Comparative study on the carbon storage capacity between indigenous and exotic forest tree species in Bangladesh

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Abstract

Forests play a vital role in reducing carbon dioxide from the atmosphere through the photosynthesis process and store carbon in different pools of forests as biomass. Biotic and abiotic factors degrade forest resources throughout the country. On the other hand, artificial plantation is increasing at a geometrical rate with consideration of biomass and carbon storage capacity. The determination of biomass and carbon storage capacity of forest tree species is essential for the sustainable development of the environment and reducing global warming. The allometric equations and systematic sampling methods were followed for the determination of biomass and carbon storage of *Albizia procera* and *Khaya anthotheca.* The findings of the study indicated that the aboveground biomass, belowground biomass, and total biomass values were 1116.37, 223.27, and 1339.64 kg tree^{-1} found in *Albizia procera* and 1064.36, 212.87, and 1277.23 kg tree^{-1} found in *Khaya anthotheca.* The results revealed that the aboveground carbon, belowground carbon, and total carbon values were 558.14, 111.64, and 664.82 kg tree^{-1} found in *Albizia procera* and 532.18, 106.44, and 632.62 kg tree^{-1} found in *Khaya anthotheca.* The *c*arbon storage capacity was 26.79 and 25.54 kg tree^{-1} year^{-1} (kg) found in *Albizia procera* and *Khaya anthotheca*, respectively at 25 years old. Finally, carbon dioxide capturing values of *Albizia procera* and *Khaya anthotheca* were 98.32 and 93.72 kg tree^{-1} year^{-1}, and oxygen releasing capacity values also were 71.77 and 68.45 kg tree^{-1} year^{-1} respectively. In this case, *Albizia procera* and *Khaya anthotheca were treated* as indigenous and exotic forest tree species, respectively. Finally, it is concluded that the carbon storage capacity of indigenous tree species is higher than exotic forest tree species. So, the findings of the study will be helpful to the administrations, policymakers, other related organisations, and persons who directly or indirectly engaged with the implementation of plantation programmes.

1 Introduction

Bangladesh is included in the northeastern part of Southeast Asia and lies from 20°34 to 26°38 north latitudes and 88°10 to 92°41 east longitudes. The total land area of Bangladesh is about 14.76 million hectares, and the total forestland is 2.53 million hectares (Alam, 2008; Alamgir *et al.*, 2014). Forests are the most important carbon sequester in nature and store it in different pools of forests. Forests and forest soil play a vital role in climate change mitigation. Normally, forest is a sound ecosystem, where trees are dominant. Forests may be natural or artificial. The natural forest may be developed in a place by natural succession, while artificial forests may be created by human interference. The natural forests are always composed of indigenous trees, and these forests are called indigenous forests. Indigenous trees are those trees that grow naturally in the ecological zone where there is the forest. These forests often play a crucial role in maintaining biodiversity and supporting various wildlife species. In contrast, artificial forests may not provide the same ecological benefits, as they often consist of non-native species that can disrupt local ecosystems. These disruptions can lead to a decline in native flora and fauna, ultimately threatening the balance of the ecosystem. Additionally, the introduction of non-native species can result in competition for resources, further endangering indigenous species that are vital for maintaining ecological harmony. Preserving native habitats is therefore essential for the resilience of ecosystems. Initiatives aimed at restoring natural landscapes can help reverse the negative impacts of artificial forests, fostering a more sustainable environment for both wildlife and plant life. The exotic trees are those trees that do not naturally grow in the area and that have been imported from another ecological zone and adapted to the new environment. Plantation is an ongoing process in Bangladesh without consideration of indigenous and exotic tree species due to insufficient planting and adaptation awareness. Though plantation is essential for increasing forest resources and reducing global warming (Trettin et al., 2006; Pan et al., 2011; Becknell et al., 2012; Charman et al., 2013; Sarkar et al., 2021; Kumar et al., 2022). Forests play a crucial role in the regional and global carbon cycle. Forests can store huge amounts of organic carbon in plants and soil. The measurement of carbon helps to understand the contribution of forests to the global carbon cycle. Carbon storage and growing stock are essential components for prediction of forest conditions and mitigation of climate change.

The determination of carbon storage of forests tree species is the most important for natural resource management and the implementation of plantation planning programs. It is estimated that 1.90 pgC was sunk in the terrestrial forests and 1.70 pgC was added to the earth due to biotic interferences (IPCC, 2001). Forest ecosystems can help to maintain balance by acting as a sink of atmospheric carbon (Ghosh et al., 2021). Several scientists reported that only forests can play an essential role in carbon capturing and global climate change mitigation (Pan et al., 2011; Becknell et al., 2012; Charman et al., 2013). It is also reported that only forests can capture about 14 PgC year^{-1} (Jensen et al., 2017). Globally, it is estimated that forest pools store about 610 PgC (Mendes et al., 2020). Trees are the dominant natural resource in forest ecosystems, and the total plant material in a forest is called plant biomass. Plants biomass depends on forest ecosystems, the nature of vegetation, age, structure, site condition, etc. (Gupta and Kumar, 2014). Tree's biomass is an essential component of forest ecosystems and plays a crucial role in the organic carbon cycle (Li et al., 2011). There are two types of tree biomass: aboveground biomass and belowground biomass. Aboveground biomass of the tree is the most important carbon pool compared to other carbon pools such as belowground biomass, undergrowth, and litter, etc. (Gibbs et al., 2007). The total amount of biomass of a tree is influenced by forest type, site variation, altitude, slope, edaphic criteria, and management, etc. (Jati, 2012). The determination of carbon storage is also important for natural resource management and the implementation of planning plantation programs. Plantation can improve soil health and maintain the ecological balance (Rai et al., 2021; Sheikh et al., 2021). Plantation reduces atmospheric carbon dioxide and is a sink (Resh et al., 2002; Ganeshamurthy et al., 2016; Thakur et al., 2021; Tamang et al., 2021).

There are many established orchards with indigenous and exotic tree species in Bangladesh. It is estimated that there are about 150 tree species planted in different natural and artificial forest areas (Baul et al., 2021; Rahman et al., 2025). However, *Albizia procera* and *Khaya anthotheca* are known as indigenous and exotic forest tree species in Bangladesh (Ahmed et al., 2009a; Ahmed et al., 2009b). Actually, the total biomass depends on the density of tree, diameter, height, wood density and basal area etc. (Joshi and Ghose, 2014). Wood density is an essential indicator for the measurement of tree biomass (Chave et al., 2014). Wood density is varied from species to species and low wood density is permitted more rapid growth in size, possibly because trees grow quicker with less expensive conductive tissue building (Preece et al., 2015). The growth rate of hard wood is less than soft wood forest tree species (Rahman *et al*., 2019). Normally, indigenous tree species is hard and their growth rate is also low, but exotic tree species is less hard than indigenous tree species and their growth rate is higher. *Khaya anthotheca* has been included in the massive plantation programme from 2000 to increase the local fuelwood demand. This demand has prompted efforts to enhance the sustainability of forest resources while also promoting economic growth in rural areas. As a result, *Khaya anthotheca* has been planted to support local fuel demand. It is clear that sufficient studies have not yet been conducted on indigenous and exotic forest tree species for the determination of biomass and carbon storage capacity. It is the most important for the determination of biomass and carbon storage capacity of indigenous and exotic tree species for the identification of contribution to mitigate global warming. Therefore, the present study has made an attempt to determine the carbon storage capacity of indigenous and exotic planted timber species in different locations of Bangladesh.

2 Materials and methods

2.1 Study areas

The study was conducted on Rajshahi University campus, Rajshahi, and Altadighi reserved forest, Dhamorhat upzila under Naogaon district in Bangladesh. The study carried out from September 2024 to May 2025. The campus lies near the Padma River and about 5 kilometers east of the Rajshahi city corporation. The Rajshahi University campus is between 24.370° North latitudes and 88.637° East longitudes. (Fig. 2.1). Two planted forest trees were selected for the determination of biomass and carbon storage such as *Albizia procera* (Roxb.) Benth. and *Khaya anthotheca* (Welw.) *etc*. In this case, the orchard of *Albizia procera* was in the Rajshahi University campus, which is illustrated in the following figure.

The Altadighi was selected for the determination of biomass and carbon of *Khaya anthotheca*, which is the most important and the first established orchard of *Khaya anthotheca* in Bangladesh. The Altadighi reserved forest area is located at 25°30′ to 25°85′ North latitudes and 88°51′ to 88°59 ′ longitudes (Fig. 2. 2). This area is also under tropical region and the north west corner of Bangladesh.

2.2 Climatic condition

The study area of Rajshahi University is a tropical and dry climate with low rainfall. The rainy season starts at the end of June and lasts until September. The average humidity is about 77%, and the driest, coldest, warmest and wettest months are December, January, April and July respectively. The rainfall annually varies from 1542.10 mm to 2235.80 mm in Rajshahi. The rainy days vary from 86 to 112 days per year. (Weather Department, 2024). The minimum and maximum temperature varies from 9^0 to 14^0C in winter. The minimum and maximum temperature varies from 24.5 to 40.1^0C in summer. On an average annual temperature is about 26- 36^0C. The soil p^H is about 5.66. This soil is perfect for agricultural and horticultural crops (BBS, 2024).

The study area of Altadighi is tropical dry region and less rainfall. The rainy season starts at the end of June and lasts until September. The average humidity is about 73%, and the driest, coldest, warmest and wettest months are December, January, April and July, respectively. The rainfall annually varies from 1502.14 mm to 1935.50 mm in Naogaon (Weather Department, 2024). The minimum and maximum temperature varies from 8^0 to 15^0C in winter. The minimum and maximum temperature varies from 22. to 40.10^0C in summer. The soil p^H is about 5.30. This soil is perfect for agricultural and horticultural crops (BBS, 2024).

2.3 Selection of plots

The map of the study area was prepared using the Geographical Information Systems (GIS). A systematic sampling method was used for selection of each plot (Pearson et al., 2007). Each plot was 100 meters apart from the others. Each plot was circular and covered 10 meters (radius). The total number of plots was 408 (four hundred eight). The total study area was 305 hectares, and the sampling area was 12.81 hectares in the Rajshahi University campus. The total area of the Altadighi National Park was about 264.12 hectares, and the sampling area was11.09 hectares. Several scientists mentioned that a sampling area of at least 1% is required for terrestrial areas (Rana et al., 2012), but more than 4.20% was covered in the present study area. The number of trees in each plot was counted, identified and recorded. Diameters were measured (1.30 m above the ground level) of all the trees in each plot with a tape. Heights were measured with a Hega-altimeter. A tree is included if > 50% of the basal area fell within the plot and excluded if < 50% of their basal area fell outside the plot. Measurement activities were accomplished carefully.

3.4 Estimation of tree biomass

The non-destructive method was followed for the measurement of biomass and carbon of trees. This method is also known as the Brown's model (Brown et al., 1989). This model is considered as the best model in the tropical regions for the determination of biomass and carbon of trees (Alves et al., 1997; Brown, 1997; Schroeder et al., 1997; Sattar et al., 1999; Rahman *et al.*, 2022b; Rahman et al., 2025).

The method is explained as follows.

$AGB = \exp. \{-2.4090 + 0.9522 \ln (D^2HS)\}$

Where,

AGB is the aboveground biomass (kg), H is the height of the trees (m), D is the diameter at breast height (cm),

S is a specific wood density of tree (kg /m^3), TB = Total biomass, TC = Total carbon

BGB was considered to be 20% of the aboveground biomass, as Mac Dicken (1997) suggested. The formula is given below:

BGB = AGB × (20 / 100)

TB = AGB + BGB

TC = TB/0.50 (Biomass contained 50% carbon, Brown et al., 1989)

2.6 Data analysis

Descriptive statistics were calculated to describe biomass and carbon in trees. Analysis of variance (ANOVA) was done at two forest tree species in same ages. Duncan's multiple range tests were done to determine the significance of the variations in mean values. Statistical Package for the Social Science (SPSS) version 28 was used to perform these analyses.

3 Results and Discussion

3.1 Determination of diameter at breast height and the total height of Albizia procera and Khaya anthotheca

The study was conducted on *Albizia procera* and *Khaya anthotheca* and both species were planted, which were about 25 years old. The present study measured diameter at breast height and the total height of *Albizia procera* and *Khaya anthotheca in* the study areas. The findings of the study revealed that the diameter at breast height and the total height of *Albizia procera and Khaya anthotheca were* 40.37 cm, 42.86 cm, 44 cm and 18.77 m, 25.90 m respectively in the 25 years old plantations (Table 1). Statistical analysis revealed that diameter and height differed significantly between *Albizia procera* and *Khaya anthotheca* at the same ($p < 0.05$).

Table 1
Diameter at breast height and height of *A. procera* and *K. anthotheca* at 25 years old.

Species	Age(years)	DBH (cm)	H(m)
A. procera	25	40.37 ± 1.02	18.77 ± 1.25
K. anthotheca	25	42.86 ± 0.36	25.90 ± 0.95
** DBH = Diameter at breast height, H = Height			

Actually, diameter and height are essential growth parameters, which play a crucial role in the total biomass and carbon storage. The elevated diameter and height values were recorded in *Khaya anthotheca* than *Albizia procera*. But, the total biomass and carbon of trees were measured based diameter, height and specific density. Normally, the exotic forest tree species attains more diameter and height that the indigenous forest tree species, which is expressed in the present findings. A study was conducted on *Eucalyptus camaldulensis for* the determination of biomass and carbon storage and reported that the diameter and height were 29.65 cm and 17.44 meter at 20 years old plantation area (Rahman et al., 2025). Another study was conducted on *Casuarina equisetifolia* and reported that the diameter and height were 23.54 cm and 20.33 meters (Rahman, 2022b). It is clear from the discussion that variable findings are recorded from species to species.

3.2 Determination of mean annual diameter increment and mean annual height increment of A. procera and K. anthotheca

The biomass and carbon depend on the mean annual diameter increment (MADI) and mean annual height increment (MAHI). The study indicated that mean annual diameter increments were 1.17 and 1.61 cm per year in *A. procera* and *Khaya anthotheca*. The mean annual height increments were 0.75 and 1.04 m per year in *A. procera* and *Khaya anthotheca*. (Table 2). These findings suggest a positive correlation between tree growth metrics and overall biomass accumulation, highlighting the importance of monitoring these increments for sustainable forest management. Furthermore, understanding these variables can aid in predicting the carbon sequestration potential of the forest ecosystem.

Table 2
Mean annual diameter increment and mean annual height increment of *A. procera* and *K. anthotheca*

Name of species	Ages(years)	MADI (cm)	MAHI (m)
A. procera	25	1.17	0.75
K. anthotheca	25	1.61	1.04
**MADI = Mean annual diameter increment and MAHI = Mean annual height increment			

Mean annual diameter increment and mean annual height increment values are depended on management, environment, and edaphic characteristics such as well management can lead to increase yield of forest production (Shiekh *et al.*,1981). Again, environmental criteria can also play a vital role to increase mean annual diameter increment and mean annual height increment of trees (Holmgren and Petters Orson, 1995). Mean annual diameter increment and mean annual height increment values are depended on genetic features (Hassan,1994).

3.3 Determination of biomass of *A. procera* and *K. anthotheca*

The main objective of the study was to determine biomass and carbon based on diameter at breast height and the total height of *A. procera* and *K. anthotheca.* The total biomass of *A. procera* and *K. anthotheca* of the same ages are presented in the following table (Table 3). The results revealed that the aboveground biomass, belowground biomass, and total biomass were 1116.37, 1064.36, 223.27, 212.87, 1339.64, and 1277.23 kg tree^{-1} respectively at 25-years-old orchards (Table 3). Statistical analysis revealed that the total biomass varied significantly between *A. procera* and *K. anthotheca* at same ages ($p < 0.05$). The total biomass value of *A. procera was higher than K. anthotheca.* Actually, the biomass values calculate based on height, diameter and specific density of trees. Besides, the biomass values depend on management, environmental factors and biotic factors etc.

Table 3
Aboveground biomass, belowground biomass and total biomass of *A. procera* and *k. anthotheca*

Name of species	Age (yrs.)	AGB (kg/tree)	BGB (kg/tree)	TB (kg/tree)
A. procera	25	1116.37 ± 3.19	223.27 ± 2.23	1339.64
K. anthotheca	25	1064.36	212.87	1277.23

**AGB = Aboveground biomass, BGB = Belowground biomass, TB = Total biomass, belowground biomass was calculated on the basis of aboveground biomass. So, F- values were the same for all parameters.

A study was conducted on the Kaptai National Park, under the Rangamati Hill Tracts district of Bangladesh, for the determination of biomass and carbon storage of different forest tree species and reported that biomass values were variable from species to species. The total biomass values were 680.63 and 471.64 kg tree^{-1} found in *Dipterocarpus turbinatus* and *Tectona grandis* respectively, which were also 25 years old (Rahman et al., 2021). In this case, their findings were less than the present findings. Another study was conducted in the Mindanao of Philippines and reported that the total tree biomass and carbon varied among species to species (Tandug, 2012). Actually, the total biomass was influenced by stem size, distribution, soil fertility, evergreen, deciduous, elevation and environmental condition etc. (Dewalt and Chave, 2004; Pragasan 2014; Pragasan 2015; Murphy et al., 2016, Salunkhe et al., 2016; Thokchom and Yadav, 2017). The total biomass value was depended on the total aboveground and the total belowground biomass values Chaturbedi *et al*., 2011; Mohanraj *et al*., 2011). The present study indicated that biomass was stored in tree but it differed from species to species. It is clear from the above findings that higher biomass is stored in *Albizia procera* than *Khaya anthotheca* at the same ages.

Determination of carbon of A. procera and K. anthotheca

The research revealed that the aboveground carbon, belowground carbon, and total carbon of *A. procera* and *K. anthotheca* were 558.14, 532.18, 111.64, 106.44, 669.82, and 638.62 kg tree^{-1} at 25 years old, respectively (Table 4). In this case, the aboveground carbon, belowground carbon, and total carbon values of *A. procera* were higher than *K. anthotheca*.

Table 4
Aboveground carbon, belowground carbon and total carbon of *A. procera* and *K. anthotheca*

Name of spp.	Age (yrs.)	AGC (kg/tree)	BGC (kg/tree)	TC (kg/tree)	kg $tree^{-1}year^{-1}$
A. procera	25	558.14	111.64	669.82	26.79
K. anthotheca	25	532.18	106.44	638.62	25.54
**AGC = Aboveground carbon, BGC = Belowground carbon, TC = Total carbon					

The main objective of the study was to determine the total carbon storage of indigenous and exotic forest tree species at the same ages. Statistical analysis revealed that the total carbon storage varied significantly between *A. procera* and *K. anthotheca* at same ages ($p < 0.05$). The total carbon storage capacity is varied from species to species such as 30.87, 25.68 kg/tree were recorded in *Acacia auriculiformis* at 11, 10 years old plantation (Rahman *et al.*, 2019). Another study was conducted on carbon storage of *Casuarina equisetifolia* and observed that 0.20, and 0.24t/tree at 15 and 20-years old plantation (Rahman et al., 2022a). A study was conducted on *Mangifera indica* at Rajshahi University campus area and observed that the biomass values were 231.50 kg /tree at 20 years old plantation (Rahman et al., 2022a). Several scientists observed that the carbon storage capacity values of *Mangifera indica*, and *Psidium guajava* were 86. 76 and 44.10kg/tree at 10–20 years old (Shinde et al., 2015). A study was conducted on fruit tree species in India and reported that a variable results in different species (Selvaraj et al., 2016; Shrestha and Malla, 2016). It is also proved that carbon storage capacity is unequal to species to species.

Determination of carbon sequestration capacity of A. procera and Khaya anthotheca

The present study indicated that the total captured carbon values of *A. procera and K. anthotheca were* 669.82 and 638.62 kg $tree^{-1}$ at 25 years old, and the average carbon storage values were 26.79 and 25.54 kg $tree^{-1}$ $year^{-1}$ in the following table (Table 5).

Table 5
Carbon storage, capturing CO_2 and releasing O_2 $tree^{-1}year^{-1}$ of *Khaya anthotheca at 25 years*

Name of species	Age (yrs.)	Carbon storage $tree^{-1}year^{-1}$(kg)	Capturing CO_2 $tree^{-1}year^{-1}$(kg)	Releasing O_2 $tree^{-1}year^{-1}$(kg)
A. procera	25	26.79	98.32	71.77
K. anthotheca	25	25.54	93.77	68.45

A single *A. procera* captured 98.32 kg of carbon dioxide per tree per year from the atmosphere and released 71.77 kg of oxygen per year. Carbon dioxide is captured by plants through photosynthesis process and carbon is stored in the body as biomass. The stored biomass is used in different physiological activities of trees. This demonstrates the significant role that these species play in carbon sequestration and oxygen production, contributing positively to the environment. Further research could explore the broader ecological impacts of these trees and their potential for enhancing carbon offset strategies. A study was conducted on *Eucalyptus camaldulensis* observed that capturing carbon dioxide and releasing oxygen capacity was about 63.26 and 45.55 kg tree^{-1} year^{-1}, which is the lower than *A. procera* and *K. anthotheca of* the present findings (Rahman et al., 2025). Actually, the plantation program should be implemented with native tree species because their carbon sequestration capacity is better than exotic tree species, which is spontaneously cleared by the present findings of the study.

Conclusion

Plantation is a traditional method in the tropical region, especially in India, Bangladesh, Myanmar, Thailand, Pakistan, etc. Artificial plantation is the main strategy for improving forest resources in third-world countries. The present research was conducted on *Albizia procera* and *Khaya anthotheca* for the determination of biomass and carbon sequestration capacity at the same ages. The findings of the present study indicated that carbon storage capacity of indigenous forest tree species is higher than the exotic forest tree species. It is also estimated that indigenous tree species play a vital role to improve soil fertility and help to increase plants essential nutrients in soil. Moreover, these findings will be helpful to researchers, scientists, and planners who are directly related to the implementation of plantation programs in Bangladesh. These findings are insufficient to generalize to the whole country of Bangladesh. The research was conducted on artificially planted, monoculture plantation areas, and a short duration on the Rajshahi University campus and Altadighi reserved forest areas. Further research is essential for determining the carbon storage capacity of different tree species, which will be included in the future implementation of massive plantation programs. The high carbon-capturing tree species should be planted to mitigate climate change, which will be helpful to reduce climate change and sustainable environment development.

Declarations

Conflicts of Interest

The authors declare that no conflicts of interest.

Author Contribution

All authors made substantial contributions to the study, including conception, design, execution, data collection, analysis, and interpretation. They were actively involved in drafting, revising, or critically reviewing the manuscript, and jointly decided on the journal for submission. Each author has approved the final version of the article and accepts responsibility for all aspects of the work.

Data Availability

The datasets generated and analysed during the study are available from the corresponding author on reasonable request. To ensure confidentiality and protect participant privacy, individual-level responses are not publicly shared.

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Figures

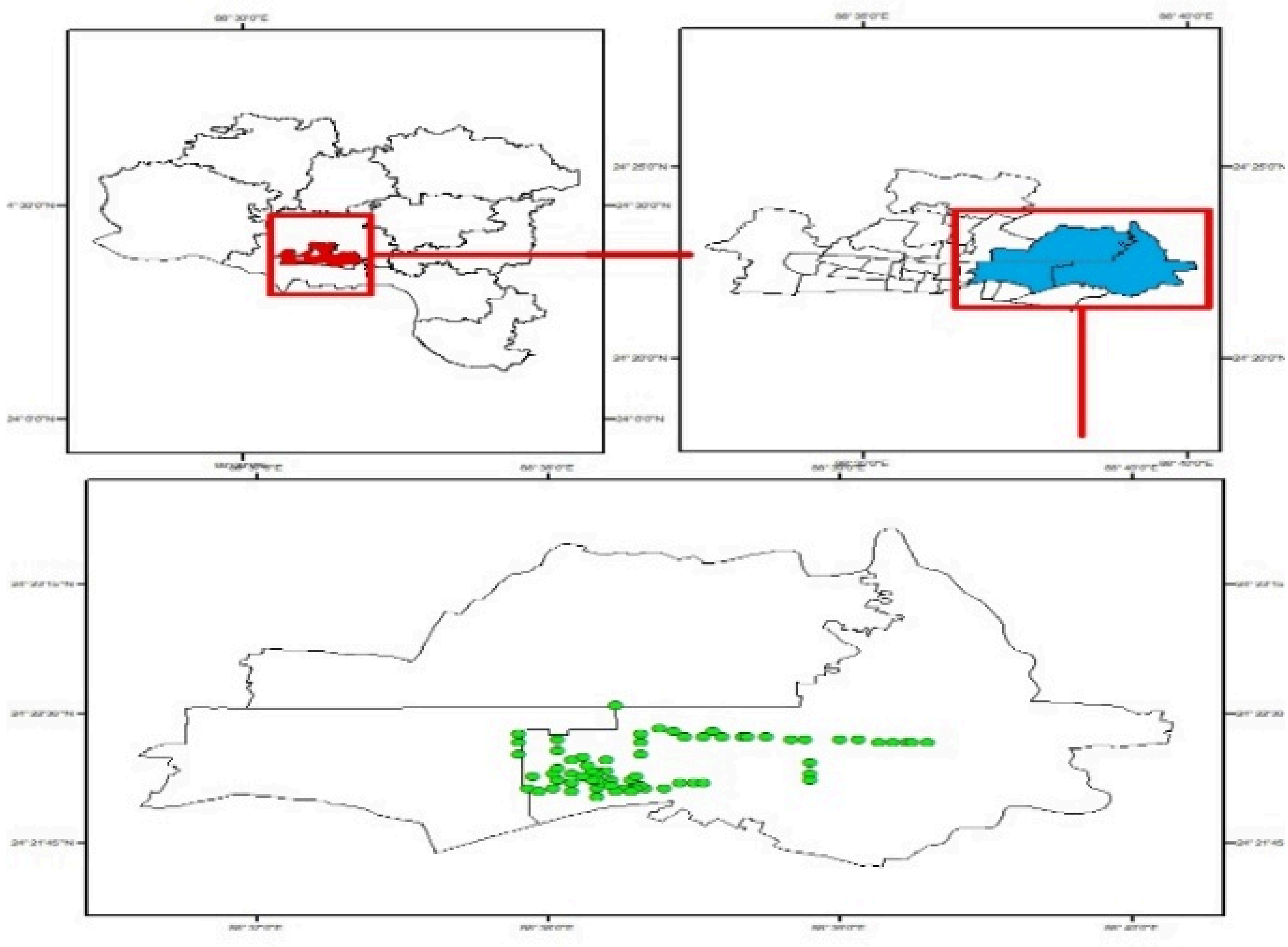

Figure 1

Figure 2.1: Location of the study area

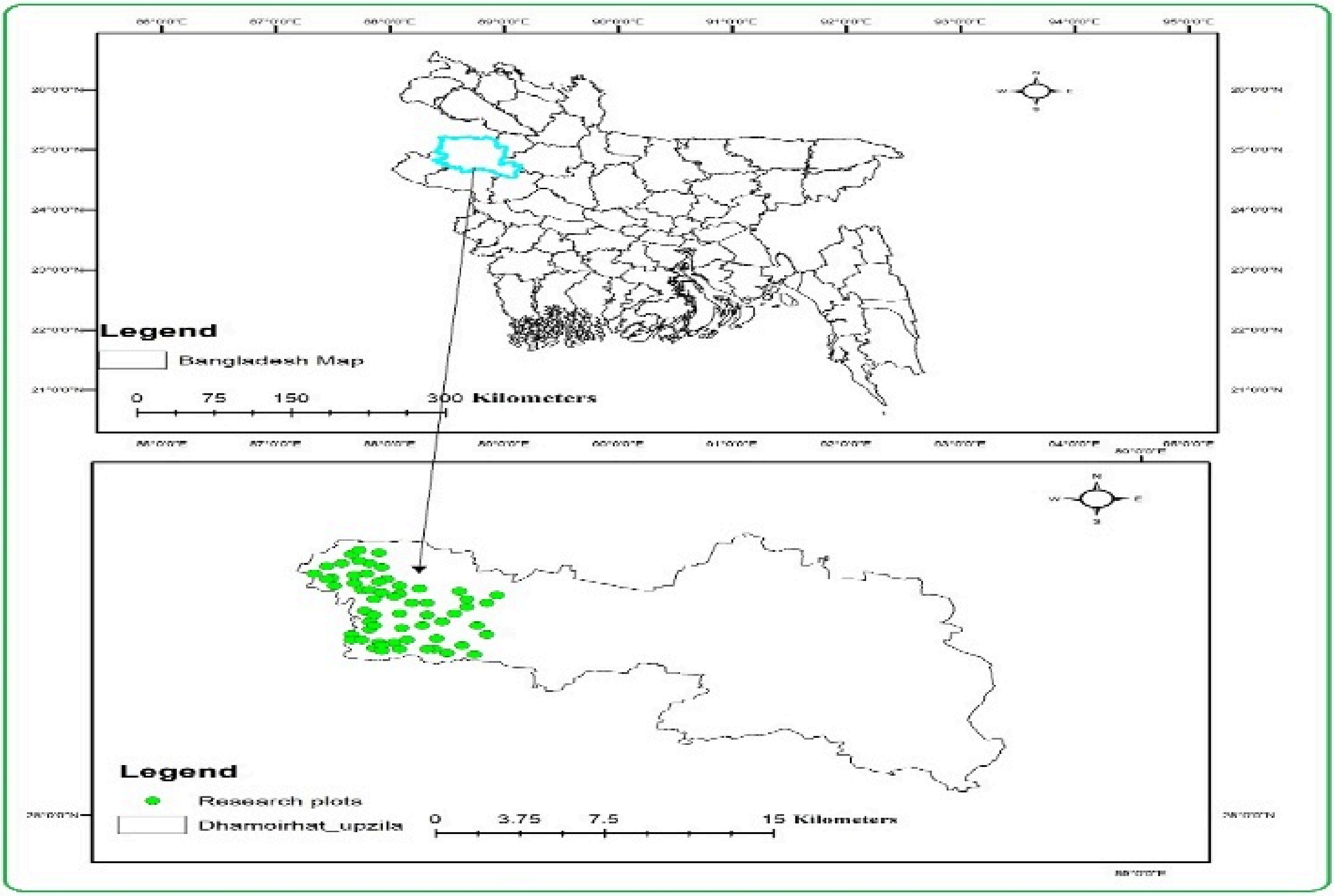

Figure 2

Figure 2.2: Location of the study area