



## Research article

## Carbon sequestration in the bio-edaphic ecosystem of National Highway-27 in Guwahati, Assam, India

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## ARTICLE INFO

## Keywords:

Tree carbon stock  
 Soil carbon stock  
 REDD+ strategy  
 AGB  
 BGB  
 Ecology  
 Agricultural science  
 Environmental science  
 Earth sciences

## ABSTRACT

Vehicular pollution in cities is engendering the need to enhance the sequestration of CO<sub>2</sub> through bio-edaphic factors, such as trees and soil. Hence, this pioneering study aimed to analyze the interdependencies of the bio-edaphic ecosystem during carbon sequestration on a national highway in Guwahati, Assam, India. To quantify the tree carbon stock, soil physicochemical properties, soil nutrients, bulk density, organic carbon, and soil carbon stock, trees with diameters at breast height (dbh) ≥ 2 cm and soil samples from different depths (0–15 cm, 15–30 cm, and 30–45 cm) were taken from six areas spread over 36 plots of equal size (2 × 10 m) arranged in a zig-zag manner. The studied parameters were compared among the different areas. It was found that the tree and soil carbon stock, along with soil nutrients, were greater in the Garchuk-Lokhra area (sample area-4). A significantly strong correlation was observed between the soil carbon stock and the above and below-ground biomass of trees (AGB,  $r = 0.865$ ; BGB,  $r = 0.847$ ), which indicated the co-dependencies of the bio-edaphic ecosystem in accumulating carbon. *Peltophorum ferrugineum* (Decne.) Benth is recommended for planting because it has emerged as a tolerant species and has the greatest carbon storage potential. The bio-edaphic ecosystem of the national highway is now on a carbon-friendly trajectory that follows the UNFCCC guidelines and the REDD+ (reducing emissions from deforestation and forest degradation) strategy. However further research on carbon budgeting is required.

## 1. Introduction

Metropolitan areas continue to expand, with growing populations and increasing volumes of both public and personal transport (Verbavatz and Barthelemy, 2019). Excessive discharge of CO<sub>2</sub>, which is a greenhouse gas; SO<sub>2</sub> and NO<sub>2</sub>, which are indirect greenhouse gases; and particulate matter, in violation of the National Ambient Air Quality Standards, has affected air quality (Guttikunda et al., 2004; Gohain and Kalita, 2016; Iankov et al., 2017).

Worldwide electric energy use (34%), industry (22%), and transport (14%) contribute to the highest amount of CO<sub>2</sub> (UNEP, 2019). It is estimated that the net CO<sub>2</sub> emission from land use and land cover change is approximately  $5.2 \pm 2.6$  Gt CO<sub>2</sub> yr<sup>-1</sup> (IPCC, 2019).

The United Nation Framework Convention on Climate Change came into existence in 1944, but CO<sub>2</sub> emission has been accelerating continuously (UNEP, 2019) particularly in India where it had increased to 2.5 Gt by 2016 (Olivier et al., 2017), and had increased by 5.5% in 2018 (UNEP, 2019). However, CO<sub>2</sub> emissions in India will decrease to below

the global average by 2030 (Dubash et al., 2018). Based on the Paris Agreement, the Intended Nationally Determined Contributions (INDC) was established under the Green Highway Policy, implemented by the Ministry of Road Transport and Highways of the Government of India in 2015. Besides providing future employment The Intended Nationally Determined Contributions are planned to decrease carbon pollution by creating an additional carbon sink equivalent to 2.5–3 billion tons of CO<sub>2</sub> through supplementary forest and tree cover by 2030 (Pali, 2018).

CO<sub>2</sub> is an important greenhouse gas that is responsible for global warming (IPCC, 2018). Article 2.1 of the Kyoto Protocol (UNFCCC, 1998) entrusted the signatory countries with adopting appropriate measures for the protection of greenhouse gas sinks and reservoirs through intensified afforestation, reforestation, and by promoting sustainable forest management (Yavasli, 2012). India has also signed the protocol and is conducting studies and adopting measures to address the problem.

CO<sub>2</sub> is absorbed from the atmosphere through the process of photosynthesis, and carbon is stored as biomass by plants present in natural forests, road plantations, and other areas, which serve as CO<sub>2</sub> sinks

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(Benites et al., 1999; Thangata and Hildebrand, 2012). Plants can also absorb SO<sub>2</sub> and NO<sub>2</sub>, two other indirect greenhouse gases if they are present in low concentrations (Morikawa et al., 1998; Chung et al., 2010; Zhang et al., 2013). Several researchers are in favor of planting forests; this effort, if successful, will account for approximately 30% of the total global effort for climate change mitigation (Webb, 1992).

India ranks eighth among the most biodiverse countries (Butler, 2016), with 21.5% (692,027 km<sup>2</sup>) of its geographical area (3,287,263 km<sup>2</sup>) under forest and tree cover (FSI, 2017). Forest occupies 66% of the total geographical area in northeast India (FSI, 2017). In India, the urban forest cover is projected to be 12,790 km<sup>2</sup>, covering 16.40% of the urban area (FSI, 2017). In Assam, forest cover has increased up to 567 km<sup>2</sup> due to plantations outside the forest area (Anon, 2019). Globally plantation forests are increasing at an accelerating rate in many areas (Liu et al., 2018). Plantation forests in urban areas can provide many environmental benefits to the ecosystem (Kim et al., 2015; Kim, 2016a; Roeland et al., 2019) while effectively storing carbon (Turner et al., 1999; Silver et al., 2000; Curlevski et al., 2010) in the form of biomass (Chavan and Rasal, 2010); moreover, they can regulate global climate (Kort and Turnock, 1998) in addition to providing oxygen (1 kg of carbon dioxide = 2.66 kg of oxygen, Mishra and Prasad, 2018).

Biomass is an important component in carbon cycle studies (Ketterings et al., 2001; Cairns et al., 2003). Forest biomass can be estimated using two methods, direct and indirect (Salazar et al., 2010). Destructive sampling is a direct method in which trees are harvested to quantify the biomass (Parresol, 1999; Salazar et al., 2010); however, this method applies only to small areas and is not applicable for degraded forests and forests having endangered species (Montes et al., 2000). For the indirect method, also known as the non-destructive method, allometric equations with measurable parameters (Ravindranath and Ostwald, 2008) are used to calculate the biomass of a tree (Brown et al., 1989; Nowak, 1993; Hughes et al., 1999). In most studies, the diameter at breast height (DBH) is used to estimate the above-ground biomass as it is strongly correlated with tree diameter (Brown and Lugo, 1984; Brown, 1997; Clark et al., 2001). A simple model requiring only the diameter as input is also accepted as an effective method to determine above-ground biomass (Brown, 1997; Nelson et al., 1999; Clark et al., 2001; Djomoa et al., 2010). For ecological and economic reasons roadside plantings are to be conserved, hence non-destructive sampling is generally used (Liu et al., 2014; Salunkhe et al., 2016).

Soil is the main reservoir of nutrients, including organic carbon, which plays a major role in the global carbon cycle and is also used as an indicator of soil health and quality (Bezdicsek et al., 1996; Doran and Parkin, 1996; Waring et al., 2014). Furthermore, it strongly influences the CO<sub>2</sub> concentration in the atmosphere (Genxu et al., 2002). More than 2000 Pg of soil-bound organic carbon is present at a soil depth of 100 cm (Batjes, 1996), which is more than the collective SOC stock of the atmosphere and vegetation (Lal, 2004); this demonstrates the potential for carbon accumulation and thus helps in climate change mitigation (Lal, 2004; Vagen and Winowiecki, 2013).

The sequestration of atmospheric carbon can be advantageous from both environmental and socio-economic perspectives. The environmental perspective includes the removal of CO<sub>2</sub> from the atmosphere, improvement of soil quality, and increasing biodiversity (Batjes and Sombroek, 1997); socio-economic benefits include increased crop yields (Sombroek et al., 1993) and financial benefits from potential carbon trading schemes (McDowell, 2002). Carbon stock mapping at regional and national levels is needed to establish forest-based policies and to develop strategies for carbon sequestration in the mitigation of climate change (Salunkhe et al., 2018).

Several researchers worldwide have focused on forests (Macias et al., 2017; Nath et al., 2019), plantation approaches in different ecosystems (Bhatta et al., 2018; Liu et al., 2018), roadside plantations (Rahman et al., 2015; Tang et al., 2016; Hosseini et al., 2019; Neto and Sarmiento, 2019), soil (Kumar et al., 2016; Arya et al., 2018; Rahaman et al., 2018), and storage of carbon. Studies have also been conducted on carbon

sequestration using both forests and soil (Snorrason et al., 2002; Byrne and Milne, 2006; Guiabao, 2016; Helen et al., 2019; Meena et al., 2019; Rangel et al., 2019). Few reports are available regarding the relationship between vegetation parameters and soil physicochemical properties (Levesque et al., 2016; Karyati et al., 2018). Moreover, the interrelationship between carbon storage and urban trees and between nutrient status and soil carbon stocks is poorly known. Carbon storage capacity is influenced by plant age, growth, and development, as well as by soil fertility (Kumar et al., 2014; Chaudhari et al., 2015; Yuliyanto et al., 2016). Work on the relationship between the tree carbon and soil carbon stock in the national highway of India is scarce, hence the present pioneering study was undertaken to establish the relationship between the tree carbon stock and soil carbon and nutrients in planted sections of National Highway-27 in Guwahati, Assam, India. We measured the trees' carbon stock, soil physicochemical properties, soil nutrients, bulk density, organic carbon, and soil carbon stocks from six different sample areas and estimated the interrelationship among various parameters. The study will indicate the role of urban plantations and soils in the sustainable extenuation of climate change following the UNFCCC mechanism and REDD + strategy, and the interdependencies of the two ecosystems to mitigate pollution for a conservation-based production system to be achieved diligently and successfully.

## 2. Materials and methods

### 2.1. Study area

Guwahati, the capital of the state of Assam, India, is situated in the North East Region (NER) lying between 26° 5' and 26° 5'N and 91° 35' and 91° 52'E (Figure 1). It is the largest city in the region and is situated on the south bank of the Brahmaputra River. It is recognized as one of the 100 fastest-growing cities of the world and the fifth fastest-growing among Indian cities.

The NH-27 highway passing through Guwahati serves as the route to various states of Northeastern India and connects the city with other states of northeastern India. Approximately 18 km of the road lies along the southwestern boundary of Guwahati (Jalukbari to Khanapara). Although the entire highway has four lanes (under East-West Corridor), it is planned to upgrade to six lanes only the by-pass from Jalukbari to Khanapara as there has been an exponential growth in the number of vehicles in this area. The present study was conducted along the aforementioned 18-km stretch of the highway between the Jalukbari and Khanapara areas in Guwahati.

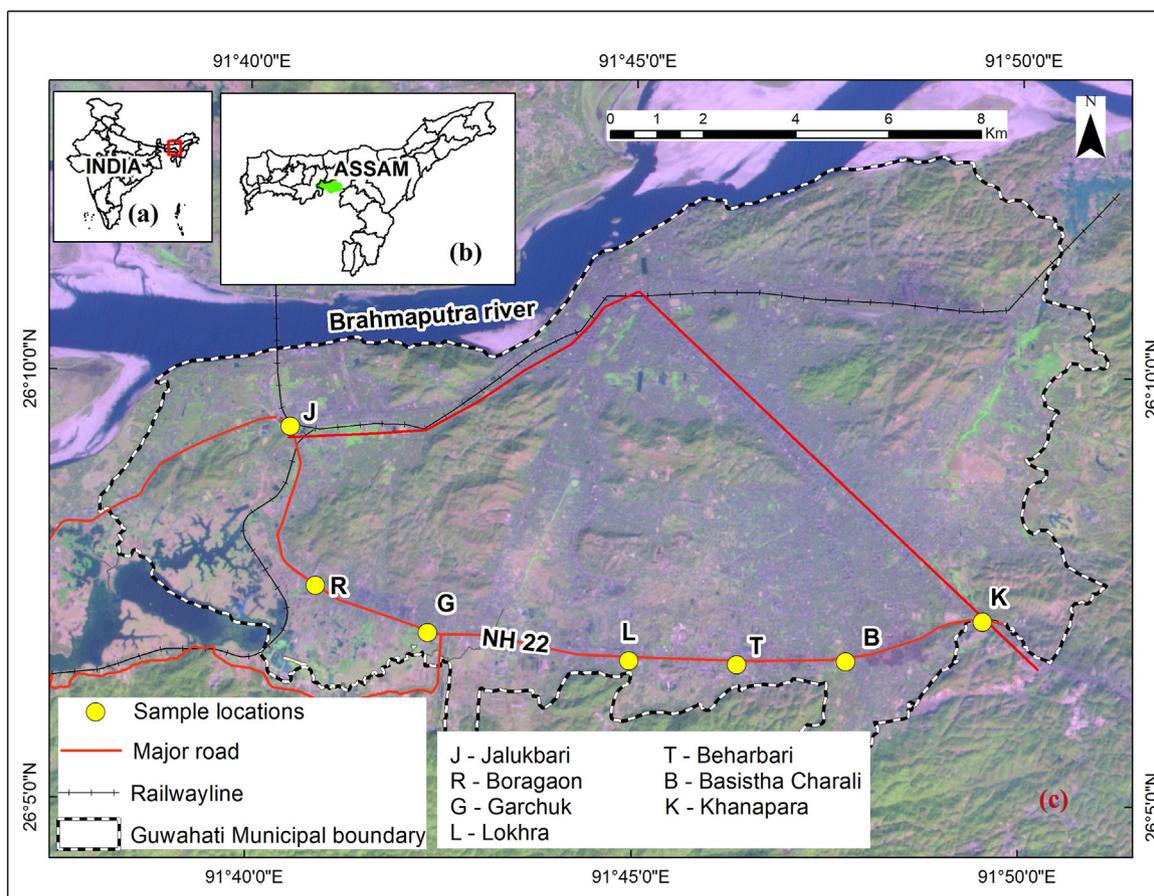
The climate of Guwahati is warm and temperate. The average annual temperature in Guwahati is 24.6 °C. The average annual rainfall is 1698 mm. The heaviest rainfall occurs during April–July while the November–February period has dry spells.

### 2.2. Sampling design

The study was conducted on both sides of the road as well as in the middle by systematically sampling 36 plots in total in a zigzag pattern (Rahman et al., 2015). The distance between each plot was 200 m. Carbon stocks were estimated using data from all 36 plots. Six sample areas [01: Khanapara-Basistha Chariali (KH-BC), 02: Basistha Chariali-Bharbari (BC-BH), 03: Bharbari-Lokhra (BH-LK), 04: Lokhra-Garchuk (LK-GCK), 05: Garchuk-Boragaon (GCK-BRG) and 06: Boragaon-Jalukbari (BRG-JLK)] were selected along the entire length of the national highway.

### 2.3. Data collection

Data was gathered using the non-destructive method from all the sample plots (Liu et al., 2014; Salunkhe et al., 2016) having a tree with dbh ≥ 2 cm on the roadside plantations in the study area. Each tree was identified at the species level at each of the sample plots. The diameter at



**Figure 1.** Study area. Khanapara, Basistha Chariali, Beharbari, Lokhra, Garchuk, Boragaon, and Jalukbari area in Guwahati city of Assam, India.

breast height (1.3 m above ground) for all the individual trees was measured with a diameter tape. The DBH and height for each tree species were used for regression analysis to obtain an estimate of above-ground biomass (Roy and Ravan, 1996). The formula used for calculating above-ground biomass (AGB) is as follows (Rajput et al., 1996):

$$\text{Above-Ground Biomass (AGB)} = \text{Volume of tree} \times \text{Species-specific gravity} \quad (1)$$

The tree volume of each species was calculated using the volume equations suggested in FSI (1996). Using the regression formula provided by Cairns et al. (1997), the below-ground biomass (BGB: fine and coarse roots) was estimated for different tree species, according to the following equations:

$$\text{BGB} = \exp \{-1.059 + 0.884 \times \ln(\text{AGB}) + 0.284\} \quad (2)$$

$$\text{Total biomass} = \text{AGB} + \text{BGB} \quad (3)$$

$$\text{Carbon (ha}^{-1}\text{)} = \text{Biomass (Mgha}^{-1}\text{)} \times 0.5 \quad (4)$$

Soil samples from different depths (0–15 cm, 15–30 cm, and 30–45 cm) in all the quadrats of the study area were collected following the composite soil sampling method. The collected soil samples were then air-dried, passed through a 0.1-mm sieve, and finally placed in labeled airtight plastic bags for further laboratory analysis. Soil pH and conductivity (1:2) were determined using the potentiometric method and a conductivity meter, respectively (Jackson, 1967). Soil nitrate, available phosphorus, and available potassium were measured using spectrophotometric (Singh, 1988; Chapman et al., 1996), colorimetric (Dickman and Bray, 1940), and ammonium acetate methods (Hanway and Heidal, 1952), respectively.

Soil organic carbon was determined using the Walkley-Black titration method (Walkley and Black, 1934), and soil bulk density was measured using the gravimetric method (Maiti, 2003; Pearson et al., 2007). Finally, the soil carbon stock was calculated using the following formula (Pearson et al., 2007):

$$\text{CS (t/ha)} = (\text{soil bulk density} \times \text{soil depth} \times \text{organic carbon}) \times 100 \quad (5)$$

The statistical variations in AGB, BGB, pH, conductivity, nitrate, available phosphorus, available potash, organic carbon, and bulk densities between different sample areas were assessed through one-way ANOVA. The least significant difference (LSD) was then applied for multiple comparisons within the sample areas for different parameters. A t-test was conducted to determine significant variations in the tree carbon stock and soil carbon stock among the sample areas. The statistical significance level was set as  $p \leq 0.05$ . A regression analysis was performed to study the relationship between soil bulk density and soil organic carbon among different soil depths per sample area, and Pearson correlation coefficients were used to determine the relationship between different selected soil and tree parameters (Gogtay and Thatte, 2017). All the analyses were conducted using the statistical software package SPSS (version 20).

QGIS 2.16.0 was used to prepare the map for tree carbon stock.

### 3. Results

#### 3.1. Tree carbon stock

Tree biomass from diverse sample areas exhibited variations (Figure 2). Sample area-4 (Lokhra-Gorchuk) recorded the highest AGB (73.42 Mg/ha) and BGB (26.49 Mg/ha), while sample area-6 recorded the lowest values

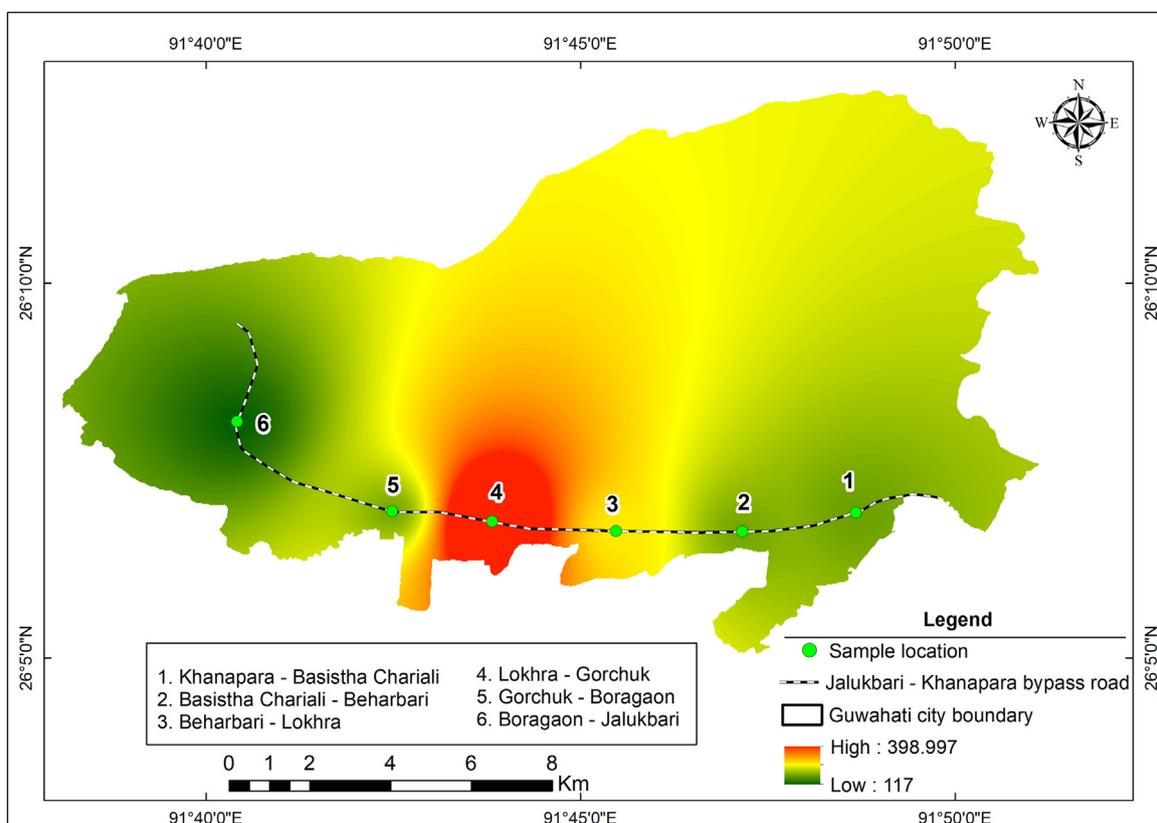


Figure 2. Tree carbon stock in roadsides plantation across the sample areas of National Highway-27 in Guwahati, Assam.

(AGB-20.02 Mg/ha, BGB-9.14 Mg/ha). The results revealed that there was a significant difference between the AGB and BGB ( $F = 7.38, p < 0.05$ ) among all the sample areas. A significant variation of the AGB as well as the BGB alone, among all the sample areas, was also observed. Furthermore, the least significant difference calculation revealed that there was a significant difference between sample area-4 and the rest of the studied areas. The contribution of the AGB was observed to be more than that of BGB among all the sample areas (Table 1).

The total carbon stock for the trees in National Highway-27 at Guwahati, Assam was 1209.47 Mg/ha. The tree carbon stock in sample area-4 (Lokhra-Gorchuk) was highest and sample area-6 (Boragaon-Jalukbari) was the lowest. Tree carbon stocks in all the studied sample areas were found to be statistically significant ( $t = 4.850, p < 0.05$ ).

A total of 26 species of trees were observed along the national highway. The results showed that *Peltophorum ferrugineum* (Decne.) Benth, with a carbon stock potential of 208.10 Mg/ha, effects more carbon sequestration than any other species in the study area. In contrast, *Tamarindus indica* has the lowest carbon stock potential, which is 0.77 Mg/Ha (Table 2).

### 3.2. Soil properties

Variations were observed in soil physicochemical properties in all of the sample areas studied.

#### 3.2.1. pH

The pH values recorded in the study ranged from slightly acidic to slightly basic. The highest pH was recorded in sample area-6 (Boragaon-Jalukbari) and the lowest in sample area-3 (Beharbari-Lokhra). The pH of other sample areas were in the following order: GCK-BRG > KH-BC > LK-GCK > BC-BH. A one-way ANOVA test showed that there was a significant difference in pH ( $F \geq 6.210, p < 0.05$ ) among the different sample areas that were studied. An LSD test further revealed a significant difference in pH between sample areas-1, 2, and 3; between 2 and 4; and between 3 and 4.

#### 3.2.2. Conductivity

The soil in sample area-3 was the most electrically conductive whereas sample area-6 recorded the least conductivity. A one-way

Table 1. Above-ground and below-ground biomass (Kg/tree) in roadsides plantation across the sample areas at National Highway-27 of Guwahati, Assam.

Sample area	AGB	One Way ANOVA	BGB	One Way ANOVA
1 Khanapara-Basistha Chariali (KH-BC)	29.88 <sup>a,a,b,a,a</sup>	4.33*	11.43 <sup>a,a,b,a,a</sup>	4.196*
2 Basistha Chariali-Beharbari (BC-BH)	28.4 <sup>a,a,b,a,a</sup>		11.73 <sup>a,a,b,a,a</sup>	
3 Beharbari-Lokhra (BH-LK)	38.47 <sup>a,a,b,a,a</sup>		15.03 <sup>a,a,b,a,a</sup>	
4 Lokhra-Gorchuk (LK-GCK)	73.42 <sup>b,b,b,a,b,a</sup>		26.49 <sup>b,b,b,a,b,b</sup>	
5 Gorchuk-Boragaon (GCK-BRG)	28.7 <sup>a,a,b,a,a</sup>		11.78 <sup>a,a,b,a,a</sup>	
6 Boragaon-Jalukbari (BRG-JLK)	20.02 <sup>a,a,b,a,a</sup>		9.14 <sup>a,a,b,a,a</sup>	

\* $p < 0.05$ . Values in the same row with different symbols are significantly different by LSD.

**Table 2.** Species wise contribution of carbon stock (Mg/Ha) along the National Highway-27 in Guwahati, Assam.

Sl. No.	Species	Family	Regression	R2	ANOVA	Pearson correlation	Carbon stock
1	<i>Peltophorum ferrugineum</i> (Decne.) Benth	Fabaceae	Y = 9.1659X-2.7104	0.929	129.969*	0.964*	208.10
2	<i>Butea monosperma</i> (Lam.) Taub.	Fabaceae	Y = 7.4071X-2.6157	0.986	486.823*	0.993*	186.95
3	<i>Neolamarckia cadamba</i> (Roxb.) Bosser	Rubiaceae	Y = 11.054X-4.6779	0.993	478.430*	0.996*	166.84
4	<i>Dalbergia sissoo</i> Roxb. ex DC.	Fabaceae	Y = 19.947X-13.377	0.968	118.490*	0.984*	131.61
5	<i>Delonix regia</i> (Bojer ex Hook.) Raf.	Fabaceae	Y = 6.5075X-1.7544	0.949	187.298*	0.974*	111.36
6	<i>Triadica sebifera</i> (L.) Roxb.	Euphorbiaceae	Y = 9.752X-3.1323	0.997	1.661E3	0.998*	68.31
7	<i>Pongamia pinnata</i> (L.) Pierre	Fabaceae	Y = 5.0503X-1.1091	0.991	1.093E3*	0.997*	65.98
8	<i>Cassia javanica</i> L.	Fabaceae	Y = 3.1739X-0.7481	0.892	49.175*	0.944*	62.48
9	<i>Polyalthia longifolia</i> Benth. & Hook. F.	Annonaceae	Y = 1.4394X-0.1275	0.908	326.208*	0.948*	39.97
10	<i>Peltophorum pterocarpum</i> (DC.) K. Heyne	Fabaceae	Y = 7.5756X-2.544	0.999	630.750*	0.999*	33.49
11	<i>Ziziphus mauritiana</i> Lam.	Rhamnaceae	Y = 3.8846X-0.9938	0.988	171.185*	0.994*	28.70
12	<i>Albizia lebbek</i> (L.) Benth.	Fabaceae	Y = 3.8612X-1.1866	0.998	558.721*	0.998*	25.06
13	<i>Ficus benjamina</i> L.	Moraceae	Y = 1.1356X+0.0075	0.813	29.191*	0.822*	16.48
14	<i>Cassia fistula</i> L.	Fabaceae	Y = 1.696X-0.3124	0.927	65.305*	0.964*	11.64
15	<i>Ficus religiosa</i> L.	Moraceae	Y = 0.4232X-0.2489	0.854	8.733	0.902*	15.61
16	<i>Cordia dicotma</i> L.	Boraginaceae	Y = 0.3173X-0.2458	1	–	1.000*	7.02
17	<i>Syzygium cumini</i> (L.) Skeels	Myrtaceae	Y = 2.8618X-0.2939	0.871	14.874	0.939*	6.23
18	<i>Bauhinia variegata</i> L.	Fabaceae	Y = 2.0358X-0.2821	0.999	–	1.000*	5.83
19	<i>Azadirachta indica</i> A. Juss.	Meliaceae	Y = 1.7689X-0.202	0.988	178.426*	0.992	4.02
20	<i>Nyctanthus arbo-tristis</i> L.	Oleaceae	Y = 1.3125X-0.1395	0.998	1.173E3*	0.999*	3.10
21	<i>Psidium guajava</i> L.	Myrtaceae	Y = 1.7228X-0.2172	0.997	75.000*	0.993*	2.59
22	<i>Gardenia jasminoides</i> J. Ellis.	Rubiaceae	Y = 1.249X-0.1256	0.998	6.500*	0.998*	2.53
23	<i>Bougainvillea glabra</i> Choisy	Nyctaginaceae	Y = 1.4157X-0.1572	0.997	120.333	0.996*	2.12
24	<i>Thevetia peruviana</i> (Pers.) K. Schum.	Apocynaceae	Y = 1.0839X-0.1035	0.999	–	1.000*	1.44
25	<i>Murraya paniculata</i> (L.) Jacq.	Rutaceae	Y = 1.1996X-0.0855	1	–	1.000*	1.21
26	<i>Tamarindus indica</i> L.	Fabaceae	Y = 0.4729X-0.0146	1.000	–	1.000*	0.77

\*p &lt; 0.05.

ANOVA test showed that there was a significant difference in conductivity ( $F \geq 7.765$ ,  $p < 0.05$ ) among the different sample areas under study. An LSD test further revealed a significant difference in conductivity among sample areas-1, 3, and 5; between 2 and 3; and between 4 and 6.

### 3.2.3. Nitrate

There was a variation in nitrate content in the soil in the studied sample areas. Sample area-4 showed the maximum whereas sample area-6 depicted the minimum nitrate content. A one-way ANOVA showed a significant difference ( $4.779E3$ ,  $p < 0.05$ ) in nitrate content between all the sample areas. LSD testing revealed that there was a significant difference between one sample area and other sample areas, however, sample areas-5 and 6 exhibited an insignificant difference (Table 3).

### 3.2.4. Available phosphorous

The available phosphate content in soil samples in the studied sample areas followed the same trend as that for nitrate, and it was statistically significant ( $F = 172.56$ ,  $p < 0.05$ ). An LSD test also revealed that there

was a significant difference between one sample area and the others (Table 3).

### 3.2.5. Available potash

The available potash content of the soil samples ranged from 233.08 to 491.72 kg/ha. Sample area-4 had the highest and sample area-6 had the lowest potash content. A one-way ANOVA showed a significant difference ( $F = 1.819E4$ ,  $p < 0.05$ ) among the sample areas in the study. An LSD test also found a significant difference in the studied sample areas (Table 3).

### 3.3. Bulk density

A distinct variation in bulk densities was recorded in all the studied sample areas, irrespective of the soil depth. The bulk density increases with soil depth irrespective of all the sample areas.

The bulk density ranged from 0.87 to 0.97 gm/cm<sup>3</sup> at depths of 0–15 cm. Sample area-6 recorded the highest and sample area-3 and 4 depicted the lowest bulk density. The bulk density was statistically insignificant; however, there was a slight variation of bulk density in all the studied

**Table 3.** Nutrient contains (Nitrate, Phosphate, and Potash) in soil across the sample areas in the roadside plantation at National Highway-27 of Guwahati, Assam.

Sample area	Nitrate (Kg/Ha)	One Way ANOVA	Phosphate (Kg/Ha)	One Way ANOVA	Potash (Kg/Ha)	One Way ANOVA
1 Khanapara-Basistha Chariali (KH-BC)	15.20 ± 0.92 <sup>a,b,b,b,b</sup>	4.779E3*	27.42 ± 1.09 <sup>a,b,b,b,b</sup>	172.56*	393.43 ± 0.86 <sup>a</sup>	1.819E4*
2 Basistha Chariali-Beharbari (BC-BH)	10.93 ± 1.15 <sup>b,a,b,b,b</sup>		16.23 ± 1.08 <sup>b,a,b,b,b</sup>		382.42 ± 0.93 <sup>b</sup>	
3 Beharbari-Lokhra (BH-LK)	17.93 ± 0.78 <sup>b,b,a,b,b</sup>		75.53 ± 0.71 <sup>b,b,a,b,b</sup>		433.97 ± 0.40 <sup>c</sup>	
4 Lokhra-Garchuk (LK-GCK)	27.27 ± 1.33 <sup>b,b,b,a,b</sup>		119.08 ± 1.29 <sup>b,b,b,a,b</sup>		491.72 ± 0.80 <sup>d</sup>	
5 Garchuk-Boragaon (GCK-BRG)	5.47 ± 1.14 <sup>b,b,b,a,a</sup>		24.43 ± 1.51 <sup>b,b,b,a,b</sup>		370.12 ± 1.00 <sup>e</sup>	
6 Boragaon-Jalukbari (BRG-JLK)	4.272 ± 1.36 <sup>b,b,b,a,a</sup>		9.92 ± 0.98 <sup>b,b,b,a,b</sup>		233.08 ± 1.99 <sup>f</sup>	

\*p &lt; 0.05. Values in the same row with different symbols are significantly different by LSD.

**Table 4.** Bulk density of soil at different depth in different sample areas across the roadside plantation in National Highway-27 of Guwahati, Assam.

Sample area	Bulk Density	One Way ANOVA	Bulk Density	One Way ANOVA
1 Khanapara-Basistha Chariali (KH-BC)	0.89 ± 0.06	0.972	1.03 ± 0.01 <sup>a,a,a,a,a</sup>	3.32*
2 Basistha Chariali-Beharbari (BC-BH)	0.91 ± 0.09		1.06 ± 0.09 <sup>a,a,b,a,a</sup>	
3 Beharbari-Lokhra (BH-LK)	0.87 ± 0.06		0.99 ± 0.07 <sup>a,a,a,a,b</sup>	
4 Lokhra-Garchuk (LK-GCK)	0.87 ± 0.03		0.93 ± 0.07 <sup>a,b,a,b,b</sup>	
5 Garchuk-Boragaon (GCK-BRG)	0.89 ± 0.09		1.04 ± 0.07 <sup>a,a,b,a,a</sup>	
6 Boragaon-Jalukbari (BRG-JLK)	0.97 ± 0.05		1.12 ± 0.03 <sup>a,a,b,b,a</sup>	

\*p < 0.05. Values in the same row with different symbols are significantly different by LSD.

sample areas. The bulk density was between 0.93 to 1.12 gm/cm<sup>3</sup> at soil depths of 15–30 cm. The bulk density in sample area-6, was the greatest and the least in sample area-4. The bulk density was significant (F = 3.32, p < 0.05) in all the sample areas studied (Table 4).

### 3.4. Organic carbon

Variations in the soil organic carbon content in the study area were found not only in the sample areas but also at depths of 0–15 cm, 15–30 cm, and 30–45 cm. There was a decline in the organic carbon content of the soil corresponding to depth irrespective of the sample areas.

The organic carbon content of the soil in the studied sample areas ranged from 2.76 to 7.6% at the 0–15 cm soil depth. A one-way ANOVA test showed a significant difference in the organic carbon content of the soil at a depth of 0–15 cm (F ≥ 5.805, p < 0.05) among all the soil samples from different sample areas. LSD testing further revealed a significant difference in organic carbon content among sample areas-1 and 2, 3 and 4, 5, and 6. At the 15–30 cm soil depth, the organic carbon content was between 2.1 to 6.51%. The organic carbon content was found to be statistically significant (F ≥ 11.422, p < 0.05) at the 15–30 cm soil depth. The LSD test revealed further that there was a significant difference in organic carbon content among sample areas-2 and 3, 4, and 5 and between 1, 3, and 5, 6. At the soil depth of 30–45 cm, the organic carbon content was between 1.64–6.34% which was found to be statistically significant (F ≥ 9.345, p < 0.05). The LSD test also indicated that there was a significant difference in organic carbon content among sample areas-2 and 3, 4, and 5 and between 1, 3, and 5, 6 (Table 5).

Regression analysis showed that there was an inverse relationship between soil organic carbon and bulk density irrespective of soil depth (Figure 3).

### 3.5. Soil carbon stock

Variations in soil carbon stock were also observed in all the sample areas. The highest carbon stock was recorded in sample area-4 (8997.46 Mg/ha), while the lowest was recorded in sample area-6 (3638.6 Mg/ha). A significant difference between sample areas (t = 7.588, p < 0.05) in terms of soil carbon stock was also observed (Table 6).

### 3.6. Relationship between different parameters

To understand the process of carbon sequestration in trees and soil along with other physicochemical parameters that influence carbon stock, a correlation analysis was performed to determine the relationship between different parameters. A significant negative correlation (r = -0.890) was observed between the pH and electrical conductivity of soil samples in the study area. Similarly, a significant negative correlation was also noted between the bulk density and certain other parameters, such as organic carbon (r = -0.869), potash (r = -0.947), and soil carbon stock (r = -0.857). However, organic carbon content exhibited a positive correlation with certain other parameters, such as nitrate (r = 0.881), available phosphorous (r = 0.908), available potash (r = 0.894), AGB (r = 0.864) and BGB (r = 0.847).

A significant correlation was also observed between nitrate and the other nutrients (r = 0.917; r = 0.873) of soil and tree biomass (AGB-r = 0.908, BGB-r = 0.894). AGB and BGB also exhibited a positive correlation (r = 0.999). Moreover, there was also a positive correlation between soil carbon stock and tree biomass (AGB-r = 0.865, BGB-r = 0.847) (Table 7).

## 4. Discussion

Trees, both in natural forests and in plantations, provide several environmental benefits, such as pollution control, temperature reduction, soil erosion control, and improved groundwater retention (Angima et al., 2000; MA, 2005; Díaz et al., 2006; Zuazo and Pleguezuelo, 2008; Wang and Liu, 2018). As the city populations grow, vehicular traffic increases resulting in increased concentration of greenhouse gases, particularly CO<sub>2</sub>. This CO<sub>2</sub> is utilized by plants during photosynthesis and is converted into biomass (Nowak et al., 2013). Worldwide, cost-effective eco-friendly technologies are receiving increasing attention, especially the utilization of urban vacant space to develop green belts (Kim, 2016b). Non-destructive measurements were performed in compliance with Indian laws regarding urban forestation. Our study revealed that roadside plants on National Highway-27 in Guwahati serve as a significant sink to store carbon. The Lokhra-Garchuk area (sample area-4) of National Highway-27 exhibited the greatest carbon stock in trees whereas, in Boragaon-Jalukbari (sample area-6) tree carbon stock is least showing that the density of the trees is more important than traffic volume as an influence on the carbon uptake. Carbon sequestration by trees in the area

**Table 5.** Organic carbon content at different soil depth in different sample areas across the roadside plantations in National Highway-27 of Guwahati, Assam.

Sample area	0–15 cm		15–30 cm		30–45 cm	
	Organic Carbon	One Way ANOVA	Organic Carbon	One Way ANOVA	Organic Carbon	One Way ANOVA
1 Khanapara-Basistha Chariali	5.43 ± 0.81 <sup>a,b,a,b,a,b</sup>	7.77*	5.64 ± 1.24 <sup>a,b,a,a,a,b</sup>	5.840*	5.27 ± 0.88 <sup>a,b,a,a,a,b</sup>	14.62*
2 Basistha Chariali-Beharbari	3.44 ± 0.88 <sup>b,a,b,b,a,a</sup>		2.35 ± 1.39 <sup>b,a,b,b,b,a</sup>		1.9 ± 1.33 <sup>b,a,b,b,b,a</sup>	
3 Beharbari-Lokhra	6.15 ± 0.60 <sup>a,b,a,a,a,b</sup>		6.45 ± 0.36 <sup>a,b,a,a,a,b</sup>		5.93 ± 0.90 <sup>a,b,a,a,a,b</sup>	
4 Lokhra-Garchuk	7.6 ± 0.60 <sup>b,b,a,b,b</sup>		6.51 ± 1.54 <sup>a,b,a,a,a,b</sup>		6.34 ± 0.79 <sup>a,b,a,a,a,b</sup>	
5 Garchuk-Boragaon	4.91 ± 1.29 <sup>a,a,b,a,b</sup>		5.46 ± 2.24 <sup>a,b,a,a,a,b</sup>		4.88 ± 0.72 <sup>a,b,a,a,a,b</sup>	
6 Boragaon-Jalukbari	2.76 ± 1.86 <sup>b,a,b,b,b,a</sup>		2.1 ± 1.18 <sup>b,a,b,b,b,a</sup>		1.64 ± 0.83 <sup>b,a,b,b,b,a</sup>	

\*p < 0.05. Values in the same row with different symbols are significantly different by LSD.

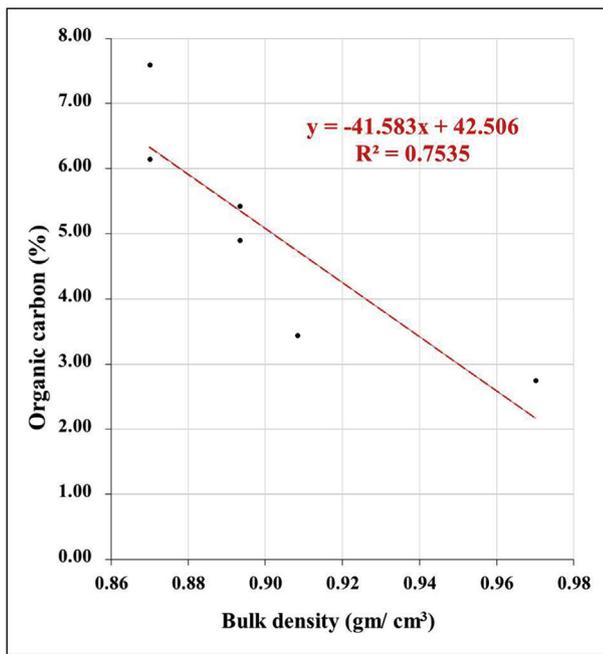


Figure 3. Regression analysis on organic carbon and bulk density at 0–15 cm soil depth.

is also due to the roadside plantation's species composition. In our study, the total carbon sequestered in the vicinity of National Highway-27 at Guwahati was 1209.46 Mg/ha, which is more than the recorded carbon stock in roadside plantations in Vadodara, Gujarat, India (73.59 t/km equivalent to 66.76 Mg) (Kiran and Kinnary, 2011) and in five districts (192.80 Mg/ha) in south-western Bangladesh (Rahman et al., 2015).

However, it is less than the carbon stock of urban trees in Boston, USA (355 Gg/ha equivalent to 355000 Mg/ha) (Raciti et al., 2014) and in Beijing, China (3.1 Gg/yr equivalent to 3100 Mg/yr) (Tang et al., 2016). The variations in carbon stock may be due to different geographical locations, environmental factors, and choice of species depending on their availability, purpose of the plantation, and cost. Taxonomical studies have been conducted on the composition of species and families of trees sequestering carbon along the roadsides (Wang, 2011; Baral et al., 2013). A total of 26 species were recorded in our study area, with legumes being dominant, which is consistent with the findings of Rahman et al. (2015). Roadside plantations usually consist of stress-tolerant trees (Sjöman and Nielsen, 2010), including plants with high pollutant tolerances (Kumar et al., 2013). Fast-growing timber species, as well as ornamental plants Li et al. (2011), were also represented in our study area. Among all species, *Peltophorum ferrugineum* (Copper Pod Tree) is the greatest contributor to total biomass in the study area contributing 208.10 Mg/Ha of carbon sequestration and at 0.77 Mg/Ha *Tamarindus indica* (Tamarind) has the lowest carbon stock potential.

Soil absorbs and accumulates atmospheric CO<sub>2</sub> serving both as a source and as a reservoir, and thus plays a vital role in the alleviation of global climate change. Annually, 8.7 Gt of carbon is emitted into the atmosphere from various anthropogenic sources; however, only 3.8 Gt/year of carbon is found in the atmosphere. The remaining 4.9 Gt/year of carbon is sequestered by the terrestrial ecosystem, including soil; this mitigates climate change (Post and Kwon, 2000; Guo and Gifford, 2002; Smith, 2008; Stockmann et al., 2013; Lal, 2014).

As carbon is consumed by both trees and soil (Karu et al., 2009), they are reliant on each other. Tree growth and health will be boosted if the soil is vigorous (Yuliyanto et al., 2016) and vice versa. Some soil characteristics, such as soil reaction, affect ion solubility (Harris, 1992), and soil physicochemical properties, such as pH, conductivity, structure, texture, depth, color, organic matter, and nutrients, affect plant growth (Fisher and Binkley, 2000; Nemali and van Iersel, 2004; Hazra and Som, 2006; Samarakoon et al., 2006; Guiabao, 2016; Signore et al., 2016).

Table 6. Carbon stock (Mg/Ha) in trees and soil of different sample areas along the National Highway-27 of Guwahati, Assam.

Sample area	Tree Carbon Stock		Soil Carbon Stock	
	Mg/Ha	t test	Mg/Ha	t test
1 Khanapara- Basistha Chariali	156.16	4.850*	6600.86	7.588*
2 Basistha Chariali - Beharbari	160.50		4251.97	
3 Beharbari - Lokhra	214.00		8460.77	
4 Lokhra - Garchuk	399.66		8997.46	
5 Garchuk - Boragaon	161.91		5808.89	
6 Boragaon - Jalukbari	117.24		3638.60	
<b>Total</b>	<b>1209.47</b>		<b>37758.55</b>	

\*p < 0.05.

Table 7. Pearson Correlation analysis reflecting the relationship between different parameters of soil and trees along the National Highway-27 in Guwahati, Assam.

Parameters	pH	Conductivity	Organic carbon	Bulk density	Nitrate	Phosphate	Potash	Carbon stock	AGB	BGB
pH	1									
Conductivity	- 0.89*	1								
Organic carbon	- 0.184	0.192	1							
Bulk density	0.520	- 0.488	- 0.869*	1						
Nitrate	- 0.329	0.260	0.881*	- 0.719	1					
Phosphate	- 0.216	0.144	0.908*	- 0.685	0.917*	1				
Potash	- 0.527	0.404	0.894*	- 0.947**	0.873*	0.809	1			
Carbon stock	- 0.154	0.167	1.000**	- 0.857*	0.879*	0.906*	0.883*	1		
AGB	- 0.114	- 0.058	0.864*	- 0.634	0.908*	0.951**	0.808	0.865*	1	
BGB	- 0.117	- 0.065	0.847*	- 0.614	0.894*	0.952**	0.791	0.847*	0.999**	1

\*p < 0.05. \*\*p < 0.01.

Simultaneously, trees also augment soil fertility by contributing organic matter that is deposited by the above and below-ground plant structures which further helps to retrieve excess CO<sub>2</sub> from the atmosphere (Kumar et al., 2014; Chaudhari et al., 2015).

Acidic pH in soils from mango agroforestry in the Philippines and oil palm plantations in Malaysian Borneo was studied by Guiabao (2016) and Rahaman et al. (2018), respectively. The present study found the pH of the sample area to range from slightly acidic to slightly basic and the pH differed significantly in the studied sample area. Our results are consistent with the findings of Chaudhari et al. (2013), Li et al. (2013), Zhiyanski et al. (2015), and Arya et al. (2018), who reported that the pH of roadsides plantations ranges from 6.4 to 7.75. The increase in soil pH may be due to the deposition of calcium ions in the soil that enhances cationic activity. The low pH in soil may be due to the elimination of basic cations because of anthropogenic activities. The pH of the area is also influenced by soil texture, mineral content, and climate.

Studies have focused on the conductivity of soil from different urban plantations (Chaudhari et al., 2013; Arya et al., 2018). Our study found that the electrical conductivity of all studied areas has normal salt content which is consistent with the finding of Kadam (2016), and the conductivity of sample area-3 (Beharbari-Lokhra) is highest (0.773 mS cm<sup>-1</sup>) whereas sample area-6 (Boragaon-Jalukbari) recorded the lowest (0.0733 mS cm<sup>-1</sup>). The increase in the electrical conductivity of the soil in our studied sample areas is ascribed to the presence of greater amounts of soluble salts (ions) in the soil and is indicative of the productivity and good health of trees.

Nutrients such as nitrogen and phosphorous are the major determinants of carbon sequestration in most of the world's forest ecosystems (Shugart et al., 1992; Kimmins, 1996; Agren et al., 2012). In some forests, the leaf area index, nutrient cycling, litterfall, decomposition, carbon stock, and species distribution are affected by the availability of nitrogen (Boring et al., 1988). Hence, there is a need, globally, to understand the relationship between photosynthetic ability and nutrient content in plants to envisage the future of carbon sequestration for mitigation of climate change (Tang et al., 2018).

The soil carbon stock is associated with the physical and minerals characteristics of soils (Rasmussen et al., 2007) as well as with above and belowground biomass, which is affected by nutrients received directly or indirectly (Armitage and Fourqurean, 2016).

The nitrate content in our study area was in the range of 4.27–27.27 kg/ha which is higher than that of 1.98 ppm as reported by Guiabao (2016) in the agroforestry system and lower than the roadsides plantation (143–224.8 kg/ha) in Haryana, India as stated by Arya et al. (2018). The available phosphorus content was observed to be in the range of 9.92–119.08 kg/ha in our study area, which is more than 5.5 ppm (equivalent to 12.353 kg/ha) as stated by Guiabao (2016). The available potash was in the range of 233.08–491.72 kg/ha which is higher than the 240.4–308.2 kg/ha of potash in the roadside plantation in Haryana, India as reported by Arya et al. (2018) and less than the 705 ppm (equivalent to 1583.43 kg/ha) in an agroforestry system in the Philippines as observed by Guiabao (2016). The potash content in our study area was more than that of nitrate and phosphorus according to Chaudhari et al. (2013) and Li et al. (2013). The Nitrate, phosphate, and potash contents were statistically significant and sample area-4 (Lokhra-Garchuk) recorded the highest concentrations while sample area-6 (Boragaon-Jalukbari) had the lowest. The recommended level of nitrogen, phosphorus, and potassium for normal plant growth is 280 kg/ha, 10 kg/ha, and 108 kg/ha respectively as per the Methods Manual of Soil Testing in *Methods Manual Soil Testing in India* (2011). The soil in our study area contains more phosphorus and potash and less nitrogen; hence, the nitrogen supply needs to be increased via outsourcing.

A vigorous soil needs air, water, and pore space for proficient root penetration and plant growth. If soil is compact or bulk density is too high, then plant roots will not propagate well, and hence yield will be reduced (Gupta and Jangid, 2011). Thus, information on bulk density will assist in soil management and in future planning to enhance soil

fertility by technological means (Chaudhari et al., 2013). Several researchers reported an increase in bulk density according to soil depth in different land-use patterns (Zhiyanski et al., 2015; Rahaman et al., 2018). Our study also found that the bulk density in the studied area increased with soil depth; however, bulk density at the 15–30 cm depth was statistically significant for all the studied sample areas at National Highway-27 in Guwahati, Assam.

Soil organic carbon has an important function in the carbon cycle; hence, its presence and availability significantly influence climate change (Smith, 2004; Vaccari et al., 2011). Our study found an organic carbon content of 2.76–7.6%, 2.1–6.51% and 1.64–6.34% at depths of 0–15 cm, 15–30 cm, and 30–45 cm respectively in all the studied sample areas which are higher than 0.35–4.14% in afforested land as reported by Zhiyanski et al. (2015) and Arya et al. (2018) (1.03–1.11%) in the roadside plantation of north-western Haryana, India. A variation was observed in the organic carbon content in the same layer of soil for different sample areas; this is similar to the findings of Zhiyanski et al. (2015). We also found that the organic carbon content of the surface layer was higher irrespective of the area studied. Humus formation and organic matter putrefaction occur in the upper soil layer. The upper soil layer exhibits a dynamic interaction with biological and anthropogenic activities and thus, is richer in organic carbon content.

Certain studies have found that the soil carbon stock decreases with soil depth (Henry et al., 2009; Venkanna et al., 2014; Adhikari et al., 2019). In contradiction, some studies found that the soil carbon stock increased with depth (Singh and Singh, 2015; Kumar et al., 2016). Our study found that the soil carbon stock was highest in sample area-4 (8997.46 Mg/ha) and lowest in sample area-6 (3638.6 Mg/ha). We further observed that the soil carbon stock decreased with soil depth, which is consistent with the findings of Toru and Kibret (2019), where they found that the soil carbon stock was 93.78 t/ha, 81.07 t/ha and 60.31 t/ha respectively at 0–20 cm, 20–40 cm, and 40–60 cm soil depths. Soil carbon stock as organic carbon content is greater in the upper soil layer owing to litter decomposition that is prevalent in the soil's surface layer. Moreover, increased anthropogenic activities intensified the carbon stock concentration in the soil's upper layer.

Toru and Kibret (2019) found that the carbon stock of soil was more than that of trees. Similarly, our study also found that the sequestration of carbon in soil was greater than that of trees. However, Byrne and Milne (2006) and Li et al. (2015) reported increased carbon stock in trees compared to that of soil. Comparatively less carbon is sequestered by trees than soil in our study area that may be due to smaller dbh and less height as most of the trees are young. Soil carbon stock is affected by land-use changes, carbon deposition by vehicles, and input of litters and nutrients from the above and below-ground biomass (Snorrason et al., 2002; Kaushal et al., 2012).

Reports are available on the positive and negative correlations among different tree and soil parameters (Chaudhari et al., 2013; Omoro et al., 2013; Pan et al., 2013; Venkanna et al., 2014; Zhiyanski et al., 2015; Rahaman et al., 2018). Our study found a negative correlation between bulk density and potash and the soil carbon stock that is consistent with the findings of Chaudhari et al. (2013). A significant positive relationship was obtained between nitrate and organic carbon content which was also reported by Zhiyanski et al. (2015) and a further significant positive correlation was found between soil carbon stock and nitrate, phosphate, and potash that is similar to that of Davy and Koen (2013). Our study also found a significant negative correlation between pH and conductivity, whereas soil carbon stock was positively correlated with both AGB and BGB.

Ecosystem-based carbon sequestration by soil initially relies on carbon elimination by trees (Paustian et al., 2019). The present study also depicted that both trees and soil are dependent on each other for their sustainability. Thus, this study will further contribute to framing carbon-friendly land-use planning and policies.

To understand the concept of carbon sequestration, site-specific studies are needed on the growth of trees and how the carbon pool is sustained by trees, soils, and carbon emissions from vehicles on the national highway of

Guwahati and other parts of Assam. Heavy metal analysis of the study area is required to understand its impact on the nutrients content of the soil. Furthermore, for enhanced carbon sequestration, the plant litter produced by urban plantations should be returned to the soil instead of being burned. Allometric models related to carbon sequestration by both soil and trees for roadside plantation must be delineated.

## 5. Conclusion

A conservation-based bio-edaphic ecosystem, along National Highway-27 of Guwahati, Assam, India is sequestering enhanced carbon emitted (1,68,550 tones/year) by vehicular traffic following urban population expansion. It pursues the UNFCCC and REDD + strategy for climate change mitigation besides being a sink for greenhouse gases and contributes to reducing the carbon footprint. *Peltophorum ferrugineum* is recommended for plantations along the national highway for green belt expansion, because this species has emerged as a tolerant species and has the greatest carbon storage potential. Such bio-edaphic ecosystems should be considered for enhancing the Ecosystem Services (ESS) and natural beautification and for transforming Guwahati into an eco-city. Besides, this approach could address local challenges such as health job creation, and poverty alleviation. The bio-edaphic ecosystem contributes to the Intended Nationally Determined Contributions (INDC) established by India, under the National Green Highway Mission. As per the Paris Agreement, sustainable roadside plantations could promote the establishment of plantations having carbon storage potential in vacant spaces with stakeholder participation and increased public awareness, especially in sample area-4. Further to this early study on the role of the bio-edaphic ecosystem in carbon sequestration, the ecological approach to mitigating transport pollution and other local challenges by implementing carbon sequestration by establishing roadside plantations in other parts of Assam, India and elsewhere requires additional exploration. The data obtained from this study can be used by various stakeholders to design green spaces on vacant land and develop strategies for pollution and climate change management.

## Declarations

### Author contribution statement

A. Bhattacharya: Conceived and designed the experiments; Analyzed and interpreted the data; Wrote the paper.  
K. Saikia: Performed the experiments.  
M. Takhelmayum, P. Sarkar: Analyzed and interpreted the data.

### Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

### Competing interest statement

The authors declare no conflict of interest.

### Additional information

No additional information is available for this paper.

## Acknowledgements

Authors are thankful to the University of Science & Technology, Meghalaya for their co-operation all through the work. The Director, Assam Agriculture Department (Soil Survey), and ABNS Scientific Services provided the laboratory help for soil analysis. Authors are grateful to Prof. Irwin Bernstein, Professor Emeritus, Georgia University, USA for technical help. The manuscript also benefited from anonymous reviewers.

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