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# CARBON STORAGE POTENTIAL OF DOMINANT MANGROVES IN WESTERN INDIAN SUNDARBANS

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## Abstract

*The Indian Sundarbans are noted for luxuriant mangrove diversity that is known to scrub carbon dioxide from the atmosphere. Precise estimation of the biomass of these species is necessary for evaluating the carbon storage pattern in the mangroves of the lower Gangetic belt. The plant biomass estimation was carried out for an average of 25 trees in 15 (10 m × 10 m) plots from the intertidal mudflats of Chemaguri (southeast portion of Sagar Island) in low tide conditions from 10$^{th}$ to 15$^{th}$ September 2022. The estimated biomass was of the order Sonneratia apetala > Avicennia alba > Avicennia marina > Excoecaria agallocha > Avicennia officinalis. The stem, branch, and leaf biomass of each species were converted into carbon by multiplying with a factor of 0.45 as per the standard procedure. The deviations observed in the results obtained from both studies call for the standardization of the process.*

**Keywords:** Carbon storage, mangroves, Above Ground Biomass (AGB), Below Ground Biomass (BGB).

## I. Introduction

Mangroves are halophytes that grow luxuriantly from brackish water to saline water in the marine and estuarine systems [XI]. This special type of vegetation is known for several ecosystem services of carbon sequestration and is perhaps very relevant in the backdrop of climate change. However, the vegetation is getting lost from the planet due to several natural and manmade activities [II]. The human threats include unplanned industrial development, urban development, and the setting of shrimp farms at the cost of mangroves [XXXVI]. Shrimp farming has caused a major loss of mangroves throughout the world [XIII], [XXXI]. The Indian Sundarbans is noted for their rich mangrove diversity [VI], [XXVII]. It is the home of several wild animals of which the Royal Bengal Tiger is famous. The common species in Indian Sundarbans are *Avicennia marina*, *Avicennia alba*, *Avicennia officinalis*, *Sonneratia apetala*, *Excoecaria agallocha,* etc. [XXVI]. The mangrove forest with 34 varieties of true mangroves is mostly confined to the eastern sector of the Indian Sundarbans [XXXIV]. The benefits received from the mangrove vegetation have placed them in an important position in the policy framework systems [XXV]. It has been documented that mangroves play a crucial role in combating the carbon dioxide rise in the atmosphere [X] and so many companies have focused on offsetting their emission through mangrove plantations [XII]. Several methodologies have been forwarded to estimate the stored carbon in mangroves [XXIX]. Many researchers differ in the drying temperature of mangrove wood before putting it in a CHN analyzer [XXI], [XXII], [V], [XXVIII]. Many researchers have also suggested that carbon constitutes 45% of the total biomass [XXXVIII]. The present paper estimates the carbon in dominant mangroves by both methods.

## II. Materials and Methods

### Study site

The study site is in the southeast portion of Sagar Island ($21^0 39^/ 04.68^{//}$ N to $21^0 52^/ 30.72^{//}$ N latitudes and $88^0 01^/ 47.28^{//}$E to $88^0 07^/ 23.88^{//}$ E meridians), the largest island of Indian Sundarbans, with River Muriganga on the eastern side and River Hugli on the western side, both of which are the arms of Ganga-Bhagirathi system meeting finally the Bay of Bengal on the south. Locally the place is known as Chemaguri ($21^0 39^/ 49.32^{//}$ N; $88^0 09^/ 11.88^{//}$ E) and faces the Muriganga River on the eastern side (Fig. 1). Samplings were carried out during the low tide period from $10^{th}$ to $15^{th}$ September 2022 in the intertidal mudflats of Chemaguri. A plot size of 10 m × 10 m was selected for the study and the average readings were documented from 15 such plots. The mean relative abundance of each species was evaluated for the order of dominance of mangrove species in the intertidal mudflats.

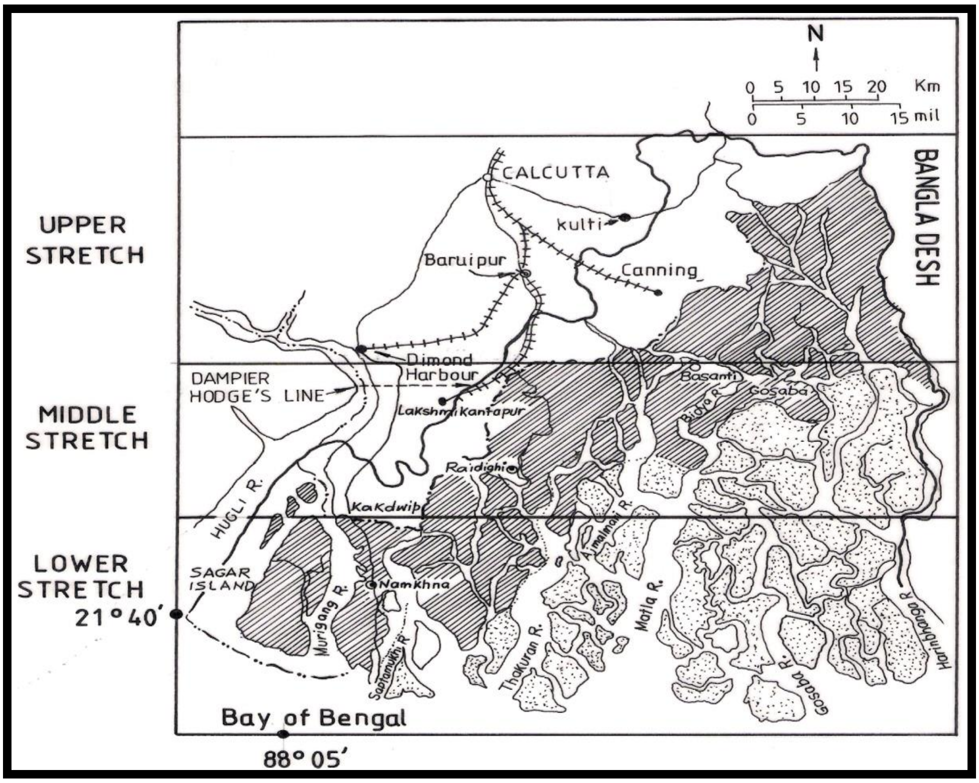


**Fig. 1.** Map showing the location of the sampling station

The above and below ground biomass of individual trees in each plot were estimated as per the standard procedure stated here and the average values of 15 plots were finally converted into biomass of dominant mangrove species per hectare in the study area.

### a) ABOVE GROUND BIOMASS (AGB) ESTIMATION OF TREES

Above Ground Biomass (AGB) in tree species refers to the sum of stem, branch, and leaf biomass that is exposed above the soil.

#### i. STEM BIOMASS ESTIMATION

The stem volume of each species in each plot (10m × 10m) was estimated using Newton's formula [XV].

$$V = h/6\,(A_b + 4A_m + A_t)$$

Where V is the volume (in $m^3$), h is the height measured with a laser beam (BOSCH DLE 70 Professional model), and $A_b$, $A_m$, and $A_t$ are the areas at the base, middle, and top respectively. The specific gravity (G) of the wood was estimated by taking the stem cores by boring 4.5 cm deep and compared with the standard data of FAO [XIV]. This was converted into stem biomass ($B_S$) as per the expression $B_S$ = GV.

The stem biomass of individual trees was finally multiplied by the number of trees of each species in all the selected plots and the mean values are expressed in tonnes per ha (Fig. 2).

**Fig. 2.** DBH measurement at 1.3 m height from the ground for estimation of the biomass of the tree

In this study, aerial images were taken by a drone camera (Phantom-3 Professional, Djibouti) which has four propellers, a camera, a GPS (Global Positioning System) receiver, and a gimbal. Further, it has an exclusive remote controller. The camera used for the experiment can take 1.2M-pixel images and video with 4K (3840 × 2160) images. We used this parallel system to estimate the exact height of the trees in meters, number of branches, and number of leaves in each branch (Fig. 3).

**Fig. 3.** Capture of the aerial image by drone to know the height, number of branches, and leaves of the trees

The stem biomass was computed using PYTHON (an interpreted, interactive, object-oriented programming language) by providing the inputs obtained from the field survey (like the circumference of the tree at breast height, the height of the tree, the wood density of the respective species, etc.) (Flowchart 1).

```
import pandas as pd

for I in range(int(input("How many zones do you have = "))):

  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)
  volume = data['Πr2h (m3)']
  density = data['Density (Kg/m3)']
  form_factor = data['Form Factor (r2/R2)']
  total_trees = data['No. of trees / 100 m2 (n)']
  stem_biomass = volume*density*form_factor*total_trees

  print(stem_biomass)
```

**Flowchart 1.** Computation of stem biomass using PYTHON

### ii. BRANCH BIOMASS ESTIMATION

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized based on basal diameter into three groups, *viz.* < 6 cm, 6–10 cm, and >10 cm. The leaves on the branches were removed by hand. The branches were cut into pieces and oven-dried at $70^0$C overnight in a hot air oven in order to remove moisture content if any present in the branches. The dry weight of two branches from each size group was recorded separately using the standard equation [VII].

$$B_{db} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \Sigma\ n_ibw_i$$

Where $B_{db}$ is the dry branch biomass per tree, $n_i$ is the number of branches in the ith branch group, $b_{wi}$ is the average weight of branches in the ith group and i = 1, 2, 3, …..n are the branch groups. The mean branch biomass of individual trees was finally multiplied by the number of trees of each species in all the plots for each site and expressed in tonnes per ha.

The biomass of all the branches of the trees (species-wise) in the 100 $m^2$ quadrant was computed using PYTHON after physically weighing a few branches for every species and subsequently, the mean values of branch biomass (species-wise) were used as the input as presented in Flowchart 2.

```
import pandas as pd

for i in range(int(input("How many zones do you have = "))):
  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)

  total_trees = data['No. of trees / 100 m2 (n)']
  no_of_branches = data['No. of branches']
  biomass_of_branch = data['Biomass of 1  branch (kg)']
  total_branch_biomass = total_trees*no_of_branches*biomass_of_branch

  print(total_branch_biomass)
```

**Flowchart 2.** Computation of branch biomass using PYTHON

### iii. LEAF BIOMASS ESTIMATION

For leaf biomass estimation, one tree of each species per plot was randomly considered. All leaves from nine branches (three of each size group) of individual trees of each species were removed and oven dried at $70^0$C and dry weight (species-wise) was estimated. The leaf biomass of each tree was then calculated by multiplying the average biomass of the leaves per branch with the number of branches in that tree. Finally, the dry leaf biomass of the selected species (for each plot) was recorded as per the expression:

$$L_{db} = n_1 Lw_1 N_1 + n_2 Lw_2 N_2 + \ldots\ldots\ldots n_i Lw_i N_i$$

Where $L_{db}$ is the dry leaf biomass of selected tree species per plot, $n_{1..}\ldots n_i$ is the number of branches of each tree of the species, $Lw_1$ …….$Lw_i$ is the average dry weight of leaves removed from the branches and $N_{1.........}N_i$ is the number of trees per species in the plots. This exercise was performed for all the sites and the mean results were finally expressed in tonnes per ha.

Again, the total leaf biomass of each tree species was computed by using PYTHON considering the mean leaf biomass per tree as the input (Flowchart 3).

```
import pandas as pd
        ⇩
for i in range(int(input("How many zones do you have = "))):
  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)
        ⇩
  total_trees = data['No. of trees / 100 m2 (n)']
  number_of_branches = data ['No. of branches']
  number_of_leaves = data ['No. of leaves / branch']
  biomass_of_1_leaf = data ['Biomass of 1 leaf (kg)']
 leaf_biomass = total_trees*number_of_branches*number_of_leaves*biomass_of_1_leaf
        ⇩
  print(leaf_biomass)
```

**Flowchart 3.** Computation of leaf biomass using PYTHON

**b) ABOVE GROUND CARBON (AGC) ESTIMATION OF TREES**

Direct estimation of percent carbon in the AGB (referred to as AGC) was done by CHN analyzer, after grinding and random mixing the oven-dried stem, branches, and leaves separately for each species. For this, a portion of a fresh sample of stem, branch, and leaf from trees (of each species) was oven dried separately at $70^0$C, and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves). The carbon content (in %) was finally analyzed for each part of each species through a *Vario MACRO elementar CHN* analyzer (Fig. 4).

The mean carbon values of these vegetative parts (expressed in %) were considered as the stored carbon in the AGB of each species (referred to as AGC).

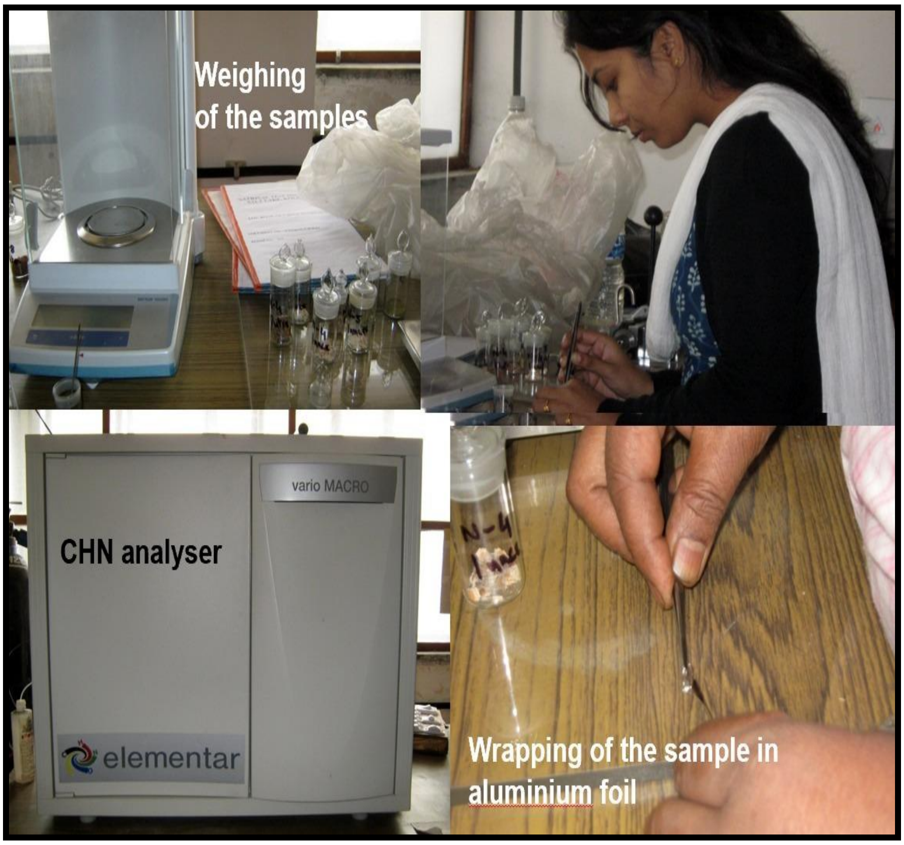


**Fig. 4.** Analysis of carbon percentage in plant samples through CHN analyzer

After analyzing the carbon percentage of stem, branch, and leaf separately for each species using a CHN analyzer, the total carbon content in the vegetative parts of the species was computed by the programming language PYTHON as highlighted in the flowcharts 4, 5, and 6.

```
import pandas as pd

for i in range(int(input("How many zones do you have = "))):
  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)

  volume = data['Πr2h (m3)']
  density = data['Density (Kg/m3)']
  form_factor = data['Form Factor (r2/R2)']
  total_trees = data['No. of trees / 100 m2 (n)']
  c_of_stem = data['% C of Stem']
  stem_biomass = volume*density*form_factor*total_trees
  Total_stem_carbon = stem_biomass*(c_of_stem/100)

  print(Total_stem_carbon)
```

**Flowchart 4.** Computation of species-wise stem carbon using PYTHON

```
import pandas as pd

for i in range(int(input("How many zones do you have = "))):
  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)

  total_trees = data['No. of trees / 100 m2 (n)']
  number_of_branches = data ['No. of branches']
  biomass_of_1_branch = data ['Biomass of 1  branch (kg)']
  c_of_branch = data['%C of Branch']
  total_branch_carbon = total_trees*number_of_branches*biomass_of_1_branch*(c_of_
branch/100)

  print(total_branch_carbon)
```

**Flowchart 5.** Computation of species-wise branch carbon using PYTHON

```
import pandas as pd

for i in range(int(input("How many zones do you have = "))):
  data = pd.read_excel('Tree Datasheet Budge Budge Correct.xls', sheet_name = i)

  total_trees = data['No. of trees / 100 m2 (n)']
  number_of_branches = data ['No. of branches']
  number_of_leaves = data ['No. of leaves / branch']
  biomass_of_1_leaf = data ['Biomass of 1 leaf (kg)']
  c_of_leaf = data ['% C of Leaf']
  total_leaf_carbon = total_trees*number_of_branches*number_of_leaves*biomass_of_1_leaf*( c_of_leaf/100)

  print(total_leaf_carbon)
```

**Flowchart 6.** Computation of species-wise leaf carbon using PYTHON

It is to be noted that two methods were followed to estimate the carbon content of each mangrove species. In the first method (M1), the stem, branch, and leaf biomass for each species was converted into carbon by multiplying with a factor of 0.45 as stated by Woomer [XXXVIII]. The second method (M2) was the direct estimation of percent carbon by a CHN analyzer. For this, a portion of a fresh sample of stem, branch, and leaf from trees of individual species was oven dried at 70$^{0}$C and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves) after random mixing. The carbon content (in %) was finally analyzed on a LECO® CHN-600 analyzer.

## III. Results and Discussion

The biomass and productivity of mangrove forests have been studied mainly in terms of wood production, forest conservation, and ecosystem management [XXXII], [XXXVI], [XVIII], [VIII], [XXIV], [XXX]. The contemporary understanding of the global warming phenomenon, however, has generated interest in the carbon-stocking ability of mangroves. The carbon stocking ability of mangroves in a particular site depends on the relative abundance of the species, the biomass of each species in the plots, and also on the year (age) of the vegetation. Carbon sequestration depends upon biomass production capacity, which in turn depends upon the interaction between edaphic, climate, and topographic factors of an area. Hence, results obtained at one place may not be applicable to another. Therefore the region-based potential of different land types needs to be worked out [XX]. In the present study, the results obtained have been compared with other regions of the world to evaluate the role of Indian Sundarbans mangrove as a carbon sink in the background of changing scenario of the climate.

### Relative abundance

Seven species of true mangroves were documented in the selected plots. The mean order of abundance of these species was *Sonneratia apetala* (33.33%) > *Excoecaria agallocha* (24.24%) > *Avicennia alba* (18.18%) > *Avicennia marina* (12.12%) > *Avicennia officinalis* (6.06%) > *Acanthus ilicifolius* (3.03%) > *Aegiceros corniculatum* (3.03%) (Table 1). Few mangrove associate floral species (like *Porteresia coarctata*, *Suaeda* sp., etc.) were also documented in the plots, but based on the relative abundance of the true mangrove species, only five dominant species namely *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* were considered for carbon stock estimation.

**Table 1: Relative abundance of mangrove species (mean of 15 plots) in the study area**

| Species | No./100m$^2$ |
|---|---|
| *Sonneratia apetala* | 11 |
| *Excoecaria agallocha* | 10 |
| *Avicennia alba* | 6 |
| *Avicennia marina* | 4 |
| *Avicennia officinalis* | 2 |
| *Acanthus ilicifolius* | 1 |
| *Aegiceros corniculatum* | 1 |

### Above-ground stem biomass

The above-ground stem biomass of the dominant mangrove trees were 66.59 tonnes per ha, 13.50 tonnes per ha, 46.41 tonnes per ha, 32.65 tonnes per ha, and 6.63 tonnes per ha for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively (Table 2). These values are comparable to the work of Komiyama *et al* [XIX] in a secondary mangrove (*Ceriops tagal*) forest in Southern Thailand.

**Table 2: Above and below-ground biomass (tonnes per ha) of five dominant mangrove species**

| Mangrove vegetative part | *Sonneratia apetala* | *Excoecaria agallocha* | *Avicennia alba* | *Avicennia marina* | *Avicennia officinalis* |
|---|---|---|---|---|---|
| Stem | 66.59 | 13.50 | 46.41 | 32.65 | 6.63 |
| Branch | 19.97 | 4.45 | 10.67 | 13.38 | 1.39 |
| Leaf | 1.98 | 1.63 | 2.21 | 2.80 | 0.28 |
| Total (AGB) | 88.54 | 19.58 | 59.29 | 48.83 | 8.30 |
| Root (BGB) | 17.71 | 3.92 | 11.86 | 9.77 | 1.66 |

**Above-ground branch biomass**

The above-ground branch biomass of the dominant mangrove trees were 19.97 tonnes per ha, 4.45 tonnes per ha, 10.67 tonnes per ha, 13.38 tonnes per ha, and 1.39 tonnes per ha for *Sonneratia apetala*, *Excoecaria agallocha*, *Avicennia alba*, *Avicennia marina*, and *Avicennia officinalis* respectively (Table 2).

**Above-ground leaf biomass**

The leaf biomass in the study site was 1.98 tonnes per ha for *Sonneratia apetala*, 1.63 tonnes per ha for *Excoecaria agallocha*, 2.21 tonnes per ha for *Avicennia alba*, 2.80 tonnes per ha for *Avicennia marina*, and 0.28 tonnes per ha for *Avicennia officinalis* (Table 2), which are comparatively less to the records of other workers like 12.1 -15.0 tonnes per ha in *Avicennia* forests [IV], 6.2 – 20.2 tonnes per ha in *Rhizophora apiculata* young plantations [I], 13.3 tonnes per ha in *Rhizophora* patch [IX] and 8.1 tonnes per ha in a matured *Rhizophora* forest [XXXVI].

**Below-ground root biomass**

Roots play an important role in the carbon cycle as they transfer considerable amounts of carbon to the ground, where it may be stored for a relatively long period. The plant uses part of the carbon in the roots to increase the total tree biomass through photosynthesis, although carbon is lost through processes like respiration, exudation, and decomposition of the roots. Some roots can extend to great depths, but the greatest proportion of the total root mass is within the first 30 cm of the soil surface [III], [XVI]. Carbon loss or accumulation in the ground is intense in the 0 – 20 cm layer of soil profiles. Hence sampling needs to be concentrated on this section of the soil profile [XXXIII]. However such samplings result in the destruction or death of the tree. Non-destructive (conservation-oriented) methods rely on calculations of below-ground biomass for similar types of vegetation and coefficient as stated in the standard literature. The below-ground biomass in the present study site was 17.71 tonnes per ha for *Sonneratia apetala*, 3.92 tonnes per ha for *Excoecaria agallocha*, 11.86 tonnes per ha for *Avicennia alba*, 9.77 tonnes per ha for *Avicennia marina*, and 1.66 tonnes per ha for *Avicennia officinalis* which are far less to the root biomass of mangrove forests elsewhere studied: 147.3-160.3 tonnes per ha in *Avicennia* forests (IV), and 32.4 tonnes per ha, 106.6 – 173.3 tonnes per ha, 187.0 – 272.9 tonnes per ha respectively for *Sonneratia*, *Bruguiera* and *Rhizophora* primary forests (including prop roots but excluding the fine roots as estimated in this peaty soil [XVII], [XVIII]. However, the present data set is comparable to the data of 17.3 tonnes C per ha in *Rhizophora* forest including prop roots [XXX].

**Comparison of carbon stock**

The results of carbon stock in the selected species are shown in Table 3. Species-wise carbon content is in the order of *Sonneratia apetala* > *Avicennia alba* > *Avicennia* *marina* > *Excoecaria agallocha* > *Avicennia officinalis* (Fig. 2). In case of stems, carbon estimates based on 0.45 factor (M1) was higher by 3.14% in *Sonneratia apetala*, 2.97% in *Avicennia alba*, 3.00% in *Avicennia marina*, 3.02% in *Avicennia officinalis* and 2.80% in *Excoecaria agallocha* than what was obtained by CHN analyzer (M2). In the case of branches of *Sonneratia apetala*, *Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *and Excoecaria agallocha* the results differed by 8.12%, 6.04%, 5.81%, 4.76%, and 3.00% respectively and in case of leaves of *Sonneratia apetala*, *Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *and Excoecaria agallocha* the results differed by 3.37%, 2.02%, 3.97%, 9.09%, and 2.74% respectively. The below-ground biomass of the selected species comprised of the underground root system (except the pneumatophore biomass) and in this case also the results obtained by carbon analyzer were less by 1.76%, 6.55%, 1.82%, 1.33%, and 2.84% in case of *Sonneratia apetala*, *Avicennia alba*, *Avicennia marina*, *Avicennia officinalis*, *and Excoecaria agallocha* respectively from those obtained by factor multiplication. The techniques, therefore, require more standardization to minimize the deviation to reach quality data. Drying time and temperature are the two important variables that require thorough standardization as carbon may be lost depending on temperature and drying time [XXIII].

**Table 3: Above and below-ground carbon stock (tonnes per ha) of five dominant mangrove species**

| **Mangrove vegetative part** | ***Sonneratia apetala*** | | ***Excoecaria agallocha*** | | ***Avicennia alba*** | | ***Avicennia marina*** | | ***Avicennia officinalis*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **M1** | **M2** | **M1** | **M2** | **M1** | **M2** | **M1** | **M2** | **M1** | **M2** |
| Stem | 29.97 | 30.91 | 6.08 | 6.25 | 20.88 | 21.50 | 14.69 | 15.13 | 2.98 | 3.07 |
| Branch | 8.99 | 9.72 | 2.00 | 2.06 | 4.80 | 5.09 | 6.02 | 6.37 | 0.63 | 0.66 |
| Leaf | 0.89 | 0.92 | 0.73 | 0.75 | 0.99 | 1.01 | 1.26 | 1.31 | 0.11 | 0.12 |
| Root (BGB) | 7.97 | 8.11 | 1.76 | 1.81 | 5.34 | 5.69 | 4.40 | 4.48 | 0.75 | 0.76 |

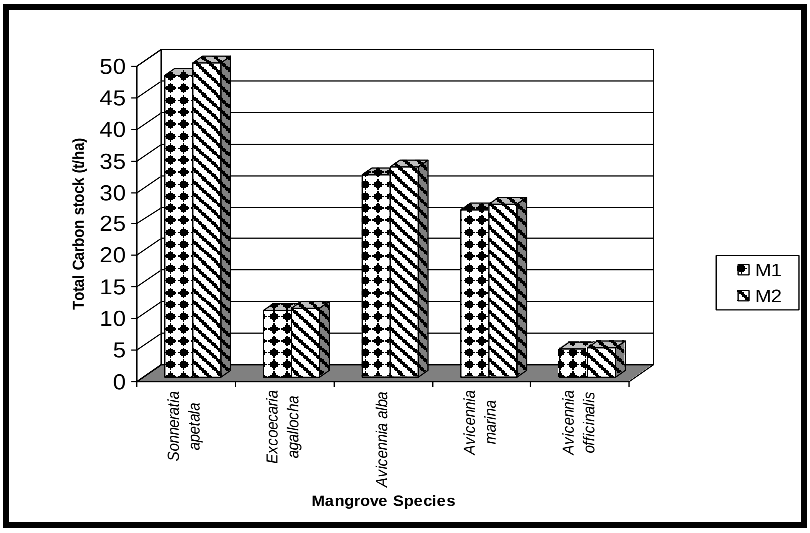


**Fig. 5.** Total carbon stock (tonnes per ha) of five dominant mangrove species

## IV. Conclusion

Mangrove forests are taxonomically diverse and highly productive but globally threatened coastal ecosystems, whose role in the carbon budget of the coastal zone has long been debated. Here a comprehensive synthesis of the available data on carbon stock in a forest patch of western Indian Sundarbans was provided. The study reveals the mangrove plantation programme as the best option to minimize atmospheric carbon. The process can simultaneously harness the opportunity for biodiversity conservation, and economic benefits of the society. It can also reduce the poverty of island dwellers through earning carbon credits under CDM in the long run, provided adequate exercise with high precision is initiated by the Academic Institutes, concerned Government departments, and NGOs with sound technical expertise.

## Conflict of Interest:

There was no conflict of interest regarding this paper.

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