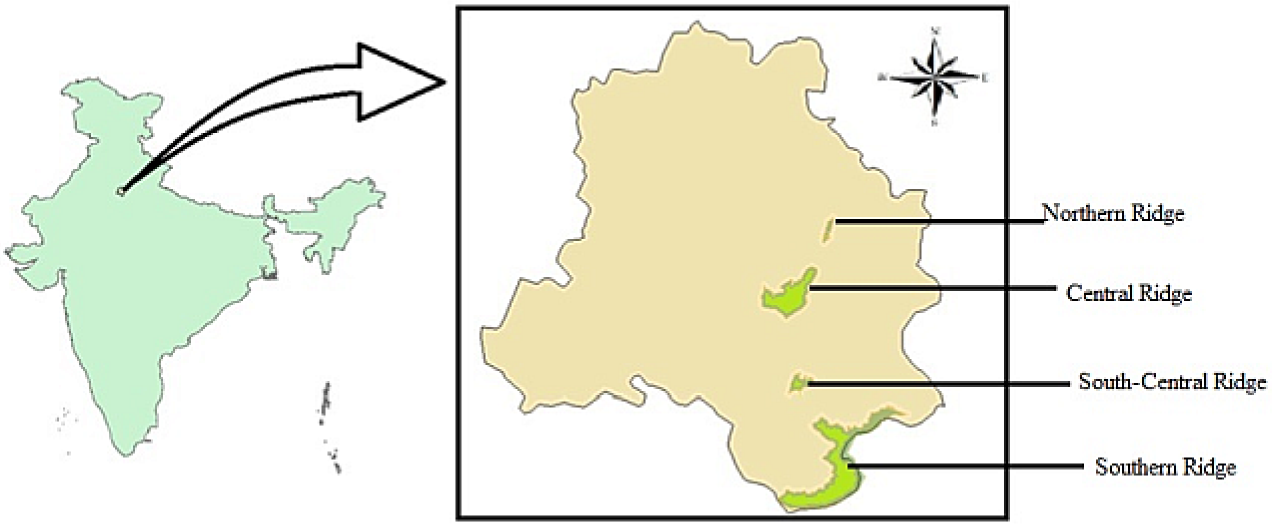

Figure 1. The four segments of Delhi Ridge

of Delhi Ridge has been largely overtaken by the non-native leguminous tree species *Prosopis juliflora*, which originated in South America. Other invasive species, including *Leucaena leucocephala* and *Lantana camara*, also proliferate. In addition to urbanization, the elements driving change and threatening the ecosystem of Delhi Ridge include the disposal of construction and demolition waste, the conversion of land into parks, and illegal encroachments.

Biomass assessment

Samples were collected from the entirety of the Northern Ridge and Central Ridge. The Sanjay Van area in the South-Central Ridge was specifically selected for sampling. At the same time, samples were gathered from the Asola Bhatti Wildlife Sanctuary and the forests of Dera Mandi in Southern Ridge. The study area was initially divided into 500 x 500 m grids, from which samples were randomly drawn. As mentioned, since multiple agencies manage Delhi Ridge, inaccessible grids were excluded from the sampling process. For sample collection, 10 x 10 m quadrats were laid out randomly, ensuring that at least one sample was taken from each accessible grid. Approximately 146 quadrats were established across all four sections of the Ridge. Using measuring tape, the circumference at breast height (CBH) was measured for each tree at a standard height of 1.37 m above ground level. This CBH was then divided by π to calculate each tree's diameter at breast height (DBH). Individuals with a DBH of 7 cm or greater were classified as trees according to the sampling criteria (Wheater et al. 2011), while those with a DBH of less than 7 cm were categorized as saplings or seedlings. The ocular method was employed to estimate the heights of the trees.

$$DBH = CBH/\pi$$

Where DBH = diameter at the breast height (cm); CBH= Circumference at Breast Height (cm)

Phytosociological parameters such as Tree Density (TD) and Basal Area (BA) for various tree species were also calculated using the following formulas:

$$TD = (ha/A)*N$$

Where TD= Tree Density; ha= one hectare; A= Area of quadrat in hectare, N=Number of trees counted in the quadrat

$$BA = CBH^2/4\pi$$

Where BA= Basal Area; CBH= Circumference at Breast Height (cm)

For biomass estimation, the non-destructive method was used. A tree's aboveground biomass (AGB) was estimated by multiplying the bio-volume by the specific wood density of tree species (Ravindranath and Ostwald 2008). The bio-volume was calculated using the following equation:

$$b = 0.4 * DBH^2 * H$$

Where b = bio-volume; DBH = Diameter at Breast Height; H = height of the tree

The AGB was calculated from the biovolume using the following equation:

$$AGB = SG * b$$

Where AGB= Above-ground Biomass; SG= Specific gravity of tree species (kg m^3), b= Bio-volume

Specific gravity values suggested by Meena et al. (2019) and Zanne et al. (2009) were used for calculations. For the calculation of belowground biomass (BGB), the following equation, as specified by Cairns et al. (1997) and Ravindranath and Ostwald (2008), was used.

$$BGB = 0.26 * AGB$$

For the calculation of total biomass (TB), the following equations were used:

$$TB = AGB + BGB$$

The AGB, BGB, and TB (in kg) were first obtained for each quadrat (100 m^2), and then the average values for all the quadrats in an area were derived. These average values were then converted into Mg ha^{-1} (considering 1 ha = 10,000 m^2) for the entire area.

Carbon stocks

Soil samples were collected from each quadrat from three different places at a depth of 10 cm using a spade. At each sampling point, samples were collected below the tree canopy and in different directions around the tree. Samples were mixed to obtain a composite sample. The samples were air-dried, passed through a 2 mm mesh sieve to remove vegetative particles and rock debris, and then analyzed for bulk density. Finally, they are stored in zip-lock polybags and marked for site location and the date the sample was collected. Bulk density was calculated using the following equation:

$$BD = W/V$$

Where BD= Bulk Density (g cm^{-3}); W= Dry soil weight (g) and V= Volume (cm)

The Walkley and Black Method was used to calculate SOC. For the assessment of SOC stocks of the soil, the following equation (Tomar and Baishya 2020) was used:

$$SOC\ (Mg\ C\ ha\text{-}1) = SOC\ (\%) * SD * BD * 10000$$

Where SOC (%) = Soil Organic Carbon Value in percentage (Note: the percentage value is divided by 100 during calculation); SD= Soil Depth in metres (Note: Soil depth value is divided by 100 to convert into cm); BD= Bulk Density (Mg m^{-3}) value is multiplied by 10,000 to get value in ha as 1 ha=10,000 m^2

It is assumed that 50% of the plant biomass is carbon. Therefore, the TB value is multiplied by 0.50 to get the value of VCS and the following formula was used:

$$VCS = TB * 0.50$$

Where VCS= Vegetation Carbon Stock (Mg C ha^{-1}); TB= Total Biomass (Mg ha^{-1})

Total Carbon Stock (TCS) is the total of vegetation carbon stock and soil organic carbon stock. The following formula was used:

$$TCS = VCS + SOCS$$

Where VCS= Vegetation Carbon Stock (Mg C ha^{-1}); SOCS= Soil Organic Carbon Stock (Mg C ha^{-1})

CO_2 equivalent was calculated using the following equation (Stoffberg et al. 2010, Snehlata et al. 2021).

$$CO_{2eq.} = TCS * (44/12)$$

Valuation of climate regulation benefits

The social cost of carbon in India is estimated at $86 (IRS 7,495) per ton of CO_2 (Ricke et al. 2018, Syed and Ullah 2021). This figure represents the environmental damage from releasing 1 ton of CO_2 into the atmosphere. We utilized this cost by applying the damage-avoided valuation method to assess the value of the climate risk reduction provided by the forests of Delhi Ridge, which capture and store CO_2.

RESULTS

In the phytosociological analysis of four distinct areas of Delhi Ridge, 45 tree species were identified. Among these areas (Table 1), the Central Ridge exhibited the highest tree density (TD) per hectare, recording 744 trees ha^{-1}. This was closely followed by the Northern Ridge at 729 trees ha^{-1} and South-Central Ridge at 724 trees ha^{-1}, while the Southern Ridge showed the lowest TD at 679 trees ha^{-1}. Notably, the Northern Ridge also had the highest mean Diameter at Breast Height (DBH) and total

Table 1. Tree Density, Mean DBH and Basal Area values for four different parts of Delhi Ridge

Forest	**Tree density (Trees ha^{-1})**	**Mean DBH (cm)**	**Basal area (m^2 ha^{-1})**
Northern Ridge	729	20.82	36.78
Central Ridge	744	18.57	28.28
South-Central Ridge	724	18.55	25.45
Southern Ridge	679	13.24	11.39
Average for Ridge forest	719	20.375	28.06

Basal Area (BA) per hectare, measuring 25.04 cm and 47.12 m^2 ha^{-1}, respectively. Across Delhi Ridge, TD values ranged from 679 to 729 trees ha^{-1}, averaging 719 trees ha^{-1}. The mean DBH varied between 12.70 and 25.04 cm, with an overall mean of 20.37 cm. In contrast, BA values fluctuated from 11.39 to 47.12 m^2 ha^{-1}, averaging 28.06 m^2 ha^{-1}. Detailed species-wise information on TD, BA, and DBH for selected species can be found in Table 2. The Northern Ridge has more individuals in the larger DBH classes (Fig. 2). In contrast, the Southern Ridge shows more individuals in the smaller DBH classes, particularly in the 0-10 cm and 10-20 cm ranges.

Biomass and vegetation carbon stocks (VCS)

If we observe the biomass values (Table 3, Fig. 3), the AGB for Northern Ridge was found to be 101.78 Mg ha^{-1}, while the BGB for this region was 26.46 Mg ha^{-1}. The TB of this area was 128.24 Mg ha^{-1}, while the VCS value was 64.12 Mg C ha^{-1}. In the case of Central Ridge, the value of AGB was 89.98

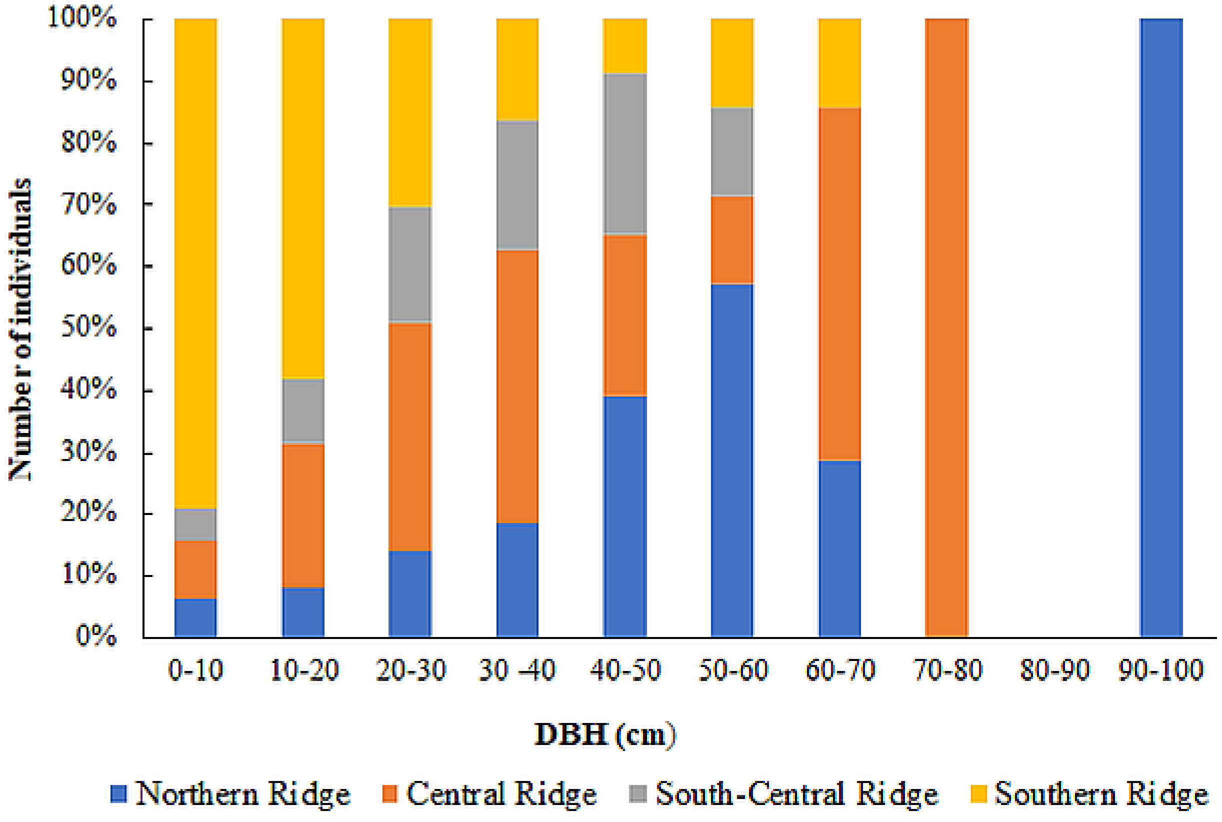

Figure 2. Tree individuals (%) in each DBH class for Delhi Ridge

Table 2. TD (Trees ha^{-1}), Mean DBH (cm), Basal area (m^2 ha^{-1}) of selected species Delhi Ridge

S.No.	**Species**	**Northern Ridge**			**Central Ridge**			**South-Central Ridge**			**Southern Ridge**		
		TD	**DBH**	**BA**	**TD**	**DBH**	**BA**	**TD**	**DBH**	**BA**	**TD**	**DBH**	**BA**
1	*Acacia catechu*	_	_	_	21	15.33	0.38	6	10.82	0.05	2	11.43	0.025
2	*Acacia leucophloea*	7	22.29	0.27	6	32.17	0.48	35	18.52	0.97	60	17.35	1.61
3	*Acacia modesta*	36	23.25	2.09	_	_	_	_	_	_	_	_	_
4	*Acacia nilotica*	_	_	_	_	_	_	_	_	_	54	9.9	0.43
5	*Albizzia lebbeck*	7	45.54	1.16	3	15.29	0.05	12	21.97	0.44	_	_	_
6	*Anogeissus pendula*	_	_	_	35	15.48	0.71	_	_	_	95	11.88	1.22
7	*Azadirachta indica*	21	48.62	4.41	9	20.94	0.27	18	39.59	2.43	1	24.84	0.05
8	*Balanites aegyptiaca*	_	_	_	_	_	_	18	20.38	0.64	41	11.34	0.46
9	*Bombax ceiba*	_	_	_	3	46.88	1.08	6	38.21	0.67	_	_	_
10	*Butea monosperma*	7	41.4	0.96	18	20.9	0.5	_	_	_	17	15.67	0.36
11	*Cassia fistula*	14	25.64	0.74	62	18.77	1.95	53	14.86	1.02	10	12.73	0.13
12	*Dalbergia sissoo*	_	_	_	6	36.62	0.33	_	_	_	46	10.45	0.43
13	*Diospyros montana*	64	10.16	0.55	9	26.75	0.51	18	10.4	0.15	23	15.63	0.5
14	*Ehretia laevis*	57	9.63	0.43	18	11.73	0.24	6	10.5	0.05	_	_	_
15	*Ficus glomerata*	7	20.7	0.24	_	_	_	6	30.89	0.44	_	_	_
16	*Ficus religiosa*	21	47.66	5.01	_	_	_	24	33.2	2.3	_	_	_
17	*Haplophragma heterophyllum*	7	12.74	0.09	24	15.88	0.59	12	10.82	0.11	14	23.2	0.98
18	*Holoptelea integrifolia*	_	_	_	29	11.69	0.39	118	13.74	2.62	25	13.59	0.37
19	*Leucaena leucocephala*	14	13.38	0.21	91	13.36	1.5	24	33.04	2.21	4	6.88	0.01
20	*Pongamia pinnata*	21	12.95	0.3	12	9.4	0.08	12	12.1	0.16	20	10.29	0.17
21	*Prosopis juliflora*	236	23.84	12.83	347	20.2	15.17	353	18.06	10.89	209	14.23	3.93
22	*Terminalia arjuna*	7	9.55	0.58	_	_	_	_	_	_	1	8.92	0.007

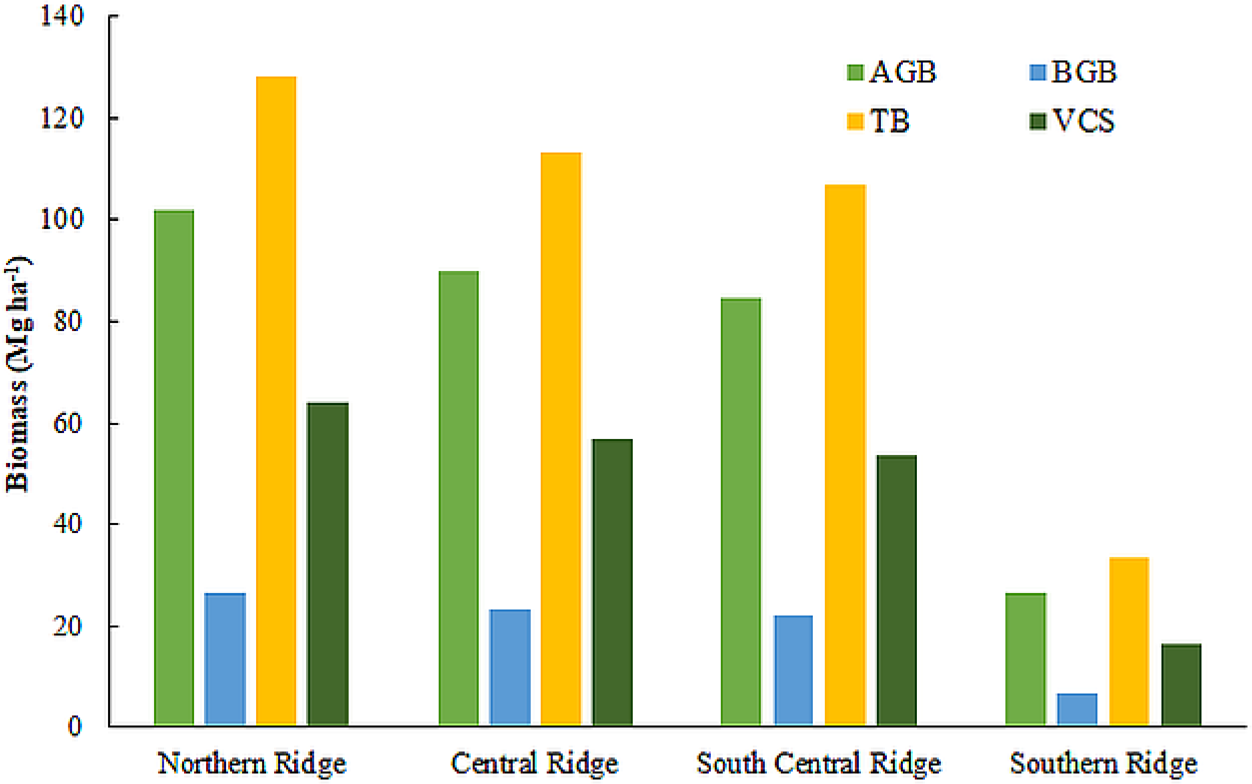

Figure 3. Comparative analysis of biomass in all four parts of Delhi Ridge

Table 3. AGB, BGB, TB and VCS in Delhi Ridge

Forest	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})	VCS (Mg C ha^{-1})
Northern Ridge	101.78	26.46	128.24	64.12
Central Ridge	89.98	23.39	113.37	56.69
South Central Ridge	84.82	22.05	106.87	53.39
Southern Ridge	26.47	6.88	33.35	16.67
Average	75.74	19.69	95.43	47.72

Mg ha^{-1}, BGB was 23.45 Mg ha^{-1}, TB was 113.66 Mg ha^{-1}, and VCS value was 56.83 Mg C ha^{-1}. AGB, BGB, TB, and VCS values were 84.74 Mg ha^{-1}, 22.03 Mg ha^{-1}, 106.77 Mg ha^{-1} and 53.39 Mg C ha^{-1}, respectively. The lowest ASGB, BGB, TB and VCS values were reported from Southern Ridge, where these are 26.47, 6.88, 33.35 and 16.67 Mg C ha^{-1}, respectively. With more individuals in higher DBH class and higher mean BA, the Northern Ridge has the highest values for AGB, BGB, TB and VCS among all the four parts of Delhi Ridge.

The aboveground biomass (AGB) values for the entire Delhi Ridge range from 26.74 to 101.78 Mg ha^{-1}, with an average of 75.74 Mg ha^{-1}. Belowground biomass (BGB) varies between 6.88 and 26.46 Mg ha^{-1}, averaging 19.71 Mg ha^{-1}. Total biomass (TB) spans from 33.35 to 128.24 Mg ha^{-1}, with a mean value of 95.51 Mg ha^{-1}. In a species-specific analysis of biomass (Table 4), it is evident that *Prosopis juliflora* contributes significantly to AGB, BGB, and TB across all four regions of the Delhi Ridge forest. Its percentage contribution to TB ranges from 34.15 to 51.71%, with the highest value recorded in the Central Ridge. Notably, individuals with low tree density (TD) but high diameter at breast height (DBH) values make substantial contributions to TB. In the Northern Ridge, for example, both *Azadirachta indica* and *Ficus religiosa*, each with a TD of 21

Table 4. Top five tree species contributors to AGB, BGB and TB in Delhi Ridge

S.No.	Species	AGB (Mg ha^{-1})	BGB (Mg ha^{-1})	TB (Mg ha^{-1})
Northern Ridge				
1	*Prosopis juliflora*	34.69	9.02	43.71
2	*Azadirachta indica*	15.20	3.95	19.15
3	*Ficus religiosa*	12.95	3.37	16.32
4	*Acacia modesta*	9.98	2.59	12.57
5	*Morus alba*	5.78	1.50	7.28
Central Ridge				
1	*Prosopis juliflora*	46.49	12.14	58.62
2	*Ficus benghalensis*	5.72	1.49	7.21
3	*Sterculia foetida*	5.63	1.44	7.04
4	*Cassia fistula*	5.47	1.42	6.89
5	*Leucaena leucocephala*	4.92	1.28	6.20
South-Central Ridge				
1	*Prosopis juliflora*	38.61	10.04	48.65
2	*Azadirachta indica*	9.78	2.54	12.32
3	*Leucaena leucocephala*	9.52	2.47	11.99
4	*Ficus religiosa*	6.56	1.70	8.26
5	*Holoptelea integrifolia*	6.54	1.70	8.24
Southern Ridge				
1	*Prosopis juliflora*	9.45	2.41	11.86
2	*Acacia leucophloea*	4.31	1.12	5.43
3	*Anogeissus pendula*	3.73	0.97	4.70
4	*Haplophragma heterophyllum*	1.45	0.38	1.82
5	*Acacia nilotica*	1.24	0.32	1.57

trees ha^{-1} and mean DBH values of 48.62 and 47.66 cm, respectively, rank as the highest contributors to TB after *Prosopis juliflora*. Similar patterns are observed in the Central Ridge and South-Central Ridge, where *Ficus benghalensis* (TD of 3 trees ha^{-1}) is the second largest contributor in the Central Ridge. *Azadirachta indica* (TD of 18 trees ha^{-1}) holds that position in the South-Central Ridge.

As anticipated, the Northern Ridge was assessed to have the highest value of VCS, recorded at 64.12 Mg C ha^{-1}. Following closely behind was the Central Ridge, with a value of 56.83 Mg C ha^{-1}. The South-Central Ridge trailed closely with a VCS value of 53.39 Mg C ha^{-1}. In contrast, the Southern Ridge had the lowest VCS value, measured at 16.67 Mg C ha^{-1}. Therefore, the VCS values across the entire Delhi Ridge range from 16.67 to 64.12 Mg C ha^{-1}, with an average value of 47.75 Mg C ha^{-1}.

SOC

The average soil organic carbon (SOC) stock at a depth of up to 10 cm for the Northern Ridge was estimated to be 30.05 Mg C ha^{-1}. South-Central Ridge exhibited SOC stocks of 28.79 Mg C ha^{-1}. Central Ridge closely trailed behind with an estimated SOC stock of 28.20 Mg C ha^{-1}. The lowest SOC values were recorded in the Southern Ridge area, at 16.02 Mg C ha^{-1}. For the entire Delhi Ridge, SOC at depth up to 10 cm, ranged from 16.02 Mg C ha^{-1} and 30.05 Mg C ha^{-1} with the mean value of 25.77 Mg C ha^{-1} (Table 5).

TCS and CO_2 equivalents

The Northern Ridge exhibits the highest total carbon stock (TCS) among the four sections of the Delhi Ridge, with a measurement of 94.17 Mg C ha^{-1}. The Central Ridge follows with an estimated TCS value of 85.03 Mg C ha^{-1}. The South-Central Ridge has a

Table 5. SOC Stock and Total Carbon Stock (TCS) for Delhi Ridge

Forest	SOC stock (Mg C ha^{-1})	TCS (Mg C ha^{-1})
Northern Ridge	30.05	94.17
Central Ridge	28.20	85.89
South Central Ridge	28.79	82.18
Southern Ridge	16.02	32.69
Average	25.77	73.48

TCS value of 82.18 Mg C ha^{-1}, while the Southern Ridge has the lowest estimated TCS value at 32.69 Mg C ha^{-1}. Overall, the TCS values across the Delhi Ridge range from 32.69 Mg C ha^{-1} to 94.17 Mg C ha^{-1}, yielding an average TCS of 73.51 Mg C ha^{-1}. Regarding CO_2 equivalent (CO_{2eq}), the Northern Ridge reports a figure of 345.29 Mg ha^{-1}. The Central Ridge has a CO_{2eq} value of 311.26 Mg ha^{-1}, while the South-Central Ridge stands at 301.33 Mg ha^{-1}. The Southern Ridge, again, registers the lowest CO_{2eq} value at 119.86 Mg ha^{-1}. Across the Delhi Ridge forest, the CO_{2eq} values range from 119.86 Mg ha^{-1} to 345.29 Mg ha^{-1}, with an average CO_{2eq} value of 269.44 Mg ha^{-1}.

Valuation of climate regulation benefits

The Delhi Ridge forest provides significant climate regulation benefits by mitigating the impacts of climate change associated with CO_2 emissions in the atmosphere (Fig. 4). These benefits are valued at approximately US$ 29694.94 ha^{-1} (IRS 2587370.60 ha^{-1}) in the Northern Ridge, US$ 26768.65 ha^{-1} (IRS 2332807.54 ha^{-1}) in the Central Ridge, US$ 25,914.09 ha^{-1} (IRS 2258335.20 ha^{-1}) in the South-Central Ridge, and US$ 10308.25 ha^{-1} (IRS 898333.06 ha^{-1}) in the Southern Ridge area. The average benefit across the entire Delhi Ridge forest amounts to US$ 23171.48 ha^{-1} (IRS 2019324.97 ha^{-1}).

DISCUSSION

Numerous studies have underscored the significance of diameter at breast height (DBH) and its positive correlation with tree biomass (Djuikouo et al. 2010, Zhang and Chen 2015, Pokhrel and Sherpa 2020). Our research indicates that trees with higher DBH contribute most significantly to total biomass (TB). In the Southern Ridge, a greater number of individuals were observed within the lower DBH

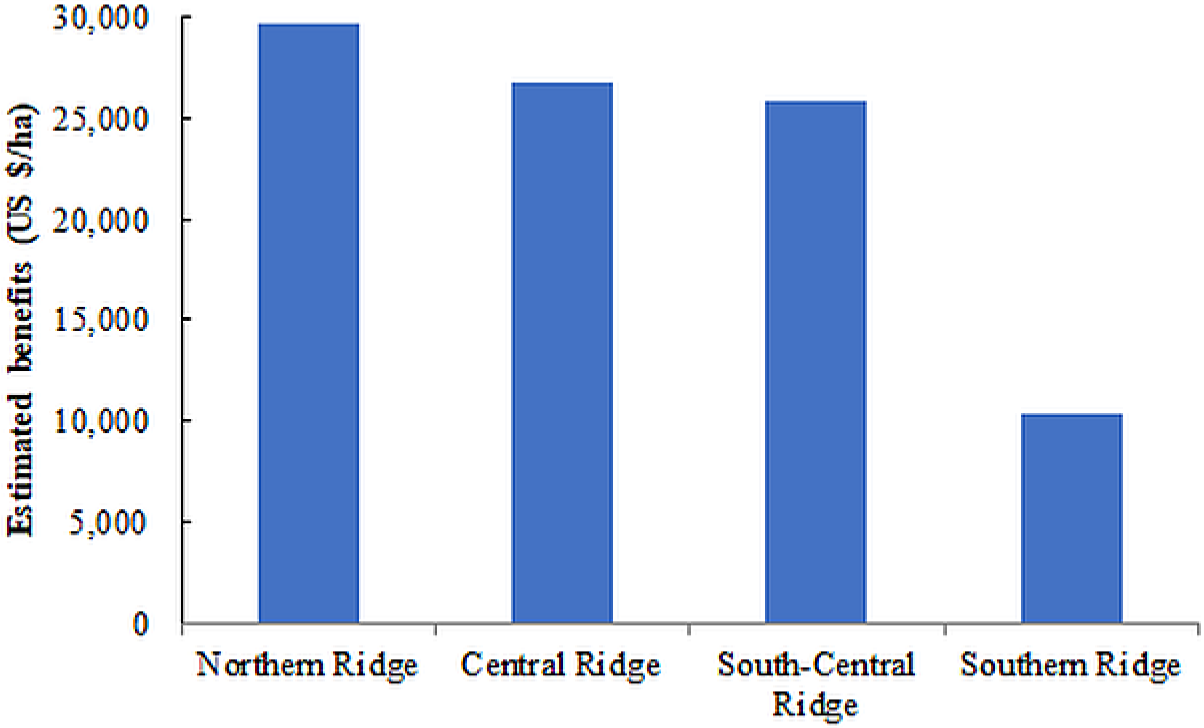

Figure 4. Estimated climate-related damage avoided benefits derived from Delhi Ridge (US$ ha^{-1})

categories, which is reflected in the lower values for aboveground biomass (AGB), belowground biomass (BGB), TB, and vegetation carbon stocks (VCS) in this area. Furthermore, this region has a history of mining activities, which have resulted in thin soil cover in some sections, leading to the predominance of secondary forests (Sharma et al. 2017). A variety of factors - including anthropogenic influences, tree age, precipitation patterns, soil structure, topography, moisture regime, and variability in DBH - play crucial roles in determining forest carbon stocks at both regional and local scales (Sundarapandian et al. 2013, Dar and Sundarapandian 2015, Joshi and Dhyani 2018). Among the four sections of the Delhi Ridge, the Central Ridge exhibited the highest tree density (TD). A prior land use and land cover (LULC) study by Chopra et al. (2022a) noted a significant increase in moderately dense forest in the Central Ridge, which this study corroborates.

The Delhi region has garnered scholarly attention regarding biomass assessment studies. Previous research on carbon pools by Meena et al. (2019) indicated that the Northern Ridge possesses higher aboveground biomass (AGB) compared to the Central Ridge, belowground biomass (BGB), and soil organic carbon (SOC) stock values measured in 2012, which corroborates our findings where a similar trend was observed. Singh et al. (2016) reported that tree biomass (TB) values at Asola Bhatti Wildlife Sanctuary vary from 0.316 to 49.62 Mg ha^{1}. Our TB value for the Southern Ridge, measured at 33.35 Mg ha^{-1}, falls comfortably within this range. Furthermore, Snehlata et al. (2021) conducted a study on carbon sequestration by trees at the National Zoological Park, Delhi, where they estimated the AGB of adult tree species to be between 65.7 and 76.1 Mg ha^{-1}, with an average of 71.8 Mg ha^{-1}; the BGB ranged from 15.8 to 18.3 Mg ha^{-1}, with a mean of 17.2 Mg ha^{-1}, while the TB was estimated to be between 85 and 96.4 Mg ha^{-1}, averaging 92.1 Mg ha^{-1}. The mean values of AGB, BGB, and TB for the Delhi Ridge are comparable to these estimates.

According to the Forest Survey of India (Anonymous 2021), the carbon stock value for tropical thorn forests in the country is reported at 37.43 Mg C ha^{-1}, while tropical dry deciduous forests show a higher value of 77.59 Mg C ha^{-1}. The values obtained in this study for the Northern Ridge, Central Ridge, and South-Central Ridge, except Southern Ridge, are greater than those for tropical thorn forests yet still fall short of tropical dry deciduous forest values.

At the national level, Singh and Singh (1991), along with Gupta and Kumar (2014), have established that the aboveground biomass (AGB) range in the tropical dry forests of North India lies between 38.6 and 239.8 Mg C ha^{-1}. The findings of the current study align with this range. However, these values are lower than those reported for urban forests in Puducherry, where Swapna and Shanmuganatha (2018) found carbon stock values 278.22 and 139.11 Mg C ha^{-1}. Additionally, the AGB and belowground biomass (BGB) values of 178.09 and 46.30 Mg ha^{-1} identified by Juwarkar et al. (2011) in their carbon sequestration research at the Tadoba Andhari Tiger Reserve, Chandrapur, Maharashtra, exceed our results. Similarly, carbon stock values ranging from 1.89 to 25.6 t·ha^{-1} were reported by Salunkhe et al. (2014) in their study on forests across four districts of Madhya Pradesh. Furthermore, Naveenkumar et al. (2017), in their assessment of biomass and carbon stocks in the tropical dry forests of the Javadi Hills in the Eastern Ghats, reported AGB (including both juvenile and adult trees) ranging from 99 to 216 Mg ha^{-1} and carbon stock values between 53 and 116 Mg C ha^{-1}. The results of the present study are consistent with these established ranges.

At the global level, the values from our study are lower than the total carbon stock (TCS) reported for the Germa-Dima forest in Ethiopia, which stands at 508.9 t ha^{-1} (Dibaba et al., 2019). Additionally, our values fall short of the mean aboveground biomass carbon stock of 191.6 ± 19.7 Mg C ha^{-1} found by Gebeyehu et al. (2019) for the Afromontane forests of Ethiopia. Furthermore, our TCS estimates are lower than the TCS value of 491 Mg C ha^{-1} for mangrove forests in Cotabato City, Philippines, as noted by Dimalen and Rojo (2019). Our study's estimated values fall within the range of 15–123.3 Mg C ha^{-1} reported for tropical forests in Southern Mexico by Aryal et al. (2014). The estimated average soil organic carbon (SOC) value for the entire Delhi Ridge forest is 25.77 Mg C ha^{-1}, which is comparable to the findings of Chaturvedi et al. (2011) for Uttar Pradesh (21.8 Mg ha^{-1}), Gandhi and Sundarapandian

(2017) for Sathnur Reserve Forest (16.92-44.65 Mg ha^{-1}), Meena et al. (2019) for Northern and Central Delhi Ridge (21.36 Mg ha^{-1}), Sharma et al. (2019) for Pushkar Valley in Rajasthan (24.91 to 37.78 t C ha^{-1}), and Gray et al. (2015) for tropical forests in Australia (29.98 Mg ha^{-1}). The estimated CO_2 equivalent value (269.53 Mg ha^{-1}) for the entire Delhi Ridge exceeds the CO_2 equivalent value (168.83 Mg ha^{-1}) reported by Snehlata et al. (2021) for the National Zoological Park in Delhi. This discrepancy is attributable to our study factoring in SOC and vegetation carbon stock (VCS).

Harishma et al. (2020) estimated that the mangrove forests of Kerala can store 513.13 t CO_2 eq ha^{-1}, while planted forests in the Brahmaputra floodplains can store 959 Mg CO_2 ha^{-1} (Gogoi et al. 2021). The disparity in CO_2 equivalents may be attributed to varying physiographic conditions and forest types, as the Delhi Ridge is classified as a semi-arid forest. In contrast, Kerala and Assam are regions with high precipitation and diverse species composition. Our study highlights the significance of Delhi Ridge in mitigating climate change risks by linking it to the social cost of carbon. This innovative approach could have substantial implications, providing policymakers and relevant stakeholders with a clearer monetary perspective regarding these forests. Such insights will aid in quantifying the costs and benefits associated with long-term planning and management of the area while also assisting in prioritizing and balancing other ecosystem services during decision-making processes. However, it is important to note that our study has focused solely on the major carbon pools, excluding biomass present in herbs, shrubs, and litter. Additionally, the evaluation of soil organic carbon (SOC) was limited to a depth of 10 cm, which may lead to an underestimation of certain carbon pools' capacities. Furthermore, this study does not account for the impacts of anthropogenic and other stressors on the health and functioning of carbon pools. While the ongoing ecological restoration efforts in the Northern Ridge and Asola Bhatti Wildlife Sanctuary, in the Southern Ridge, are somewhat reflected in the TCS values presented in our study, a comprehensive quantification of the relationship between these initiatives and forest biomass falls outside the scope of this paper.

CONCLUSIONS

The carbon sequestration benefits associated with the Delhi Ridge have been previously explored. However, our study introduces a new perspective by comprehensively examining the climate regulation impact of the Delhi Ridge in monetary terms. This analysis will serve as a foundation for evaluating other green spaces in Delhi and neighbouring cities about their climate regulation advantages. Furthermore, the findings of this study bring Delhi Ridge into focus for the conceptualization and development of the city's climate action plan, ultimately contributing to the achievement of Sustainable Development Goal 13 (Climate Action). This approach will also encourage the creation of ecosystem-centric policies to enhance climate resilience in Delhi and other cities, helping to reach net zero emission targets. India faces a significant social cost of carbon, and existing ecosystems can play a crucial role in managing this challenge. This study offers a fresh perspective on conserving urban natural landscapes and the development of effective policies to safeguard these vital areas from the ongoing pressures of urbanization.

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REFERENCES

Anonymous. 2018. Summary for Policymakers. In: Global warming of 1.5°C. (2018, October 8). https://www.ipcc.ch/2018/10/08/summary-for-policymakers-of-ipcc-specialreport-on-global-warming-of-1-5c-approved-by-governments/ (accessed on 28/11/2022).

Anonymous. 2021. India State of Forest Report. Forest Survey of India, Ministry of Environment and Forests, Government of India, Dehradun. 586 pages. https://fsi.nic.in/forest-report-2021-details

Aryal, D.R., De Jong, B.H., Ochoa-Gaona, S., Esparza-Olguin, L., Mendoza-Vega, J. 2014. Carbon stocks and changes in tropical secondary forests of southern Mexico. Agriculture, Ecosystems & Environment, 195, 220-230. https://doi.org/10.1016/j.agee.2014.06.005

Beer, C., Reichstein, M., Tomelleri, E., Ciais, P., Jung, M., Carvalhais, N., Rödenbeck, C., Arain, M.A., Baldocchi, D., Bonan, G.B., Bondeau, A., Cescatti, A., Lasslop, G., Lindroth, A., Lomas, M., Luyssaert, S., Margolis, H.A., Oleson, K.W., Roupsard, O., Veenendaal, E., Viovy, N., Williams, C. Woodward, F.I. and Paple, D. 2010. Terrestrial gross carbon dioxide uptake: Global distribution and covariation with climate. Science, 329(5993), 834-838. https://doi.org/10.1126/science.1184984

Bijalwan, A., Swamy, S.L., Sharma, C.M., Sharma, N.K., and Tiwari, A. 2010. Land-use, biomass and carbon estimation in dry tropical forest of Chhattisgarh region in India using satellite remote sensing and GIS. Journal of Forestry Research, 21(2), 161-170. https://doi.org/10.1007/s11676-010-0026-y

Brahma, B., Nath, A.J., Sileshi, G.W. and Das, A.K. 2018. Estimating biomass stocks and potential loss of biomass carbon through clear-felling of rubber plantations. Biomass and Bioenergy, 115, 88-96. https://doi.org/10.1016/j.biombioe.2018.04.019

Brown. S., Sathaye, J., Cannell, M. and Kauppi, P.E. 1996. Mitigation of carbon emissions to the atmosphere by forest management. The Commonwealth Forestry Review, 75, 80-91. http://www.jstor.org/stable/42607279

Champion, H. G., and Seth, S. K. (1968). A Revised Survey of the Forest Types of India. Manager of publications, New Delhi, India.

Chang, F., Ko, C., Yang, P.M., Chen, K. and Chang, K. 2017. Carbon sequestration and substitution potential of subtropical mountain Sugi plantation forests in central Taiwan. Journal of Cleaner Production, 167, 1099-1105. https://doi.org/10.1016/j.jclepro.2016.08.016

Chaturvedi, R.K., Raghubanshi, A.S. and Singh, J.S. 2011. Carbon density and accumulation in woody species of tropical dry forest in India. Forest, Ecology and Management, 262(8), 1576-1588. https://doi.org/10.1016/j.foreco.2011.07.006

Chaturvedi, R.K., Raghubanshi, A.S. and Singh, J.S. 2012. Effect of grazing and harvesting on diversity, recruitment and carbon accumulation of juvenile trees in tropical dry forests. Forest, Ecology and Management, 284, 152-162. https://doi.org/10.1016/j.foreco.2012.07.053

Chavan, B. and Rasal, G. 2010. Sequestered standing carbon stock in selective tree species grown in university campus at Aurangabad, Maharashtra, India. International Journal of Engineering Science and Technology, 2, 3003-3007. https://www.ijmra.us/project%20doc/IJPSS_MARCH2012/IJMRA-PSS822.pdf

Chave, J., Andalo, C., Brown, S., Cairns, M.A., Chambers, J.Q., Eamus, D., Fölster, H., Fromard, F., Higuchi, N., Kira, T., Lescure, J.P., Nelson, B., Ogawa, H., Puig, H., Riéra, B. and Yamakura, T. 2005. Tree allometry and improved estimation of carbon stocks and balance in tropical forests. Oecologia, 145(1), 87-99. https://doi.org/10.1007/s00442-005-0100-x

Chopra, B., Khuman, Y.S.C. and Dhyani, S. 2022b. Advances in ecosystem services valuation studies in India: Learnings from a systematic review. Anthropocene Science, 1, 342-357. https://doi.org/10.1007/s44177-022-00034-0

Chopra, B., Singh, B. and Khuman, Y. 2022a. Spatio-temporal analysis of land use/land cover changes in urban forest ecosystem. International Review for Spatial Planning and Sustainable Development, 10(3), 128-147. https://doi.org/10.14246/irspsd.10.3_128

Choudhary, B.K., Majumdar, K. and Datta, B.K. 2017, Tree diversity and ecosystem carbon stock patterns along selected land use, land cover systems in Tripura, Northeastern India. International Journal of Ecology and Environmental Science, 42(5), 91-106. https://nieindia.org/Journal/index.php/ijees/article/view/1096/308

Chu, X., Zhan, J., Li, Z., Zhang, F. and Qi, W. 2019. Assessment on forest carbon sequestration in the Three-North Shelterbelt Program region, China. Journal of Cleaner Production, 215, 382-389. https://doi.org/10.1016/j.jclepro.2018.12.296

Dar, J.A. and Sundarapandian, S. 2015. Variation of biomass and carbon pools with forest type in temperate forests of Kashmir Himalaya, India. Environmental Monitoring and Assessment, 187(2), 55. https://doi.org/10.1007/s10661-015-4299-7

Dibaba, A., Soromessa, T. and Workineh, B, 2019. Carbon stock of the various carbon pools in Gerba-Dima moist Afromontane Forest, South-western Ethiopia. Carbon Balance and Management, 14(1), 1. https://doi.org/10.1186/s13021-019-0116-x

Dimalen, F.K. and Rojo, M.J. 2019. Carbon Stock Assessment of a Mangrove Forest in Cotabato City, Philippines. Journal of Biodiversity and Environmental Science, 14, 1-8. https://ssrn.com/abstract=3588114

Djuikouo, M.N.K., Doucet, J.L., Nguembou, C.K., Lewis, S.L. and Sonké, B. 2010. Diversity and aboveground biomass in three tropical forest types in the Dja Biosphere Reserve, Cameroon. African Journal of Ecology, 48(4), 1053-1063. https://doi.org/10.1111/j.1365-2028.2010.01212.x

Gandhi, D.S. and Sundarapandian, S.2017. Large-scale carbon stock assessment of woody vegetation in tropical dry deciduous forest of Sathanur reserve forest, Eastern Ghats, India. Environmental Monitoring and Assessment, 189(4), 187. https://doi.org/10.1007/s10661-017-5899-1

Gebeyehu, G., Soromessa, T., Bekele, T. and Teketay, D. 2019. Carbon stocks and factors affecting their storage in dry Afromontane forests of Awi Zone, northwestern Ethiopia. Journal of Ecology and Environment, 43(1), art 7. https://doi.org/10.1186/s41610-019-0105-8

Gogoi, A., Ahirwal, J. and Sahoo, U.K. 2021. Plant biodiversity and carbon sequestration potential of the planted forest in Brahmaputra flood plains. Journal of Environmental Management, 280, 111671. https://doi.org/10.1016/j.jenvman.2020.111671

Gray, J.M., Bishop, T.F. and Wilson, B.R. 2015. Factors Controlling Soil Organic Carbon Stocks with Depth in Eastern Australia. Soil Science Society of America Journal, 79(6), 1741-1751. https://doi.org/10.2136/sssaj2015.06.0224

Gupta, S.R. and Kumar, R. 2014. Biodiversity Conservation and Ecosystem Services of Forests in Siwaliks of Northern India. International Journal of Ecology and Environmental Science, 40(1), 15-28. https://nieindia.org/Journal/index.php/ijees/article/view/360/134

Harishma, K.M., Sandeep, S. and Sreekumar, V.B. 2020. Biomass and carbon stocks in mangrove ecosystems of Kerala, southwest coast of India. Ecological Processes, 9(1), art 31. https://doi.org/10.1186/s13717-020-00227-8

Houghton, R. A. 2005. Aboveground forest biomass and the global carbon balance. Global Change Biology, 11(6), 945-958. https://doi.org/10.1111/j.1365-2486.2005.00955.x

India Meteorological Department. (IMD). https://city.imd.gov.in/citywx/extreme/MAY/safdarjung2.htm (accessed on 27/10/2022).

Joshi, R. K., and Dhyani, S. 2018. Biomass, carbon density and diversity of tree species in tropical dry deciduous forests in Central India. Acta Ecologica Sinica, 39(4), 289-299. https://doi.org/10.1016/j.chnaes.2018.09.009

Juwarkar, A.A., Varghese, A.O., Singh, S.K., Aher, V.V. and Thawale, P.R. 2011. Carbon sequestration potential in aboveground biomass of natural reserve forest of Central India. International Journal of Agriculture: Research and Review, 1(2), 80-86.

Lin, B. and Ge, J. 2019. Valued Forest carbon sinks: How much emissions abatement costs could be reduced in China. Journal of Cleaner Production, 224, 455-464. https://doi.org/10.1016/j.jclepro.2019.03.221

Lun, F., Liu, Y., He, L., Yang, L., Liu, M. and Li, W. 2018. Life cycle research on the carbon budget of the *Larix principis-rupprechtii* plantation forest ecosystem in North China. Journal of Cleaner Production, 177, 178-186. https://doi.org/10.1016/j.jclepro.2017.12.126

Meena, A., Bidalia, A., Hanief, M., Dinakaran, J. and Rao, K.S. 2019. Assessment of above- and belowground carbon pools in a semi-arid forest ecosystem of Delhi, India. Ecological Processes, 8(1), 163. https://doi.org/10.1186/s13717-019-0163-y

Mitchard, E.T.A. 2018. The tropical forest carbon cycle and climate change. Nature, 559, 527-534. https://doi.org/10.1038/s41586-018-0300-2

Naikoo, M.W., Rihan, M., Ishtiaque, M. and Shahfahad. 2020. Analyses of land use land cover (LULC) change and built-up expansion in the suburb of a metropolitan city: Spatio-temporal analysis of Delhi NCR using landsat datasets. Journal of Urban Management, 9(3), 347-359. https://doi.org/10.1016/j.jum.2020.05.004

Nath, A.J., Tiwari, B.K., Sileshi, G.W., Sahoo, U.K., Brahma, B., Deb, S., Devi, N.B., Das, A.K., Reang, D., Chaturvedi, S.S., Tripathi, O.P., Das, D.J. and Gupta, A. 2019. Allometric models for estimation of forest biomass in north East India. Forests, 10(2), 103. https://doi.org/10.3390/f10020103

Naveenkumar, J., Arunkumar, K.S. and Sundarapandian, S. 2017. Biomass and carbon stocks of a tropical dry forest of the Javadi Hills, Eastern Ghats, India. Carbon Management, 8(5-6), 351-361. https://doi.org/10.1080/17583004.2017.1362946

Pan, Y., Birdsey, R.A., Phillips, O.L. and Jackson, R.B. 2013. The structure, distribution, and biomass of the world's forests. Annual Review of Ecology, Evolution and Systematics. 44(1), 593-622. https://doi.org/10.1146/annurev-ecolsys-110512-135914

Pandey, P.C., Srivastava, P.K., Chetri, T., Choudhary, B.K. and Kumar, P. 2019. Forest biomass estimation using remote sensing and field inventory: a case study of Tripura, India. Environmental Monitoring and Assessment, 191, 593. https://doi.org/10.1007/s10661-019-7730-7

Pandey, S.S., Maraseni, T.N. and Cockfield, G. 2014. Carbon stock dynamics in different vegetation dominated community forests under REDD+: A case from Nepal. Forest Ecology and Management, 327, 40-47. https://doi.org/10.1016/j.foreco.2014.04.028

Pokhrel, S. and Sherpa, C. 2020. Analyzing the relationship, distribution of tree species diversity, and above-ground biomass on the Chitwan-Annapurna landscape in Nepal. International Journal of Forest Research, 2020, 1-10. https://doi.org/10.1155/2020/2789753

Ramachandra, T.V. and Bharath, S. 2020. Carbon sequestration potential of the forest ecosystems in the Western Ghats, a global biodiversity hotspot. Natural Resources Research, 29, 2753-2771. https://oi.org/10.1007/s11053-019-09588-0

Ravindranath, N.H. and Ostwald, M. 2008. Methods for estimating above-ground biomass. Pp 113-114. In: Ravindranath, N.H. and Ostwald, M. (Eds.) Carbon Inventory Methods: Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Round Wood Production Projects. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-6547-7_10

Reid, W.V., Mooney, H.A., Cropper, A., Capistrano, D., Carpenter, S.R., Chopra, K., Dasgupta, P., Dietz, T., Duraiappah, A.K., Hassan, R., Kasperson, R., Leemans, R., May, R.M., McMichael, T.A.J., Pingali, P., Samper, C., Scholes, R., Watson, R.T., Zakri, A.H., Shidong, Z., Ash, N.J., Bennett, E., Kumar, P., Lee, M.J., Raudsepp-Hearne, C., Simons, H., Thonell, J. and Zurek, M.B. 2025. Ecosystems and Human Well-being: Synthesis report of Millennium Ecosystem Assessment. Island Press, Washington, DC. 155 pages. https://www.millenniumassessment.org/documents/document.356.aspx.pdf

Ricke, K., Drouet, L., Caldeira, K. and Tavoni, M. 2018. Country-level social cost of carbon. Nature Climate Change, 8(10), 895-900. https://doi.org/10.1038/s41558-018-0282-y

Salunkhe, O. and Khare, P.K. 2016. Aboveground biomass and carbon stock of tropical deciduous forest ecosystems of Madhya Pradesh, India. International Journal of Ecology and Environmental Science, 42(6), 75-81. https://nieindia.org/Journal/index.php/ijees/article/view/1091/306

Salunkhe, O., Khare, P.K., Kumari, R. and Khan, M.L. 2018. A systematic review on the aboveground biomass and carbon stocks of Indian forest ecosystems. Ecological Processes, 7(1), 130. https://doi.org/10.1186/s13717-018-0130-z

Salunkhe, O., Khare, P.K., Sahu, T.R. and Singh, S. 2014. Aboveground biomass and carbon stocking in tropical deciduous forests of state of Madhya Pradesh, India. Taiwania, 59(4), 353-359. https://taiwania.ntu.edu.tw/pdf/tai.2014.59.353.pdf

Sharma, G., Sharma, L.K. and Sharma, K.C. 2019. Assessment of land use change and its effect on soil carbon stock using multitemporal satellite data in semiarid region of Rajasthan, India. Ecological Processes, 8, 42. https://doi.org/10.1186/s13717-019-0193-5

Sharma, V., Chaudhry, S. and Singhai, A.2017. Monitoring post mining forest dynamics of the tropical thorn forest in Asola Bhatti Wildlife Sanctuary, India using multi-temporal satellite data. International Journal of Applied Environmental Science, 12(5), 1031-1044. https://www.ripublication.com/ijaes17/ijaesv12n5_24.pdf

Singh, L. and Singh, J.S. 1991. Species structure, dry matter dynamics and carbon flux of a dry tropical forest in India. Annals of Botany, 68(3), 263-273. https://doi.org/10.1093/oxfordjournals.aob.a088252

Singh, V., Gupta, S.R. and Singh, N. 2016. Carbon sequestration potential of tropical dry deciduous forests in Southern Haryana, India. International Journal of Ecology and Environmental Sciences, 42(S), 51-64. https://nieindia.org/Journal/index.php/ijees/article/view/1089/304

Snehlata, Rajlaxmi, A. and Kumar, M. 2021. Urban tree carbon density and CO_2 equivalent of National Zoological Park, Delhi. Environment Monitoring and Assessment, 193(12), art 841. https://doi.org/10.1007/s10661-021-09619-5

Stoffberg, G.H., Van Rooyen, M.W., van der Linde, M.J. and Groeneveld, H.T. 2010. Carbon sequestration estimates of indigenous street trees in the City of Tshwane, South Africa. Urban Forestry & Urban Greening, 9(1), 9-14. https://doi.org/10.1016/j.ufug.2009.09.004

Sundarapandian, S.M., Dar, J.A., Gandhi, D.S., Srinivas, K. and Subashree, K. 2013. Estimation of biomass and carbon stocks in tropical dry forests in Sivagangai district, Tamil Nadu, India. International Journal of Environmental Science and Engineering Research, 4(3), 66-76.

Swapna, S.K. and Shanmuganatha, J. 2018. Tree diversity and carbon sequestration potential of an urban forest patch of Pondicherry, India. Journal of Tree Sciences, 37(1), 58-71. https://doi.org/10.5958/2455-7129.2018.00009.2

Syed, F. and Ullah, A. 2021. Estimation of economic benefits associated with the reduction in the CO_2 emission due to COVID-19. Environmental Challenges, 3, 100069. https://doi.org/10.1016/j.envc.2021.100069.

Tagesson, T., Schurgers, G., Horion, S., Cias, P., Tian, F., Brandt, M., Ahlström, A., Wigneron, J.P., Ardö, J., Olin, S., Fan, L., Wu, Z. and Fensholt, R. 2020. Recent divergence in the contributions of tropical and boreal forests to the terrestrial carbon sink. Natural Ecology and Evolution, 4, 202-209. https://doi.org/10.1038/s41559-019-1090-0

Tomar, U. and Baishya, R. 2020. Moisture regime influence on soil carbon stock and carbon sequestration rates in semi-arid forests of the National Capital Region, India. Journal of Forestry Research, 31, 2323-2332. https://doi.org/10.1007/s11676-019-01032-6

Vashum, K.T. and Jayakumar, S. 2012. Methods to estimate aboveground biomass and carbon stock in natural forests - A review. Journal of Ecosystem and Ecography, 2(4), art 16. https://doi.org/10.4172/2157-7625.1000116

Wheater, P.C., Bell, J.R. and Cook, P.A. 2011. Practical Field Ecology: A Project Guide (2nd ed.). Wiley-Blackwell, West-Sussex. 389 pages.

Zanne, A.E., Lopez Gonzalez, G., Comes, D.A., Ilic, J., Janson, S., Lewis, S.L., Miller, R.B., Swenson, N.G., Wiemann, M.C. and Chave, J. 2009. Global wood density database. Dryad digital repository. https://doi.org/10.5061/dryad.234

Zhang, Y. and Chen, HYH. 2015. Individual size inequality links forest diversity and above-ground biomass. Journal of Ecology, 103(5), 1245-1252. https://doi.org/10.1111/1365-2745.12425

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