Study on Carbon Sequestration of Akashmoni, Eucalyptus and Sal in The Districts of South Bengal, West Bengal (INDIA)

OFFICE OF THE PRINCIPAL CHIEF CONSERVATOR OF FOREST
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Preface

The present *era* is facing climate induced terrorism in different sectors of life starting from agriculture to fishery, environmental quality to biodiversity and even natural resource base to human health. Preventing degradation, destruction and promoting restoration of forest ecosystems are important approaches that can mitigate climate change. The forests of South Bengal divisions dominated by Akashmoni, Eucalyptus and Sal are potential sink of carbon. When lost or destroyed, they not only shut down the process of sequestering carbon, but also release their deposits of carbon and become new sources of carbon emissions which can last for centuries. Recent scientific syntheses have documented the global total estimated emissions from degraded and converted forest ecosystems each year at between 300 and 900 million tonnes of carbon dioxide. Considering this alarming bell, a research programme entitled "….**STUDY ON CARBON SEQUESTRATION OF AKASHMONI, EUCALYPTUS AND SAL IN THE DISTRICTS OF SOUTH BENGAL, WEST BENGAL (INDIA)**…." was initiated by the Office of the PCCF (Research, Monitoring and Development) on and from 25th November, 2021. The focal theme of the project is to evaluate the carbon sequestration potential of the forest habitats under South Bengal Forest Divisions in the state of West Bengal. It has two important components *viz.* (1) Knowledge base development on the air quality using carbon dioxide gas as indicator in and around the South Bengal Forest Divisions (2) species-wise potential of carbon sequestration. The present report is an approach to cover the second component in details as it has documented the carbon storage potential of Akashmoni, Eucalyptus and Sal, which if destroyed or degraded may accelerate the pace of climate change.

The Office of the PCCF (Research, Monitoring and Development) acknowledges the sincere efforts given by Dr. Abhijit Mitra, Director, Research (Hony), Techno India University, West Bengal and his team members along with all the officers and staffs of the West Bengal Forest Department for their contributions in completing the project.

Vinod Kumar Yadav

(PCCF; Research, Monitoring and Development,
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Abbreviation

AGB	Above Ground Biomass
AGC	Above Ground Carbon
ARD	Afforestation, Reforestation and Deforestation
BGB	Below Ground Biomass
CFC	Chlorofluorocarbons
COP	Conference of the Parties
GPS	Global Positioning System
GWP	Global Warming Potential
HFCs	Hydrofluorocarbons
KP	Kyoto Protocol
NBP	Net Biome Productivity
NEP	Net Ecosystem Productivity
NPP	Net Primary Productivity
PFCs	Perfluorocarbons
SF6	Sulphur hexafluoride
SOC	Soil Organic Carbon
TER	Total Ecosystem Respiration
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WMO	World Meteorological Organization

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A. Executive Summary

1) It is since the past few decades, anthropogenic emissions of carbon dioxide (primarily as a result of rapid pace of urbanization, intense industrialization, fossil fuel burning and change of land use pattern) increased at a rate of 3.4% per year. The level of carbon dioxide concentration in the atmosphere at the advent of industrial revolution in the 19th century rose from 280 ppmv to the present level of 388 ppmv and is estimated to hit 525 ppmv by 2100 (IGBP, 2009). The carbon dioxide concentration in the Indian sub-continent is gradually increasing over a period of time. A study conducted by the Indian researchers suggests that atmospheric carbon dioxide concentration has increased linearly from 372 ppm in 2002 to 386 ppm in 2008, which is at the rate of 2.33 ppm/year. The most recent data on atmospheric carbon dioxide level states that it has touched 420.83 ppm as on 13th February, 2022 (https://www.co2.earth/daily-co2).

2) The rising Green House Gases (GHGs) emissions and the associated adverse impacts on the ecosystem has lead to increased interest in identifying floral species with high carbon sequestration potential. The present study has attempted to focus on the accurate estimations of stored carbon in three dominant species of South Bengal districts in the martime state of West Bengal namely Akashmoni (*Acacia auriculiformis*), Eucalyptus (*Eucalyptus globulus*) and Sal (*Shorea robusta*).

3) Floral communities of the planet Earth (which are popularly called producers of the ecosystem) absorb carbon dioxide from the ambient environment/atmosphere during the process of photosynthesis and store it as biomass. Carbon is stored in five pools, namely above-ground biomass (AGB), below-ground biomass (BGB), leaf litter, dead wood and soil carbon stock in forest ecosystems (Fig. A). Below-ground biomass is an important carbon pool for many vegetation types and land-use systems and accounts for about 20% to 26% of the total biomass. Below-ground biomass accumulation is closely linked to the dynamics of above-ground biomass. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface. Revegetation of degraded land leads to continual accumulation of below-ground biomass whereas any disturbance to topsoil leads to loss of below-ground biomass.

In this project we have estimated species-wise AGB, AGC, BGB (using empirical formula), sequestered carbon (based on AGC and age of the species), CO_2 – equivalent, soil organic carbon (SOC), soil pH and CO_2 level in the ambient air.

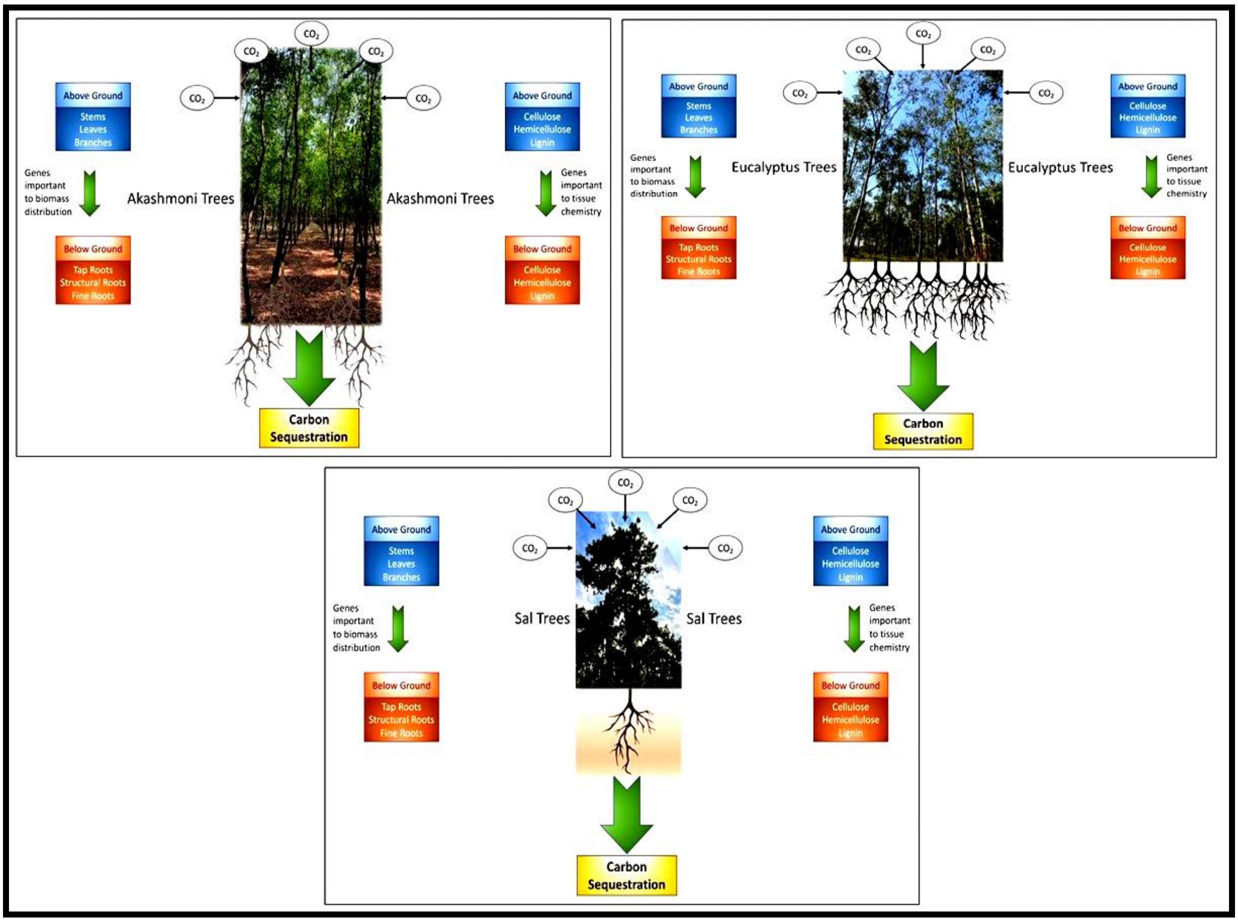

Fig. A. Selected tree species serving as carbon pool in the South Bengal Forest Divisions, West Bengal

4) Forests act as both sink and source of carbon dioxide when they are conserved and destroyed respectively. The destruction is associated with deforestation, but eco-restoration through plantation (considering the species with high carbon sequestration potential) again makes the system a unique sink of GHGs preferably CO_2. Moreover a systematic, continuous and well planned scientific management can reduce the emission of GHGs at the local level. The recycling of fallen and decomposed twigs, branches and leaves into bioferitilizer (as stated in the recommendation section) is an approach toward this direction.

5) The present programme was undertaken preferably in the CFC locations for 2021-22 in the Bankura North Division, Durgapur Division, Burdwan Division, Birbhum Division and Jhargram Division. 90 plots were covered from these 5 divisions (30 for each species to provide statistical accuracy) as highlighted in Table A.

Table A Plots covered for the three selected tree species in five divisions of South Bengal

Plantation	Division	Site Name	Area (ha)	No. of study plots
Akashmoni	Durgapur	Mouza Bishnupur, Rakhitpur, Durgapur	5	3
		Paranganj Mouza	5	1
		Chotkar Mouza, Gourandi Beat (Felling site)		2
		Aliganj Mouza, Gourandi Beat	30	5
	Burdwan	Balarampur Mouza, Khandari, Panagarh	10	2
		Alefnagar, Guskara	20	3
		Jadavganj Mouza, Jadavganj, Kumarganj		3
	Jhargram	Kharsuli, Chandri II Beat, Lodhasuli Range	20	2
		Muroikhuti, Chandri II Beat, Lodhasuli Range	15	1
	Birbhum	Birupur, Rashpur Beat, Md. Bazar Range	10	1
		Kariya-Nimdaspur, Rashpur Beat, Md. Bazar Range	10	2
		Chandpur Mouza, Tumbani Beat, Rampurhat Range	8	1
		Vatina, Tumbani Beat, Rampurhat Range	10	1
		Darikanathpur Mouza, Bolpur Range	7	1
	Bankura North	Searbaid Mouza, Murlu Beat, Saltora Range	6.5	2
Total				**30**
Eucalyptus	Durgapur	Gopalpur Mouza, Vill. Bandra, Durgapur	7	2
		Jemua Mouza, Fuljhora	16	6
	Burdwan	Khandari Mouza, Khandari		2
	Jhargram	Tulibar Bamundiha, Godrasol Beat, Gidhni Range	10	3
		Telamuri, Godrasol Beat, Gidhni Range	15	6
	Birbhum	Chandpur Mouza, Tumbani Beat, Rampurhat Range	8	2
		Vatina, Tumbani Beat, Rampurhat Range	10	5
	Bankura North	Samantamara Mouza, Beliatore Beat, Beliatore range	10	4
Total				**30**
Sal	Durgapur	Mouza Bishnupur, Rakhitpur, Durgapur		3
		Kataberia Mouza, Kataberia (Felling site)	20	6
	Burdwan	Balarampur Mouza, Khandari, Panagarh	10	3
		Jadavganj Mouza, Jadavganj, Kumarganj		5

	Jhargram	Gamaria, Pukuria beat, Jhargram Range	10	3
		Golbandhi, Balivasa Beat, Manikpara Range	10	3
	Birbhum	Moubelia, Rashpur Beat, Md. Bazar	5	2
	Bankura North	Baramesia Mouza, Belboni Beat, Bankura North Range	10	5
Total				**30**

6) The soil is a potential reservoir of carbon and plays a major role in the carbon dynamics of the ecosystem. The litter and detritus contributed by the forest vegetation add organic carbon to the soil, while decomposers present in the soil compartment return the carbon to the atmosphere in the form of carbon dioxide. In the present study, the average soil organic carbon in **Akashmoni forest habitat** varied as per the order Jhargram (1.56 %) > Bankura North (1.43 %) > Birbhum (1.40 %) > Burdwan (1.39 %) > Durgapur (1.14 %); the average soil organic carbon in **Eucalyptus clone habitat** varied as per the order Jhargram (1.23 %) > Bankura North (1.18 %) > Birbhum (1.15 %) > Burdwan (1.10 %) > Durgapur (1.06 %) and the average soil organic carbon in **Sal forest habitat** varied as per the order Jhargram (1.87 %) > Bankura North (1.72 %) > Birbhum (1.69 %) > Burdwan (1.54 %) > Durgapur (1.28 %).

7) The soil pH is one of the most important variables affecting the health of the forest. Its value is around 6.70 in all the study sites, which indicates a congenial soil condition in the plantation sites. However, at the nursery adjacent to Arrah Forest Rest House (in Durgapur division), the soil pH was around 5.82, where sprinkling of 2% lime at fortnightly interval is suggested for 6 months during the period of nursery raising, preferably in the premonsoon season.

8) In **Bankura North Division**, the **AGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 191.245 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **AGB in Eucalyptus** was 654.024 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 611.430 tha^{-1}.

9) In **Bankura North Division**, the **AGC of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 84.189 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of

AGC in Eucalyptus was 300.940 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 285.291 tha^{-1}.

10) In **Bankura North Division**, the **BGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 49.724 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **BGB in Eucalyptus** was 170.046 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 158.972 tha^{-1}. The carbon stored in the root could not be estimated through direct field based survey as there was no provision for uprooting. We estimated the BGB of the selected species on the basis of AGB values as per the standard method (*https://www.climate-policy-watcher.org/carbon-stocks/grass-biomass-production-above-the-ground.html*).

11) In **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 7.016 tha^{-1}y^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value in **Eucalyptus** was 25.078 tha^{-1}y^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 19.019 tha^{-1}y^{-1}.

12) In **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 308.975 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **CO_2-equivalent in Eucalyptus** was 1104.450 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 1047.019 tha^{-1}.

13) In **Durgapur Division**, the **AGB of Akashmoni** ranged from 38.611 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 64.957 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the AGB ranged from 134.816 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 156.103 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the AGB ranged from 99.857 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site); 23°33′18.0″N; 87°21′09.6″E) to 131.365 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is interesting to note that in the Durgapur Division the **AGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 70.558 tha^{-1}. The significant low value in natural Sal is attributed to low population density of the species, which is only 2/100m^2.

14) In **Durgapur Division**, the **AGC of Akashmoni** ranged from 17.583 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 29.964 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **AGC** ranged from 59.721 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 68.212 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **AGC** ranged from 45.932 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 59.591 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is observed that in the Durgapur Division the **AGC of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 32.995 tha^{-1}. The significant low value in natural Sal is attributed to low population density of the species, which is only 2/100m^2.

15) In **Durgapur Division**, the **BGB** of **Akashmoni** ranged from 10.039 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 16.889 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **BGB** ranged from 35.052 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 40.587 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **BGB** ranged from 25.963 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 34.155 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

In the Durgapur Division the **BGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 18.345 tha^{-1}. The significant low value of BGB in natural Sal is attributed to low population density of the species, which is only 2/100m^2.

16) In **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 1.764 $tha^{-1}y^{-1}$ (at Paranganj Mouza; 23°33′18.0″N; 87°21′09.6″E) to 6.182 $tha^{-1}y^{-1}$ (at Aliganj Mouza, Gourandi Beat; 23°49′51.5″N; 86°59′52.4″E).

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** ranged from 4.263 $tha^{-1}y^{-1}$ (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E) to 14.930 $tha^{-1}y^{-1}$ (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E).

In case of **Sal**, the **carbon sequestered in AGB** ranged from 9.186 $tha^{-1}y^{-1}$ (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 14.898 $tha^{-1}y^{-1}$ (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It has also been observed that in the Durgapur Division, **the carbon sequestered in the AGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) is 1.138 $tha^{-1}y^{-1}$ and this low value is attributed to low population density of the species in the depot as stated earlier.

The variation in the magnitude of sequestered carbon in the above ground biomass is thus attributed to the AGB, age of the trees under each species and population density, although edaphic factors have a regulatory influence on carbon percentage of the species.

17) In **Durgapur Division**, the **CO_2-equivalent of Akashmoni** ranged from 64.530 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 109.969 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** ranged from 219.176 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 250.340 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **CO_2-equivalent** ranged from 168.569 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 218.698 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is again observed that in the Durgapur Division the **CO_2-equivalent of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was considerably low ~121.093 tha^{-1} due to low population density of the species at this particular site.

18) In **Burdwan Division**, the **AGB of Akashmoni** ranged from 47.253 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 56.079 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **AGB** was 155.700 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **AGB** ranged from 139.109 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 161.027 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

19) In **Burdwan Division**, the **AGC of Akashmoni** ranged from 21.563 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 25.612 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **AGC** was 64.124 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **AGC** ranged from 63.778 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 74.065 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

20) In **Burdwan Division**, the **BGB of Akashmoni** ranged from 12.286 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 14.581 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **BGB** was 40.482 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **BGB** ranged from 36.168 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 41.867 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

21) In Burdwan Division, the **sequestered carbon in AGB of Akashmoni** ranged from 3.856 $tha^{-1}y^{-1}$ (at Jadavgang Mouza, Kumargang; 23°28′23.4″N; 87°39′46.5″E) to 6.403 $tha^{-1}y^{-1}$ (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** was 16.031 $tha^{-1}y^{-1}$ (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **carbon sequestered in AGB** ranged from 12.344 $tha^{-1}y^{-1}$ (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation) to 15.945 $tha^{-1}y^{-1}$ (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E).

22) In **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 79.137 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 93.997 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** was 235.334 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **CO_2-equivalent** ranged from 234.067 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 271.817 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

23) In **Birbhum Division**, the **AGB of Akashmoni** ranged from 57.578 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 240.196 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **AGB** ranged from 543.224 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 705.900 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **AGB** was 395.359 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

24) In **Birbhum Division**, the **AGC of Akashmoni** ranged from 25.408 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 108.993 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **AGC** ranged from 248.625 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 325.016 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **AGC** was 184.106 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

25) In **Birbhum Division**, the **BGB of Akashmoni** ranged from 14.970 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 62.451 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **BGB** ranged from 141.238 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 183.534 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **BGB** was 102.793 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

26) In **Birbhum Division**, the **sequestered carbon in AGB** of Akashmoni ranged from 1.694 $tha^{-1}y^{-1}$ (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 9.083 (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E) $tha^{-1}y^{-1}$.

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** ranged from 16.251 $tha^{-1}y^{-1}$ (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E) to

16.575 $tha^{-1}y^{-1}$ (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E).

In case of **Sal**, the **carbon sequestered in AGB** was 15.342 $tha^{-1}y^{-1}$ (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

27) In **Birbhum Division**, **the CO_2-equivalent of Akashmoni** ranged from 93.249 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 400.003 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** ranged from 912.452 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 1192.809 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **CO_2-equivalent** was 675.668 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

28) In **Jhargram Division**, the **AGB of Akashmoni** ranged from 202.590 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 339.502 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **AGB** ranged from 737.567 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 766.207 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **AGB** ranged from 512.209 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 801.365 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

29) In **Jhargram Division**, the **AGC of Akashmoni** ranged from 93.127 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 157.072 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **AGC** ranged from 339.402 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 353.701 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **AGC** ranged from 238.011 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 374.902 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

30) In **Jhargram Division**, the **BGB** of **Akashmoni** ranged from 52.673 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 88.271 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **BGB** ranged from 191.767 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 199.214 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **BGB** ranged from 133.174 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 208.355 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

31) In **Jhargram Division**, the **sequestered carbon in AGB** of Akashmoni ranged from 7.761 $tha^{-1}y^{-1}$ (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 10.471 $tha^{-1}y^{-1}$ (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **carbon sequestered in AGB** ranged from 28.284 $tha^{-1}y^{-1}$ (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 29.475 $tha^{-1}y^{-1}$ (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the carbon sequestered in AGB ranged from 15.867 $tha^{-1}y^{-1}$ (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 24.993 $tha^{-1}y^{-1}$ (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

32) In **Jhargram Division**, **the CO_2-equivalent of Akashmoni** ranged from 341.778 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 576.456 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **CO_2-equivalent** ranged from 1245.606 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 1298.082 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **CO_2-equivalent ranged** from 873.500 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 1375.889 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

33) The data generated from 90 plots (30 plots of each species) of South Bengal Forest Divisions in the state of West Bengal were analysed to evaluate the inter-relationships between sequestered carbon of each species, Soil Organic Carbon (SOC), soil pH and near surface atmospheric CO_2 level.

34) For all the species, **significant positive correlations were observed between sequestered carbon and the underlying SOC indicating considerable contribution of carbon of the trees to the soil compartment through litter and detritus**. The **significant negative relationships between sequestered carbon by the selected tree species and near surface atmospheric carbon dioxide confirm the potential of the trees as unique sink of carbon**. The sequestered carbon is taken from the CO_2 reservoir of the ambient atmosphere due which the negative correlations have been generated as the output.

35) A significant negative relationship between the sequestered carbon and soil pH irrespective of all the three species reflects the possibility of a feedback effect where lime treatment is needed seasonally to maintain an optimum soil pH value.

B. Technical Contents

- ♣ **INTRODUCTION**
- ♣ **OBJECTIVES**
- ♣ **METHODOLOGY**
- ♣ **RESULTS**
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- ♣ **CONCLUSION & RECOMMENDATION**
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INTRODUCTION

INTRODUCTION

The recent trends of industrialization, urbanization, expansion of tourism, mining activities, at the cost of forest patches have altered the level of carbon dioxide (CO_2) in the atmosphere. Destruction of vegetation due to several anthropogenic and industrial activities has squeezed the sink of carbon dioxide in the present age, due to which the level of atmospheric carbon dioxide has hiked up.

Intensified human activities, mainly fossil fuel burning and deforestation have increased carbon dioxide emissions since the dawn of the industrial revolution, about two centuries ago. This resulted in a steadily rising atmospheric CO_2 concentration (NASA, 2006). As depicted in Fig. 1a, atmospheric CO_2 concentrations increased from 285 ppm in 1850 to 310 ppm in 1950. A further increase to 378 ppm CO_2 in 2004 was observed at the measuring station at Mauna Loa (Fig. 1b). As such, atmospheric CO_2 concentrations are higher today than they have been over the last half million years or longer (NASA, 2006). Moreover, the rate of change in atmospheric CO_2 concentration, which was 1.3 ppm $year^{-1}$ during the last 46 years on average, and 1.8 ppm $year^{-1}$ in the period 1994 to 2004, is higher than has been observed ever before (Bolin and Sukumar, 2000).

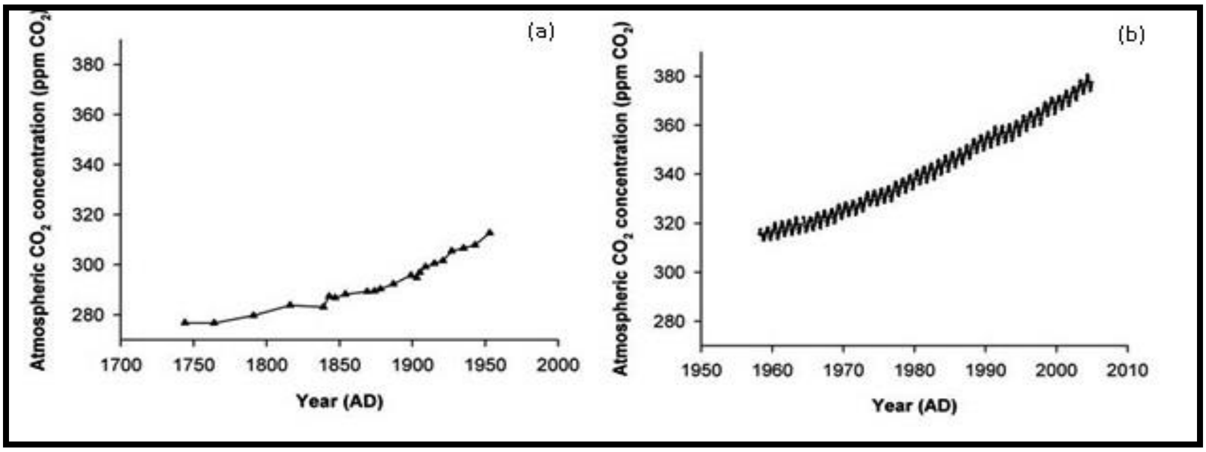


Fig. 1. Atmospheric carbon dioxide concentrations obtained from a) measurements on air occluded in Antarctic ice cores, taken at Siple Station and b) measurements on air samples taken at the measuring station at Mauna Loa, Hawaii (graphs based on data from CDIAC (2006)). The oscillations in atmospheric CO_2 concentrations depicted in b) are the result of the change in photosynthetic capacity of major terrestrial ecosystems over the year

The increasing amount of CO_2 in the atmosphere disturbs the natural greenhouse effect, of which a simplified scheme is given in Fig. 2. Most incoming (short-wave) solar radiation is absorbed by the earth's surface, and some is reflected back to space. On average, for the earth as a whole, incoming solar radiation is balanced by outgoing terrestrial radiation. Some of the (long-wave) infrared (IR) radiation emitted by the earth's surface passes relatively unimpeded through the atmosphere. The bulk of the IR radiation, however, is intercepted and absorbed by the atmosphere which in turn emits radiation both up - and downwards. The atmosphere consists mostly of nitrogen and oxygen (78% and 21 % of dry air respectively), which are transparent to IR radiation. Other gases as water vapour, carbon dioxide and methane are present in much smaller quantities in the atmosphere, but they absorb and re-emit a large part of the thermal radiation leaving the earth's surface, and are therefore called greenhouse gases (GHGs) (Bengtsson, 1994; Trenberth *et al.,* 1995). Because of the heat-trapping characteristics of these gases, the lower part of the atmosphere and the earth's surface are warmed, and the average global surface air temperature, excluding Antarctica, is about 16 °C. Without this natural greenhouse effect, the mean surface air temperature would have been about -18 °C, and life on earth would have been impossible (Bengtsson, 1994; AAS, 2006).

The increasing release of greenhouse gases to the atmosphere by human activities results in an enhanced greenhouse effect, due to the increased heat-trapping capacity of the atmosphere (EPA, 2006a). Consequently, global mean surface temperature is rising (Kasting, 1998), and climates are changing. Measurements have shown that mean global surface temperature has increased by about 0.3 °C to 0.6 °C since the late 19th century, and by about 0.2 °C to 0.3 °C over the period from 1954 to 1994 (Houghton *et al.*, 1995).

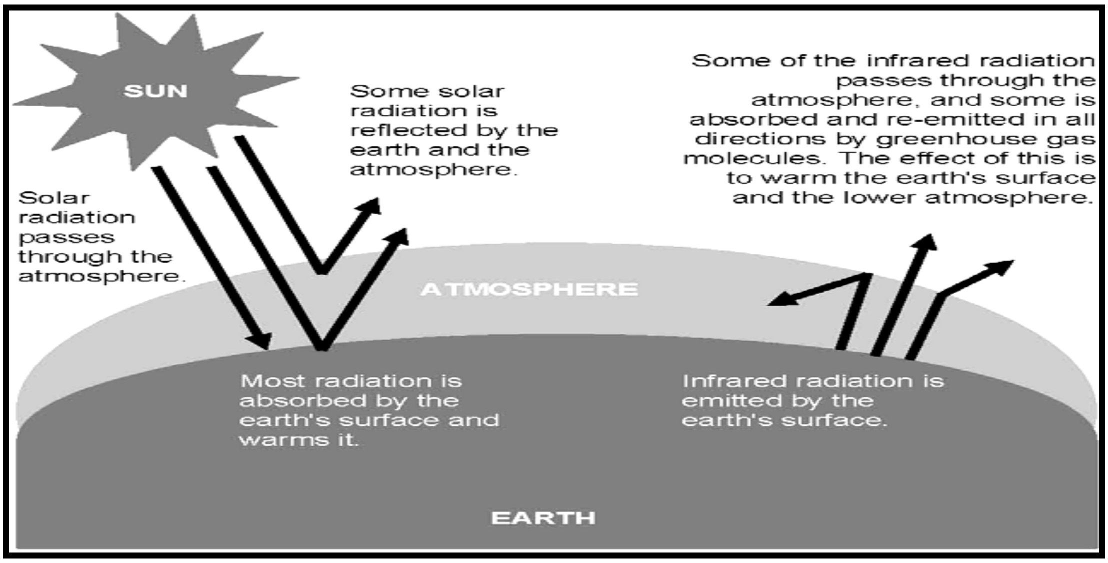


Fig. 2. Simplified overview of the greenhouse effect (after EPA, 2006a)

The effects of global warming are widespread and are expected to be disastrous (Grace, 2004). Global warming could result in more frequent and more extreme weather events, such as droughts and floods. Evaporation will increase as climate warms, which will increase average global precipitation. Even relatively small rises in sea level, resulting from expansion of the oceans and retreating glaciers and ice- caps (Bengtsson, 1994), will make densely settled coastal plains uninhabitable while an increased risk of certain diseases and pests can be expected due to shifting climatic zones (Houghton *et al.*, 1995). Agricultural regions and natural ecosystems are also susceptible to climate changes that could result in increased insect populations and plant diseases. Degradation of natural ecosystems could lead to reduced biological diversity. Desertification will threaten some areas, while other regions could become colder because of direction changes in ocean currents (AAS, 2006).

Besides CO_2, other greenhouse gases like methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) are being emitted by human activities (Kasting, 1998). The greenhouse potential of different gases is expressed as the Global Warming Potential (GWP) of the gas. Conventionally, GWP of CO_2 equals 1. GWP for methane is 21, while nitrous oxide has a GWP of 310 on a 100 years' time horizon (Schimel *et al.*, 1995, EPA, 2006b). This means that methane and nitrous oxide have much stronger warming capacities than carbon dioxide. However, because of the enormous amounts of CO_2 being emitted to the atmosphere, this gas is the largest individual contributor to the enhanced greenhouse effect, accounting for about 64 % of the increase in heat trapping globally (Schimel *et al.*, 1995).

Carbon dioxide is cycling naturally between the atmosphere, oceans and terrestrial biosphere, as illustrated in Fig. 3. During photosynthesis, plants utilize solar energy to combine CO_2 from the atmosphere with water to form organic matter and to release oxygen to the air. This photosynthesis is balanced, on average, by plant and animal respiration, and by decomposition of dead organic material. In a similar way, CO_2 is rapidly exchanged between the atmosphere and the surface ocean, and between the surface - ocean and marine biota.

Until the early 19th century, carbon (C) fluxes to and from the atmosphere were approximately balanced (Kasting, 1998). The dark chapter started few decades back when intense industrialization, massive urbanization, unplanned tourism, change of land use of pattern and deforestation were initiated at mass scale to provide food, shelter and employment to population that exploded exponentially.

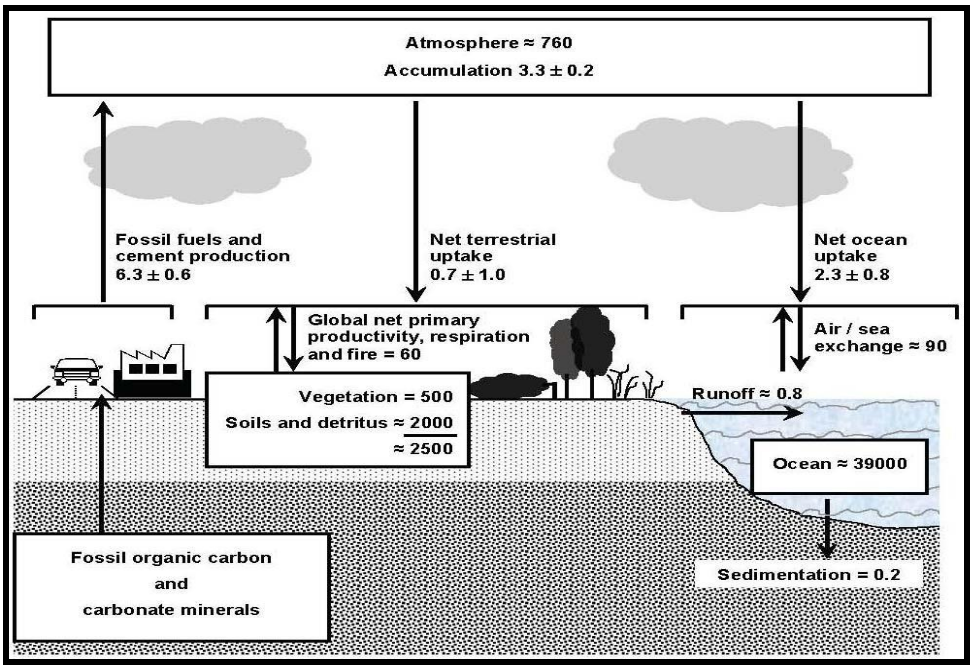


Fig. 3. The global carbon cycle, showing the carbon stocks in pools (boxes, in Gt C = 10^{15} g C) and carbon fluxes (arrows, in Gt C year^{-1}) relevant to the anthropogenic perturbation as annual averages over the decade from 1989 to 1998. The emission of carbon due to land-use changes is not depicted, but is assessed at 1.6 ± 0.8 Gt C year^{-1} for this period (after Bolin and Sukumar, 2000)

The major (natural) fluxes in the global carbon cycle are more than ten times as large as the man-made injection of CO_2 to the atmosphere. However, human activities, mainly fossil fuel burning and deforestation, strongly disturbed the dynamic equilibrium between the natural carbon fluxes during the last two centuries (Goudriaan, 1987; Schulze *et al.*, 2002). About half of the amount of CO_2 emitted by human activities accumulates in the atmosphere, while one third is taken up by the ocean. The remaining part is often referred to as the ‘missing carbon sink’ (Scholes *et al.*, 1999). This part of the global carbon budget is the least understood, but it is evident that this amount of carbon is being removed from the atmosphere by increased carbon storage in the terrestrial biosphere (Kasting, 1998). Several scenarios could cause the land to take up more carbon dioxide than is released each year. Regrowth of forests since the massive deforestation in the northern hemisphere over the last century could account for the missing carbon, while changing climate could also contribute by stimulating plant growth (Taylor and Lloyd, 1992, Schimel *et al.*, 1995, Bolin and Sukumar, 2000). In order to predict how atmospheric CO_2 levels and climate may change in the future, it is critically important to understand the processes controlling the sources and sinks of carbon (Taylor and Lloyd, 1992, Kasting, 1998, NASA, 2006).

Importance of forests in the global carbon cycle

Terrestrial ecosystems can influence the climate system through exchanges of carbon dioxide, influencing as such atmospheric CO_2 concentrations. As can be seen in Table 1, the total amount of carbon stored in vegetation of terrestrial ecosystems is assessed at 466 Gt C. On a global scale, soil carbon stocks largely exceed carbon stocks in vegetation, and amount to 2011 Gt C. The ratio soil-to-vegetation C stock ranges from about 1 in tropical forests to 5 in boreal forests, and much larger factors in grasslands and wetlands. Changes in soil carbon stocks are therefore important for carbon budgets as changes in vegetation carbon stocks (Bolin and Sukumar, 2000). On this background, the present study has given due weightage to the soil organic carbon status in all the assigned divisions of South Bengal.

Forest ecosystems contain more than three fourths of the carbon stored in terrestrial vegetation, as carbon is stored in stems and branches, foliage and roots of trees (Bolin and Sukumar, 2000). Moreover, while only 28 % of the total area is covered with forests, forest soils contain 39 % of all carbon stored in soils (Table 1). Conversion of forests to agricultural land releases carbon, mostly from trees, to the atmosphere through burning and decay. Depending on the agricultural practices applied, there may be an accompanying decline in the quantity of carbon stored in the soil (Scholes *et al.*, 1999, Schlesinger and Andrews, 2000). Conversely, re-growth of forests on abandoned lands withdraws carbon from the atmosphere and stores it again in trees and soils. Because of the high carbon storage capacity of forests, and the long residence time of carbon in forests, more and more attention has been dedicated in recent years to the mitigating role that forest ecosystems can play in reducing the build-up of CO_2 in the atmosphere (Winjum and Schroeder, 1997).

Table 1: Global carbon stocks in vegetation and top 1 m of soils of terrestrial ecosystems (Bolin and Sukumar, 2000)

Biome	**Area (10^6 km^2)**	**Carbon Stocks (Gt C)**		
		Vegetation	**Soils**	**Total**
Tropical forests	17.6	212	216	428
Temperate forests	10.4	59	100	159
Boreal forests	13.7	88	471	559
Tropical savannas	22.5	66	264	330
Temperate grasslands	12.5	9	295	304
Deserts and semideserts	45.5	8	191	199
Tundra	9.5	6	121	127
Wetlands	3.5	15	225	240
Croplands	16.0	3	128	131
Total	151.2	466	2011	2477

Cycling of carbon in a forest ecosystem

The uptake of carbon from the atmosphere by plants is called gross primary productivity (GPP). Plant respiration releases CO_2 back to the atmosphere, and reduces GPP to net primary productivity (NPP) (Fig. 4). In an ecosystem, further CO_2 losses occur because of decomposition of dead organic matter. NPP minus heterotrophic respiration results in net ecosystem productivity (NEP). A positive NEP indicates that the ecosystem has accumulated carbon during the considered time period, while a negative NEP denotes a loss of carbon from the ecosystem to the atmosphere. On a time scale of years, most forests accumulate carbon through tree growth and an increase in soil carbon, until the next disturbance occurs (Bolin and Sukumar, 2000). On the longer term (decades to centuries), and at a regional level (including a range of ecosystems, called a biome), additional C losses are caused by disturbances such as fire, wind-throw, drought, pests and human activities (e.g., wood harvest). The resulting net imbalance can be interpreted as the net biome productivity (NBP) (Mooney *et al.*, 1999; Bolin and Sukumar, 2000; Grace, 2004).

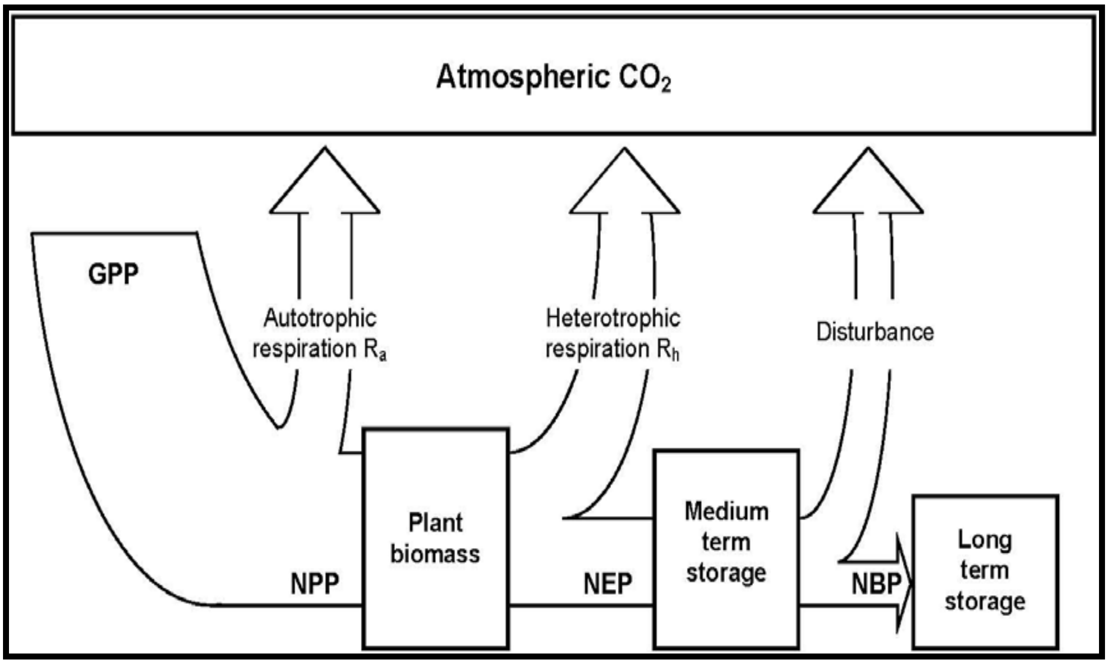


Fig. 4. Terms used to define various components of ecosystem productivity; GPP: gross primary productivity, NPP: net primary productivity, NEP: net ecosystem productivity, NBP: net biome productivity (after Scholes *et al.*, 1999)

In Fig. 5, a more detailed overview of the main carbon pools and fluxes in forest ecosystems is given. Exact values for the C stocks contained in the pools and for the fluxes are not given here, as they vary strongly between forest ecosystems. As was already illustrated in Table 1, large amounts of carbon are stored in the above- and belowground biomass components, in the litter layer, and in the mineral soil. Other carbon pools that are not indicated on the graph comprise the shrub and herb layer, and the dead wood lying on top of the forest floor. The main carbon flux in a forest ecosystem is the gross photosynthesis (GPP). Part of the carbon taken up by the plants is released by respiration of the foliage (R_f), the woody biomass components (R_w) and the roots (R_r). These respiration fluxes add up to the total autotrophic respiration R_a. Decomposition of organic matter by heterotrophic respiration (R_h) also releases carbon to the atmosphere. R_a together with R_h defines the total ecosystem respiration or TER. The balance between GPP and TER, the net ecosystem productivity (NEP), determines whether the forest acts as a source or a sink for carbon (Schulze *et al.*, 2002). NEP values of forests may reach values of 7 t C ha^{-1} $year^{-1}$ (Bolin and Sukumar, 2000), and are described to depend on climatic conditions, soil fertility, stand age, stand structure and species composition. A change in the balance between photosynthesis and respiration will change the carbon stock in forests, and also has potential to alter the CO_2 content of the atmosphere (Melillo *et al.*, 1995).

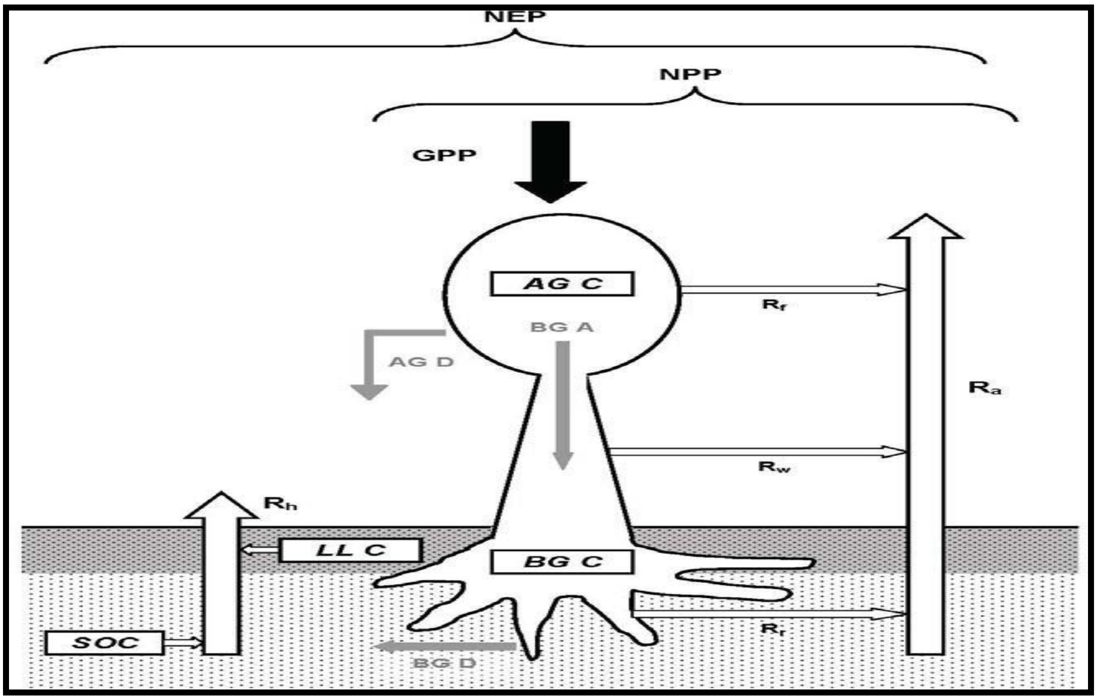


Fig. 5. Main carbon pools (boxes) and fluxes (arrows) in a forest ecosystem; AGC: aboveground biomass carbon stock, BGC: belowground biomass C stock, LLC: C stock in the litter layer, SOC: C stock in the mineral soil layer; GPP : gross primary productivity; R_f: foliage respiration, R_w: wood respiration, R_r: root respiration, R_a: autotrophic respiration; R_h: heterotrophic respiration; AGD: aboveground detritus (litter fall and mortality), BGD: belowground detritus (fine root turnover, exudation and root mortality), BGA : belowground allocation; NPP: net primary productivity; NEP: net ecosystem productivity (after Bolin and Sukumar, 2000, Williams *et al.*, 2005)

The ancient hypothesis of ecological equilibrium assumed that forest ecosystems tend towards a stage where assimilation and respiration are balanced. However, even old-growth forests have been shown to be carbon sinks (Carey *et al.,* 2001, Schulze *et al.,* 2002, Poulton *et al.,* 2003). As such, three main phases can be considered in the development of a forest stand. During the early phase of stand development, which is expected to last 10 to 20 years, a forest is likely to be a source of carbon, as trees are small, and as such, photosynthesis cannot compensate for the carbon loss from soil and detritus. In a second phase, biomass production in the young forest stand is high, while the carbon content of the soil layer is fairly constant. In this phase, forests are a strong carbon sink. This phase can last for a century or even longer. In a third phase, the amount of carbon in the living biomass reaches a more or less constant level. Due to tree mortality, root and foliage decay, the soil carbon content enhances. Consequently, the total carbon stock in the forest ecosystem can still increase, even while the vegetation carbon stock slightly diminishes (Bolin and Sukumar, 2000). Therefore, replacing mature forests by actively growing plantations in order to capture more carbon from the atmosphere can be counterproductive, as exploitation of old forests results in large carbon losses, due to the harvest of a very large C stock and to soil disturbance, which favours carbon losses through soil respiration processes (Schulze *et al.,* 2002).

International agreements and obligations

In response to the growing awareness about global change, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established the Intergovernmental Panel on Climate Change (IPCC), in 1988. Four years later, in 1992, 162 countries adopted a treaty, known as the United Nations Framework Convention on Climate Change (UNFCCC) at the first Earth Summit held in Rio de Janeiro, Brazil (AAS 2006). The stated objective of the Framework Convention is "to achieve stabilization of the greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system. Such a level should be achieved within a time frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner". In this treaty, developed countries were asked to reduce their greenhouse gas emissions to 1990 levels by the year 2000, as to avert extreme climate change. It was also stated that on the longer term (2100), the global greenhouse gas emissions have to decrease with 40 to 50 % in comparison to 1990. Countries that ratified the UNFCCC were committed to a number of obligations, including the reporting of their national greenhouse gas emissions, the development of strategies and measures to reduce these emissions, among which enhancing energy use efficiency and searching for alternative and renewable energy sources, and the protection of greenhouse gas sinks such as forests (Schimel *et al.*, 1995).

At the third Conference of the Parties (COP), which was held in December 1997 in Kyoto (Japan), the UNFCCC was extended with the Kyoto Protocol (KP). This protocol can be considered as a first modest step to stabilize atmospheric greenhouse gas concentrations. The KP sets the collective global target of reducing greenhouse gas emissions by 5.2 % compared to 1990 levels in the industrialized countries (so-called Annex I countries), and this during the first commitment period (2008-2012) (Schulze *et al.*, 2002; AAS, 2006). Under the KP, not only carbon dioxide is considered, but a basket of six (groups of) greenhouse gases is taken into account: CO_2, methane, nitrous oxide, sulphur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). These two latter groups of gases are replacing chlorofluorocarbons, of which the use was seriously restricted because of the damage they caused to the ozone layer in the atmosphere. To enable comparison of the greenhouse strength of the different gases, their Global Warming Potential is used to express the greenhouse strength in CO_2 equivalents.

At 16th February 2005, the Kyoto Protocol entered into force, following ratification by Russia on 18th November 2004. As such, 163 countries had ratified the protocol, and they were representing 61.6 % of the total CO_2 emissions of all Annex I countries. This was far more than the 55 countries and 55 % of the total of CO_2 emissions for 1990 of the Annex I countries, which were the prerequisites for the protocol to become legally binding.

Under the Kyoto Protocol, the overall reduction target for the 15 then-members of the European Union was set at 8 % of 1990 emission levels (Schulze *et al.*, 2002). Within the European Union, differential reduction rates were applied. For Belgium, the emission reduction commitment was fixed at 7.5 % compared to 1990. In March 2004, it was agreed that Flanders should reduce its GHG emissions with 5.2 % compared to 1990 levels and Wallonia with 7.5 %, during the first commitment period. The remaining GHG emission reduction needed to reach the Belgian commitment will be compensated by the federal government, which will purchase emission rights at the international market (Wittoeck, 2006). In 2003, total greenhouse gas emissions in Belgium amounted to 147719 kt CO_2 equivalents, an increase with 1.4 % compared to 1990 (EMIS, 2006). CO_2 contributed 85.5 % to the total Belgian GHG emissions. Moreover, CO_2 emissions increased with 6.2 % during the period 1990 to 2003, while emissions of methane (6.8 % of GHG emissions) and nitrous oxide (8.5 % of GHG emissions) were reduced with 20.9 and 7.7 %, respectively.

In the Kyoto Protocol, direct reference is made to the carbon sequestration capacity of forest ecosystems. Art. 3.3 states that afforestation, reforestation and deforestation (ARD) activities since 1990 can be used to meet the emission reduction commitments. Afforestation refers to the planting of trees on former arable land or grassland, while reforestation can be described as the planting or natural regeneration of trees on arable land or grassland, which had been forest before cultivation by humans (Thuille and Schulze, 2006). Under Art. 3.4, additional human- induced activities related to changes in greenhouse gas emissions by sources and removals by sinks in the agricultural and the land-use change and forestry categories can be taken into account for the calculations of GHG budgets, provided that these activities have taken place since 1990.

The Glasgow Climate Pact in 2021 agreed at the UN Climate Change Conference of the Parties (COP 26) to accelerate action on climate this decade.

The United Nations Secretary-General António Guterres in his wrap up message to the conference stated that "….It is an important step but is not enough. Our fragile planet is hanging by a thread. We are still knocking on the door of climate catastrophe. It is time to go into emergency mode — or our chance of reaching net-zero will itself be zero…." On this background, the present study has great implications at ecosystem level as it is a step to move forward to curb atmospheric carbon dioxide level by forest plantations.

OBJECTIVES

OBJECTIVES

The present programme was undertaken in CFC locations under Bankura North Division, Durgapur Division, Burdwan Division, Birbhum Division and Jhargram Division with the following objectives:

1. *Monitoring the variation of stored carbon in the Above Ground Biomass (AGB) of Akashmoni, Eucalyptus and Sal.*
2. *Measurement of Below Ground Biomass (BGB) of the selected species.*
3. *Assessment of carbon sequestration by the Above Ground Biomass (AGB) of the selected species and their respective CO_2 equivalents.*
4. *Monitoring relevant environmental (abiotic variables) like near surface atmospheric CO_2 level, soil pH, soil organic carbon (SOC) etc in the selected forest divisions.*
5. *Provide comprehensive management action plan to upgrade the environment in the selected divisions.*

METHODOLOGY

PHASE A: SITE SELECTION & SAMPLING

West Bengal is a maritime state in the eastern part of India at the apex of Bay of Bengal, covering total area of 88,752 Kms. The State lies between 21°29'N to 27°13'N latitude and 85°50'E to 89°52' E longitude. It is surrounded by Sikkim and Bhutan in the north, Assam in the northeast, Bangladesh in the east, Bay of Bengal in the south, Odisha in the southwest, Jharkhand & Bihar in the west, and Nepal in the northwest.

There are 23 districts in West Bengal, namely Alipurduar, Bankura, Paschim Bardhaman, Purba Bardhaman, Birbhum, Cooch Behar, Dakshin Dinajpur, Darjeeling, Hooghly, Howrah, Jalpaiguri, Jhargram, Kalimpong, Kolkata, Maldah, Murshidabad, Nadia, North 24 Parganas, Paschim Medinipur, Purba Medinipur, Purulia, South 24 Parganas and Uttar Dinajpur.

In the state of West Bengal five divisions were selected in the South Bengal region for carrying out the present study. These are:

(1) Bankura North Division
(2) Durgapur Division
(3) Burdwan Division
(4) Birbhum Division
(5) Jhargram Division

Each of these divisions consists of some beats, which encompass mouzas. 1-5 mouzas were selected in each division for studying the carbon pool in the habitat of selected trees species *viz*., Akashmoni, Eucalyptus and Sal (Table 2).

Table 2: Geographical locations of the selected sites

Division	**Range**	**Beat**	**Mouza**	**Coordinates**	**View**
Bankura North	Beliatore	Beliatore H.Q.	Samantamara	23°18′58.1″N; 87°09′48.0″E	
	Bankura North	Belboni	Baramesia	23°16′11.3″N; 87°12′16.5″E	

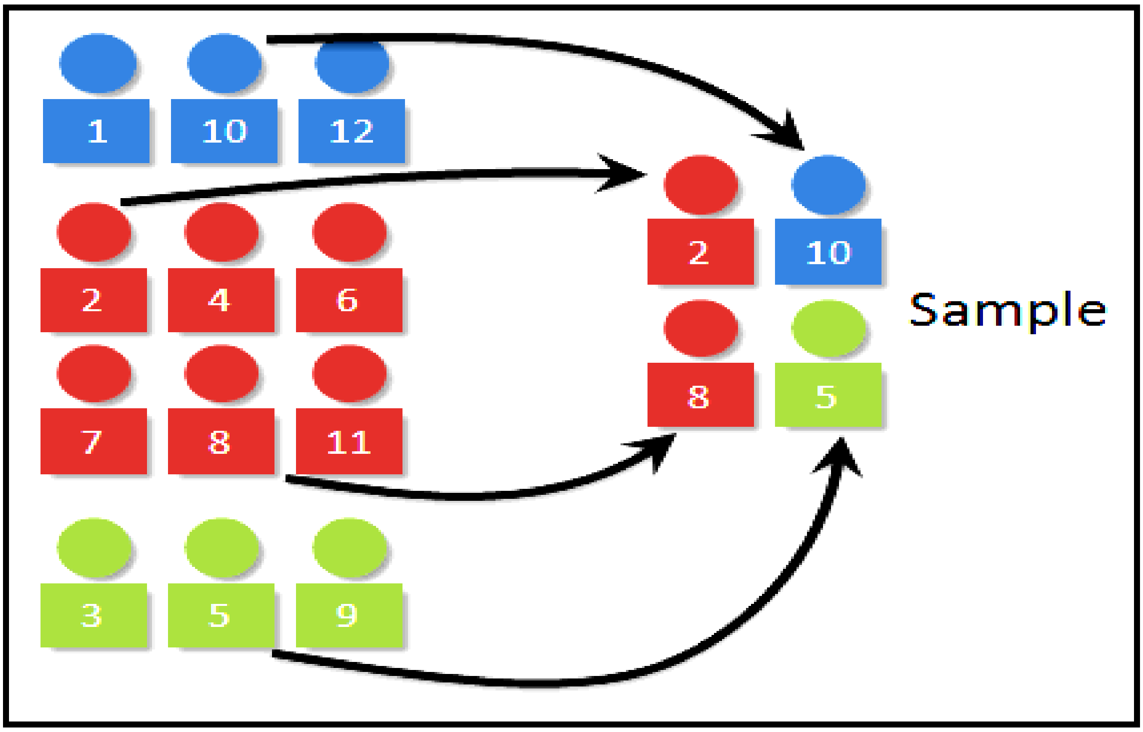
	Saltora	Murlu	Searbaid	23°30′17.2″N; 86°55′03.3″E	
Durgapur	Durgapur	Rakhitpur	Bishnupur	23°34′00.3″N; 87°25′38.4″E	
		Gopalpur	Gopalpur	23°29′36.9″N; 87°24′12.3″E	
	Ukhra	Fuljhora	Jemua	23°33′30.8″N; 87°21′33.5″E	
			Paranganj	23°33′18.0″N; 87°21′09.6″E	
			Kataberia	23°36′18.6″N; 87°22′09.0″E	
	Asansol	Gourandi	Chotkar	23°48′46.8″N; 86°57′50.5″E	
			Aliganj	23°49′51.5″N; 86°59′52.4″E	

Burdwan	Panagarh	Khandari	Balarampur	23°27′12.4″N; 87°30′56.6″E	
			Khandari	23°26′51.5″N; 87°31′42.5″E	
	Guskara		Alefnagar	23°31′36.2″N; 87°38′41.4″E	
		Jadavganj, Kumarganj	Jadavganj	23°28′23.4″N; 87°39′46.5″E	
Birbhum	Md. Bazar	Mollapur	Moubelia	24°04′08.0″N; 87°39′59.0″E	
		Rashpur	Birupur	23°59′42.4″N; 87°30′53.0″E	
			Kariya-Nimdaspur	23°59′51.1″N; 87°29′13.8″E	
	Rampurhat	Tumbani	Chandpur	24°11′43.1″N; 87°40′35.4″E	

			Vatina	24°10′20.1″N; 87°43′02.0″E	
	Bolpur	Bolpur	Darikanathpur	23°40′09.6″N; 87°44′17.0″E	
Jhargram	Gidhni	Godrasol	Tulibar	22°23′09.7″N; 86°52′04.6″E	
			Teramuri	22°22′04.4″N; 86°52′14.1″E	
	Jhargram	Pukuria	Gamaria	22°22′36.7″N; 86°56′37.9″E	
	Manikpara	Balivasa	Golbandhi	22°20′47.8″N; 87°05′26.3″E	
	Lodhasulii	Chandri II	Kharsuli	22°19′59.1″N; 86°56′05.2″E	
			Muroikhuti	22°19′40.4″N; 86°55′56.7″E	

Plots were selected in each of these Mouzas (GPS based coordinates specified), where stratified random sampling design was followed. The basic idea in stratified random sampling is to divide a heterogeneous population into sub-populations, usually known as strata, each of which is internally homogeneous in which case a precise estimate of any stratum mean can be obtained based on a small sample from that stratum and by combining such estimates, a precise estimate for the whole population can be obtained.

Stratified sampling provides a better cross section of the population than the procedure of simple random sampling. It may also simplify the organisation of the field work. Geographical proximity is sometimes taken as the basis of stratification. The assumption here is that geographically contiguous areas are often more alike than areas that are far apart. Administrative convenience may also dictate the basis on which the stratification is made. For example, the staff already available in each range of a forest division may have to supervise the survey in the area under their jurisdiction. Thus, compact geographical regions may form the strata. A fairly effective method of stratification is to conduct a quick reconnaissance survey of the area or pool the information already at hand and stratify the forest area according to forest types, stand density, site quality etc. (Scheme 1).



Scheme 1. Stratified Random sampling followed for Relative Abundance analysis of the selected floral community in South Bengal forest divisions under West Bengal Forest Department

If the characteristic under study is known to be correlated with a supplementary variable for which actual data or at least good estimates are available for the units in the population, the stratification may be done using the information on the supplementary variable. For instance, the volume estimates obtained at a previous inventory of the forest area may be used for stratification of the population. In stratified sampling, the variance of the estimator consists of only the 'within strata' variation. Thus the larger the number of strata into which a population is divided, the higher, in general, is the precision, since it is likely that, in this case, the units within a stratum will be more homogeneous.

Before sampling, it is assumed that the population is divided into k strata of N_1, N_2,..., N_k units respectively, and that a sample of n units is to be drawn from the population. The problem of allocation concerns the choice of the sample sizes in the respective strata, *i.e.*, how many units should be taken from each stratum such that the total sample is n. In this context 30 plots of each of three species were considered (n = 90 for all the three species).

Estimation of mean and variance

In this study, the population of N units is first divided into k strata of N_1, N_2,...,N_k units respectively. These strata are non-overlapping and together they comprise the whole population, so that

$N_1 + N_2 + ... + N_k = N$

When the strata have been determined, a sample is drawn from each stratum, the selection being made independently in each stratum. The sample sizes within the strata are denoted by n_1, n_2, ..., n_k respectively, so that

$n_1 + n_2 + ... + n_3 = n$

Let y_{tj} (j = 1, 2,…., N_t ; t = 1, 2,.….k) be the value of the characteristic under study for the j the unit in the tth stratum. In this case, the population mean in the stratum is given by the expression:

$$\bar{Y}_t = \frac{1}{N_t}\sum_{j=1}^{N_t} y_{tj}, (t = 1, 2, \ldots, k)$$

The overall population mean is given by

$$\bar{Y} = \frac{1}{N}\sum_{t=1}^{k} N_t \bar{Y}_t$$

The estimate of the population mean $\bar{Y}$, in this case was obtained by

$$\hat{\bar{Y}} = \frac{\sum_{t=1}^{k} N_t \bar{y}_t}{N}$$

Where, $\bar{y}_t = \sum_{j=1}^{n_t} \frac{y_{tj}}{n_t}$

Estimate of the variance of $\hat{\bar{Y}}$ is given by

$$\hat{V}(\hat{\bar{Y}}) = \frac{1}{N^2} \sum_{t=1}^{k} N_t (N_t - n_t) \frac{s^2_{t(y)}}{n_t}$$

Where, $s^2_{t(y)} = \sum_{j=1}^{n_t} \frac{(y_{tj} - \bar{y}_t)^2}{n_t - 1}$

Stratification, if properly done generates lower variance for the estimated population total or mean than a simple random sample of the same size. This leads to the assurance of quality data, which is followed in all the selected divisions to achieve the relative abundance of each species. This is the foundation of assessing plot/site - and species-wise biomass and stored carbon.

PHASE B: EXPERIMENTAL DESIGN

1. ABOVE GROUND BIOMASS (AGB) ESTIMATION

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

i. STEM BIOMASS ESTIMATION

The stem volume of each species in each plots (10m × 10m) of all mouzas was estimated using the Newton's formula (Husch *et al.*, 1982).

$$\mathbf{V = h/6\ (A_b + 4A_m + A_t)}$$

Where V is the volume (in m^3), h is the height measured with laser beam (BOSCH DLE 70 Professional model), and A_b, A_m, and A_t are the areas at base, middle and top respectively. Specific gravity (G) of the wood was estimated taking the stem cores by boring 4.5 cm deep. This was converted into stem biomass (B_S) as per the expression B_S = GV. The stem biomass of individual tree was finally multiplied by the number of trees of each species in all the selected mouzas and the mean values are expressed in t ha^{-1}.

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 metres.

ii. BRANCH BIOMASS ESTIMATION

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized on the basis of 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 oven-dried at 70^0C overnight in hot air oven in order to remove moisture content if any present in the branches. Dry weight of two branches from each size group was recorded separately using the equation of Chidumaya (1990).

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

Where B_{db} is the dry branch biomass per tree, n_i the number of branches in the ith branch group, b_{wi} 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 tree was finally multiplied with the number of trees of each species in all the plots for each site and expressed in t ha^{-1}.

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 70^0C 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:

$$\mathbf{L_{db} = n_1Lw_1N_1 + n_2Lw_2N_2 + \ldots\ldots\ldots n_iLw_iN_i}$$

Where L_{db} is the dry leaf biomass of selected urban species per plot, n_{1}…..n_i are the number of branches of each tree of the species, Lw_1 …….Lw_i are the average dry weight of leaves removed from the branches and N_1………N_i are the number of trees per species in the plots. This exercise was performed for all the mouzas and the mean results were finally expressed in t ha^{-1}.

2. ABOVE GROUND CARBON (AGC) ESTIMATION

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 fresh sample of stem, branch and leaf from trees (of each species) was oven dried at 70^0C, randomly mixed 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.

The mean carbon values of these vegetative parts were considered as the stored carbon in AGB of each species.

3. BELOW GROUND BIOMASS (BGB) ESTIMATION

The below ground biomass (BGB) includes all biomass of live roots excluding the fine roots. The BGB, in the present study was calculated by multiplying AGB × 0.26 factors considering the root: shoot ratio (Saral, A. Mary *et al.*, 2017). Thus BGB was calculated by following BGB (kg/tree) = AGB (kg/tree) × 0.26. This exercise was performed for all the selected species present in the sampling plots per site.

4. CO_2 - EQUIVALENT ESTIMATION

The weight of CO_2 is C + 2 × O (Oxygen) = 43.99915. Hence, the ratio of CO_2 to C is calculated as: 43.99915/12.001118 = 3.6663. Therefore, in order to determine the weight of carbon dioxide sequestered in the tree (CO_2-equivalent), the weight of carbon in the vegetative parts of the tree (AGC) is multiplied by 3.6663.

5. SOIL ORGANIC CARBON (SOC) ESTIMATION

Soil samples from the upper 5 cm were collected from all the plots of all mouzas and dried at 60^0C for 48 hrs. For analysis, visible plant particles were handpicked and removed from the soil. After sieving the soil through a 2 mm sieve, the samples of the bulk soil (50 gm from each plot) were ground finely in a ball – mill. The fine dried sample was randomly mixed to get a representative picture of the study site. Modified version of Walkley and Black method (1934) was then followed to determine the organic carbon of the soil in %. The flow chart for determining of SOC is shown in Scheme 2.

1 gm of dried soil was taken in a conical flask

↓

1 ml of phosphoric acid (H_3PO_4) and 1 ml of distilled water were added

↓

The mixture was heated for 10 min at 100 to 110° C

↓

10 ml 1 N potassium dichromate ($K_2Cr_2O_7$) and 20 ml concentrated sulphuric acid (H_2SO_4) with silver sulphate (Ag_2SO_4) were added and mixed.

↓

Allowed the mixture to stand for 30 minutes

↓

The mixture was diluted to 200 ml with distilled water and 10 ml of phosphoric acid (H_3PO_4) and 1 ml of indicator (diphenyl amine) were added.

↓

The colour of the mixture changed to bluish purple

↓

The mixture was titrated with Mohr salt solution [$(NH_4)_2Fe(SO_4)_2.6H_2O$] until the colour of the solution changed to brilliant green

↓

The same titration was repeated without taking soil and the volume of the potassium dichromate required to oxidize organic carbon was calculated from the difference

Scheme 2. Estimation of Soil Organic Carbon by Walkley and Black method

CALCULATION

% of CARBON = 3.951/g × (1/ B/S)

Where, g = weight of sample in grams

B = Mohr salt solution for blank

S = Mohr salt solution for Sample

6. SOIL pH

The measurement of soil pH was done in the field with a micro pH meter (Systronics, Model No, 362) with glass – calomel electrode (sensitivity ± 0.01) and standardized with buffer 7.0.

RESULT

For convenience, the results of the present study may be broadly divided into Biotic and Abiotic components.

1. Biotic Components

The biotic components encompass species-wise AGB, AGC, BGB, sequestered carbon and CO_2- equivalent (based on AGC).

1.A] In **Bankura North Division**, the **AGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 191.245 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **AGB in Eucalyptus** was 654.024 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 611.430 tha^{-1}.

In **Bankura North Division**, the **AGC of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 84.189 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **AGC in Eucalyptus** was 300.940 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 285.291 tha^{-1}.

In **Bankura North Division**, the **BGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 49.724 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **BGB in Eucalyptus** was 170.046 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 158.972 tha^{-1}. The carbon stored in the root could not be estimated through direct field based survey as there was no provision for uprooting. We estimated the BGB of the selected species on the basis of AGB values as per the standard method (*https://www.climate-policy-watcher.org/carbon-stocks/grass-biomass-production-above-the-ground.html*).

In **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 7.016 $tha^{-1}y^{-1}$; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value in **Eucalyptus** was 25.078 $tha^{-1}y^{-1}$ and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 19.019 $tha^{-1}y^{-1}$.

In **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Searbaid Mouza, Murlu Beat under Saltora range (23°30′17.2″N; 86°55′03.3″E) was 308.975 tha^{-1}; in Samantamara Mouza, Beliatore Beat under Beliatore range (23°18′58.1″N; 87°09′48.0″E) the value of **CO_2-**

equivalent in Eucalyptus was 1104.450 tha^{-1} and of **Sal** in Baramesia Mouza, Belboni Beat under Bankura North range (23°16′11.3″N; 87°12′16.5″E) was 1047.019 tha^{-1}.

1.B] In **Durgapur Division**, the **AGB of Akashmoni** ranged from 38.611 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 64.957 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the AGB ranged from 134.816 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 156.103 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the AGB ranged from 99.857 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site); 23°33′18.0″N; 87°21′09.6″E) to 131.365 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is interesting to note that in the Durgapur Division the **AGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 70.558 tha^{-1}. The significant low value in natural Sal is attributed to low population density of the species, which is only 2/100m^{2}.

In **Durgapur Division**, the **AGC of Akashmoni** ranged from 17.583 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 29.964 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **AGC** ranged from 59.721 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 68.212 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **AGC** ranged from 45.932 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 59.591 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is observed that in the Durgapur Division the **AGC of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 32.995 tha^{-1}. The significant low value in natural Sal is attributed to low population density of the species, which is only 2/100m^{2}.

In **Durgapur Division**, the **BGB** of **Akashmoni** ranged from 10.039 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 16.889 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **BGB** ranged from 35.052 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 40.587 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **BGB** ranged from 25.963 tha^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 34.155 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

In the Durgapur Division the **BGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was 18.345 tha^{-1}. The significant low value of BGB in natural Sal is attributed to low population density of the species, which is only 2/100m^2.

In **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 1.764 tha^{-1}y^{-1} (at Paranganj Mouza; 23°33′18.0″N; 87°21′09.6″E) to 6.182 tha^{-1}y^{-1} (at Aliganj Mouza, Gourandi Beat; 23°49′51.5″N; 86°59′52.4″E).

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** ranged from 4.263 tha^{-1}y^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E) to 14.930 tha^{-1}y^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E).

In case of **Sal**, the **carbon sequestered in AGB** ranged from 9.186 tha^{-1}y^{-1} (at Kataberia Mouza, Kataberia -Felling site; 23°33′18.0″N; 87°21′09.6″E) to 14.898 tha^{-1}y^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It has also been observed that in the Durgapur Division, **the carbon sequestered in the AGB of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) is 1.138 tha^{-1}y^{-1} and this low value is attributed to low population density of the species in the depot as stated earlier.

The variation in the magnitude of sequestered carbon in the above ground biomass is thus attributed to the AGB, age of the trees under each species and population density, although edaphic factors have a regulatory influence on carbon percentage of the species.

In **Durgapur Division**, the **CO_2-equivalent of Akashmoni** ranged from 64.530 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E) to 109.969 tha^{-1} (at Chotkar Mouza, Gourandi Beat; 23°48′46.8″N; 86°57′50.5″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** ranged from 219.176 tha^{-1} (at Jemua Mouza, Fuljhora; 23°33′30.8″N; 87°21′33.5″E) to 250.340 tha^{-1} (at Gopalpur Mouza, Village Bandra; 23°29′36.9″N; 87°24′12.3″E).

In case of **Sal**, the **CO_2-equivalent** ranged from 168.569 tha^{-1} (at Kataberia Mouza, Kataberia - Felling site; 23°33′18.0″N; 87°21′09.6″E) to 218.698 tha^{-1} (at Bishnupur Mouza, Rakhitpur; 23°34′05.2″N; 87°25′47.5″E).

It is again observed that in the Durgapur Division the **CO_2-equivalent of natural Sal at Kataberia Depot** (23°36'15.4" N and 86°22'13.6" E; age 29 years) was considerably low ~121.093 tha^{-1} due to low population density of the species at this particular site.

1.C] In **Burdwan Division**, the **AGB of Akashmoni** ranged from 47.253 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 56.079 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **AGB** was 155.700 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **AGB** ranged from 139.109 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 161.027 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

In **Burdwan Division**, the **AGC of Akashmoni** ranged from 21.563 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 25.612 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **AGC** was 64.124 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **AGC** ranged from 63.778 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 74.065 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

In **Burdwan Division**, the **BGB of Akashmoni** ranged from 12.286 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 14.581 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **BGB** was 40.482 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **BGB** ranged from 36.168 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 41.867 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

In Burdwan Division, the **sequestered carbon in AGB of Akashmoni** ranged from 3.856 $tha^{-1}y^{-1}$ (at Jadavgang Mouza, Kumargang; 23°28′23.4″N; 87°39′46.5″E) to 6.403 $tha^{-1}y^{-1}$ (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** was 16.031 $tha^{-1}y^{-1}$ (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **carbon sequestered in AGB** ranged from 12.344 $tha^{-1}y^{-1}$ (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation) to 15.945 $tha^{-1}y^{-1}$ (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E).

In **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 79.137 tha^{-1} (at Alefnagar, Guskara 23°31′36.2.4″N; 87°38′41.4″E) to 93.997 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′18.4″N; 87°30′58.9″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** was 235.334 tha^{-1} (at Khandari Mouza, Khandari; 23°26′51.5″N; 87°31′42.5″E).

In case of **Sal**, the **CO_2-equivalent** ranged from 234.067 tha^{-1} (at Balarampur Mouza, Khandari; 23°27′12.4″N; 87°30′56.6″E) to 271.817 tha^{-1} (at Jadavgang Mouza, Kumargang; 23°28′24.1″N; 87°39′46.6″E during 2015 plantation).

1.D] In **Birbhum Division**, the **AGB of Akashmoni** ranged from 57.578 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 240.196 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **AGB** ranged from 543.224 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 705.900 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **AGB** was 395.359 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

In **Birbhum Division**, the **AGC of Akashmoni** ranged from 25.408 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 108.993 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **AGC** ranged from 248.625 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 325.016 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **AGC** was 184.106 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

In **Birbhum Division**, the **BGB of Akashmoni** ranged from 14.970 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 62.451 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **BGB** ranged from 141.238 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 183.534 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **BGB** was 102.793 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

In **Birbhum Division**, the **sequestered carbon in AGB** of Akashmoni ranged from 1.694 $tha^{-1}y^{-1}$ (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 9.083 (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E) $tha^{-1}y^{-1}$.

In case of **Eucalyptus clone**, the **carbon sequestered in AGB** ranged from 16.251 $tha^{-1}y^{-1}$ (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E) to 16.575 $tha^{-1}y^{-1}$ (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E).

In case of **Sal**, the **carbon sequestered in AGB** was 15.342 $tha^{-1}y^{-1}$ (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

In **Birbhum Division**, **the CO_2-equivalent of Akashmoni** ranged from 93.249 tha^{-1} (at Birupur, Rashpur Beat, Md. Bazar Range; 23°59′42.4″N; 87°30′53.0″E) to 400.003 tha^{-1} (at Darikanathpur Mouza, Bolpur; 23°40′09.6″N; 87°44′17.0″E).

In case of **Eucalyptus clone**, the **CO_2-equivalent** ranged from 912.452 tha^{-1} (at Chandpur Mouza, Tumbani Beat, Rampurhat Range; 24°11′43.1″N; 87°40′35.4″E) to 1192.809 tha^{-1} (at Vatina, Tumbani Beat, Rampurhat Range; 24°10′20.1″N; 87°43′02.0″E).

In case of **Sal**, the **CO_2-equivalent** was 675.668 tha^{-1} (at Moubelia, Rashpur Beat, Md. Bazar; 24°04′08.0″N; 87°39′59.0″E).

1.E] In **Jhargram Division**, the **AGB of Akashmoni** ranged from 202.590 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 339.502 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **AGB** ranged from 737.567 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 766.207 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **AGB** ranged from 512.209 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 801.365 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

In **Jhargram Division**, the **AGC of Akashmoni** ranged from 93.127 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 157.072 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **AGC** ranged from 339.402 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 353.701 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **AGC** ranged from 238.011 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 374.902 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

In **Jhargram Division**, the **BGB** of **Akashmoni** ranged from 52.673 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 88.271 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **BGB** ranged from 191.767 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 199.214 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **BGB** ranged from 133.174 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 208.355 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

In **Jhargram Division**, the **sequestered carbon in AGB** of Akashmoni ranged from 7.761 $tha^{-1}y^{-1}$ (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 10.471 $tha^{-1}y^{-1}$ (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **carbon sequestered in AGB** ranged from 28.284 $tha^{-1}y^{-1}$ (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 29.475 $tha^{-1}y^{-1}$ (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the carbon sequestered in AGB ranged from 15.867 $tha^{-1}y^{-1}$ (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 24.993 $tha^{-1}y^{-1}$ (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

In **Jhargram Division**, **the CO_2-equivalent of Akashmoni** ranged from 341.778 tha^{-1} (at Muroikhuti, Chandi II Beat; 22°19′40.4″N; 86°55′56.7″E) to 576.456 tha^{-1} (at Kharsuli, Chandi II Beat; 22°19′59.1″N; 86°56′05.2″E).

In case of **Eucalyptus**, the **CO_2-equivalent ranged** from 1245.606 tha^{-1} (at Telamuri, Godrasol Beat; 22°22′04.4″N; 86°52′14.1″E) to 1298.082 tha^{-1} (at Tulibar, Bamundiha; Godrasol Beat; 22°23′09.7″N; 86°52′04.6″E).

In case of **Sal**, the **CO_2-equivalent ranged** from 873.500 tha^{-1} (at Gamaria, Pukuria Beat; 22°22′36.7″N; 86°56′37.9″E) to 1375.889 tha^{-1} (at Golbandhi, Balivasa Beat; 22°20′47.8″N; 87°05′26.3″E).

The core findings that emerged from our field-based monitoring are highlighted in separate boxes for three candidate species.

Box 1: Pattern of biotic components for Akashmoni (*Acacia auriculiformis*)

Division-wise pattern/spatial-pattern	1. We estimated the plot-wise AGB of Akashmoni in all the five divisions and the mean values of each division were considered to evaluate the above ground biomass pattern, which exhibited the order Jhargram (271.046 tha^{-1}) > Bankura North (191.245 tha^{-1}) > Birbhum (171.167 tha^{-1}) > Burdwan (51.247 tha^{-1}) > Durgapur (50.401 tha^{-1}) (Fig. 6). 2. We estimated the plot-wise AGC of Akashmoni in all the five divisions and the mean values of each division were considered to evaluate the growth/biomass pattern, which exhibited the order Jhargram (125.100 tha^{-1}) > Bankura North (84.189 tha^{-1}) > Birbhum (77.984 tha^{-1}) > Burdwan (23.437 tha^{-1}) > Durgapur (23.140 tha^{-1}) (Fig. 7). 3. For BGB, we followed the shoot: root empirical ratio, and the mean values of each division considering all the plots exhibited the order Jhargram (70.472 tha^{-1}) > Bankura North (49.724 tha^{-1}) > Birbhum (44.504 tha^{-1}) > Burdwan (13.324 tha^{-1}) > Durgapur (13.104 tha^{-1}) (Fig. 8). 4. We estimated the plot-wise sequestered carbon in AGB of Akashmoni in all the five divisions and the mean values of each division were considered to carbon sequestration pattern, which exhibited the order Jhargram (9.116 $tha^{-1}y^{-1}$) > Bankura North (7.016 $tha^{-1}y^{-1}$) > Birbhum (5.347 $tha^{-1}y^{-1}$) > Burdwan (5.217 $tha^{-1}y^{-1}$) > Durgapur (4.028 $tha^{-1}y^{-1}$) (Fig. 9). 5. We estimated the plot-wise CO_2-equivalent of Akashmoni in all the five divisions, which exhibited the order Jhargram (459.117 tha^{-1}) > Bankura North (308.975 tha^{-1}) > Birbhum (286.200 tha^{-1}) > Burdwan (86.013 tha^{-1}) > Durgapur (84.924 tha^{-1}) (Fig. 10).

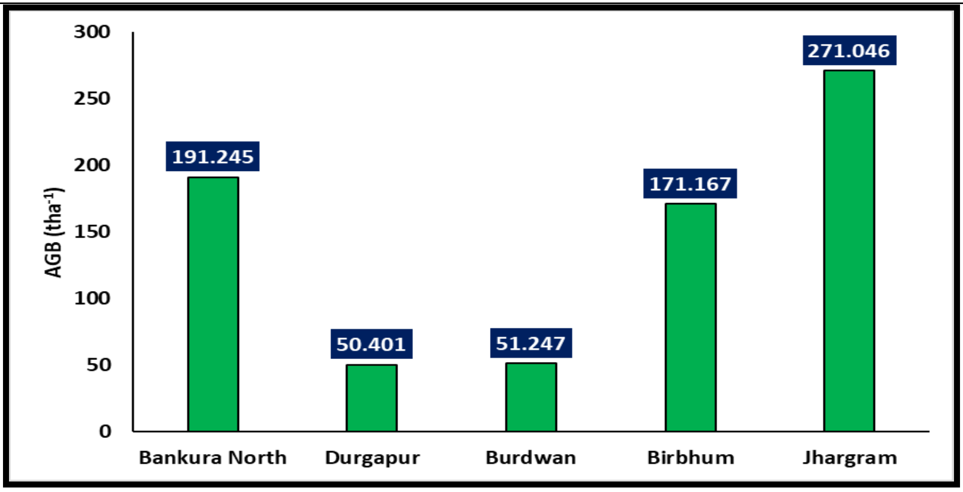


Fig. 6. AGB (in tha^{-1}) of Akashmoni in the five selected forest divisions during the study period

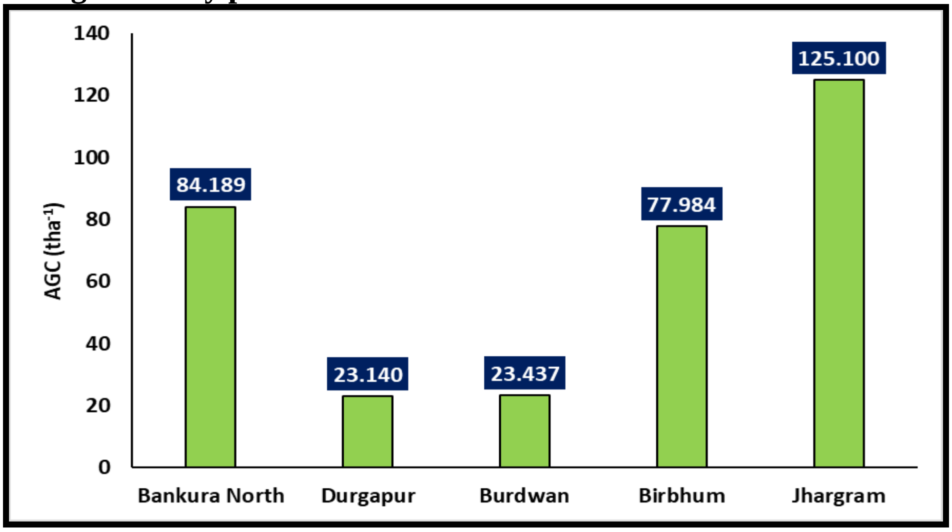


Fig. 7. AGC (in tha^{-1}) of Akashmoni in the five selected forest divisions during the study period

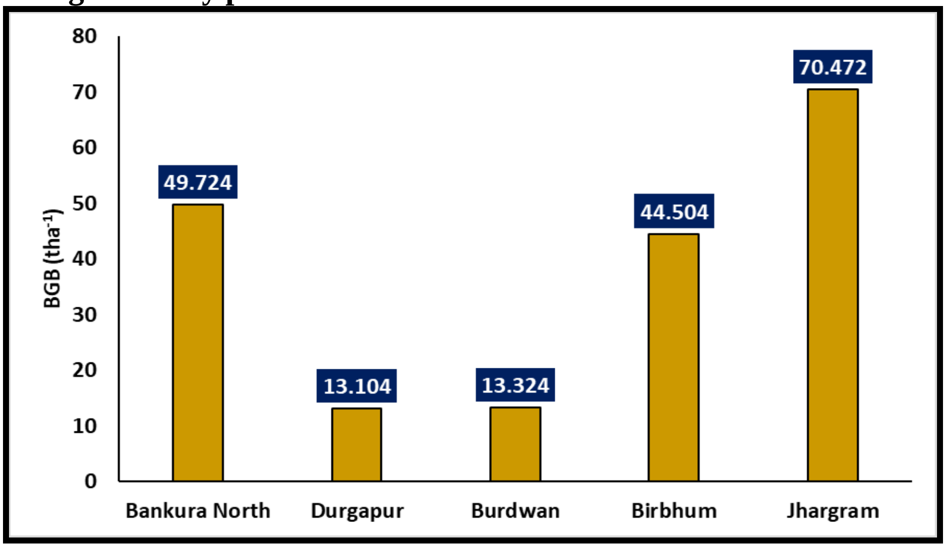


Fig. 8. BGB (in tha^{-1}) of Akashmoni in the five selected forest divisions during the study period

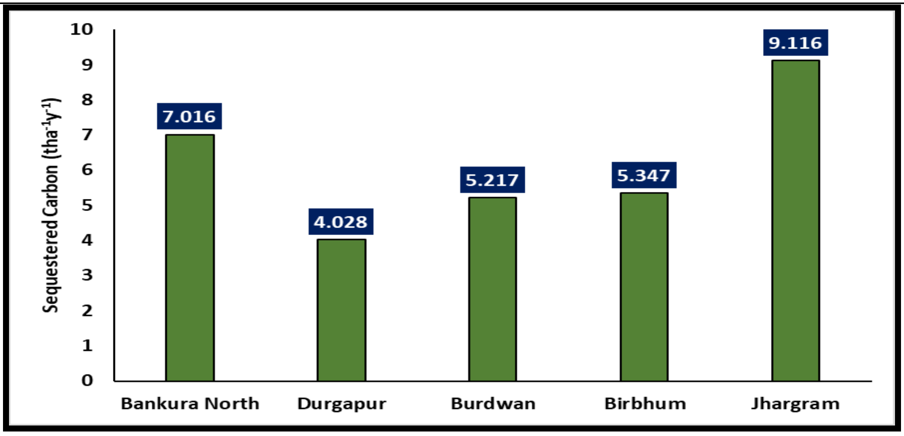


Fig. 9. Sequestered carbon (in tha^{-1}y^{-1}) in AGB of Akashmoni in the five selected forest divisions during the study period

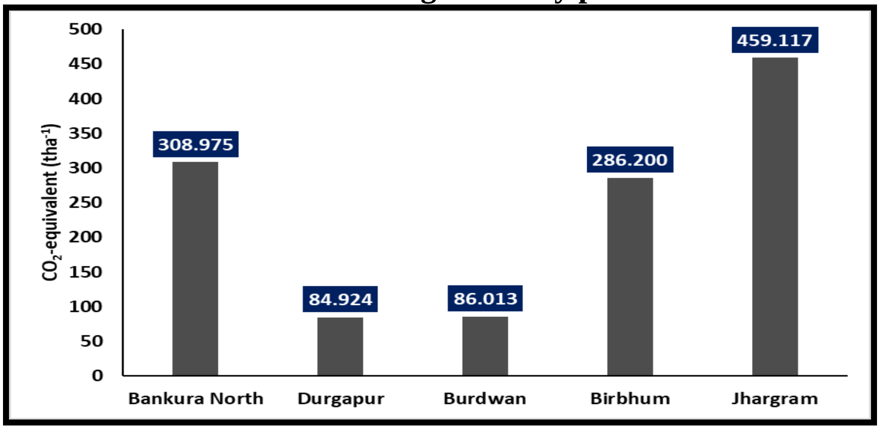


Fig. 10. CO_2-equivalent (in tha^{-1}) of Akashmoni in the five selected forest divisions during the study period

Box 2: Pattern of biotic components for Eucalyptus (*Eucalyptus globulus*)

Division-wise pattern/spatial pattern

1. We estimated the plot-wise AGB of Eucalyptus in all the five divisions, which exhibited the order Jhargram (751.887 tha^{-1}) > Bankura North (654.024 tha^{-1}) > Birbhum (624.562 tha^{-1}) > Burdwan (155.700 tha^{-1}) > Durgapur (145.460 tha^{-1}) (Fig. 11).

2. We estimated the plot-wise AGC of Eucalyptus in all the five divisions, which exhibited the order Jhargram (346.552 tha^{-1}) > Bankura North (300.940 tha^{-1}) > Birbhum (286.820 tha^{-1}) > Burdwan (64.124 tha^{-1}) > Durgapur (63.967 tha^{-1}) (Fig. 12).

3. For BGB shoot: root empirical ratio was followed and the mean values of each division considering all the plots exhibited the order Jhargram (195.491 tha^{-1}) > Bankura North (170.046 tha^{-1}) > Birbhum (162.386 tha^{-1}) > Burdwan (40.482 tha^{-1}) > Durgapur (37.819 tha^{-1}) (Fig. 13).

4. We estimated the plot-wise sequestered carbon in AGB of Eucalyptus in all the five divisions, which exhibited the order Jhargram (28.879 tha^{-1}y^{-1}) > Bankura North (25.078 tha^{-1}y^{-1}) > Birbhum (16.413 tha^{-1}y^{-1}) > Burdwan (16.031 tha^{-1}y^{-1}) > Durgapur

(9.597 $tha^{-1}y^{-1}$) (Fig. 14).

5. We estimated the plot-wise CO_2-equivalent of Eucalyptus in all the five divisions and the mean values of each division were considered for CO_2-equivalent, which exhibited the order Jhargram (1271.844 tha^{-1}) > Bankura North (1104.450 tha^{-1}) > Birbhum (1052.630 tha^{-1}) > Burdwan (235.334 tha^{-1}) > Durgapur (234.758 tha^{-1}) (Fig. 15).

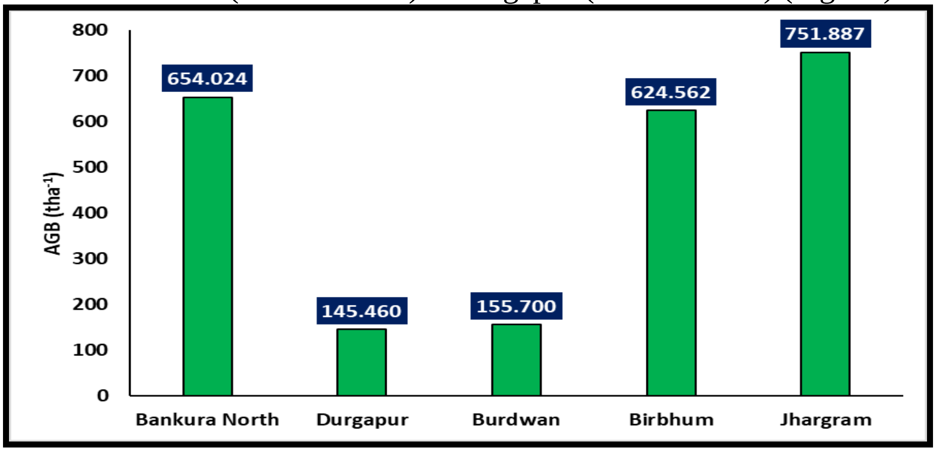


Fig. 11. AGB (in tha^{-1}) of Eucalyptus in the five selected forest divisions during the study period

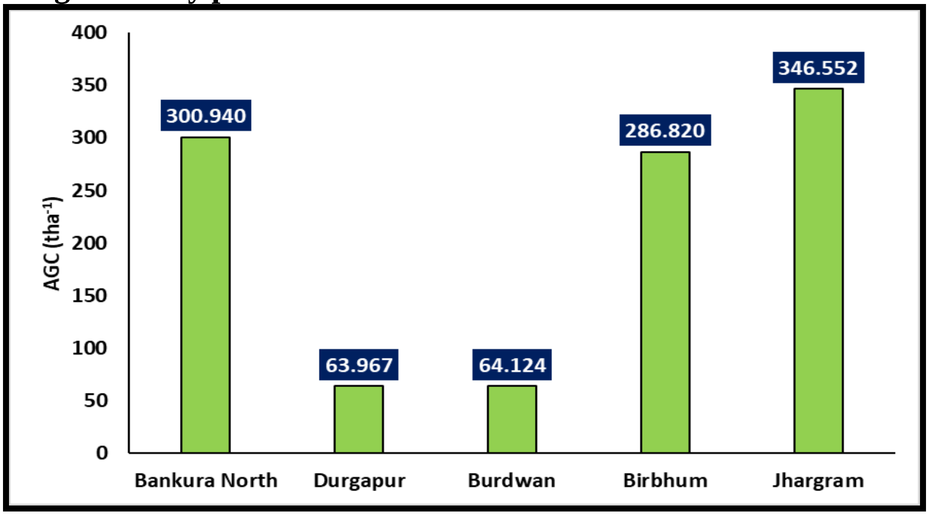


Fig. 12. AGC (in tha^{-1}) of Eucalyptus in the five selected forest divisions during the study period

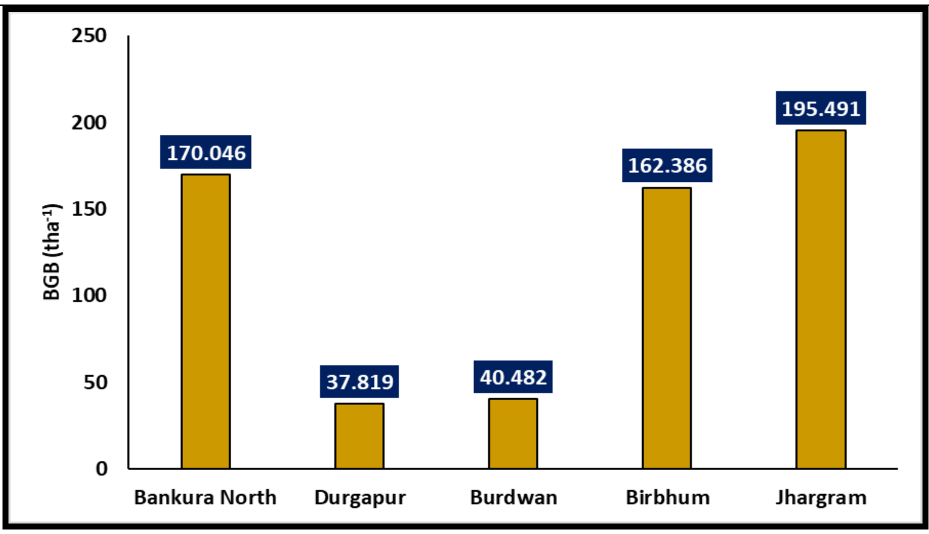


Fig. 13. BGB (in tha^{-1}) of Eucalyptus in the five selected forest divisions during the study period

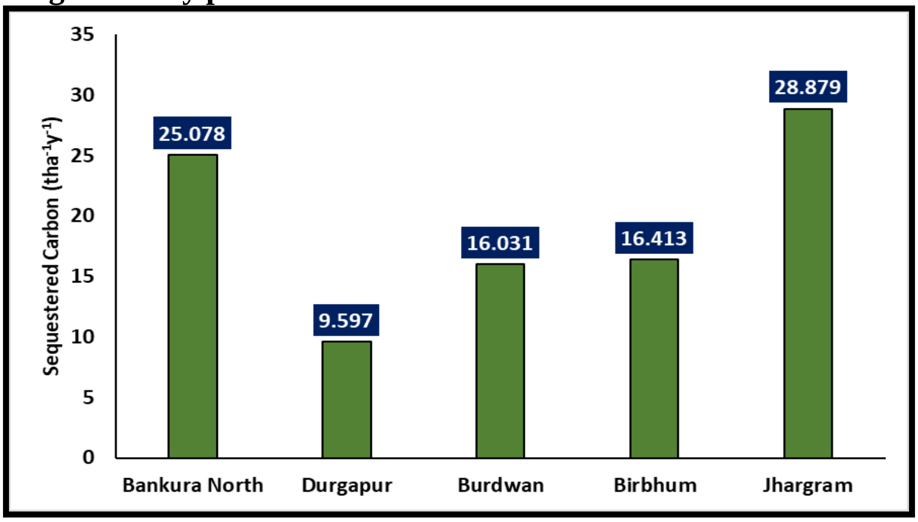


Fig. 14. Sequestered carbon (in $tha^{-1}y^{-1}$) in AGB of Eucalyptus in the five selected forest divisions during the study period

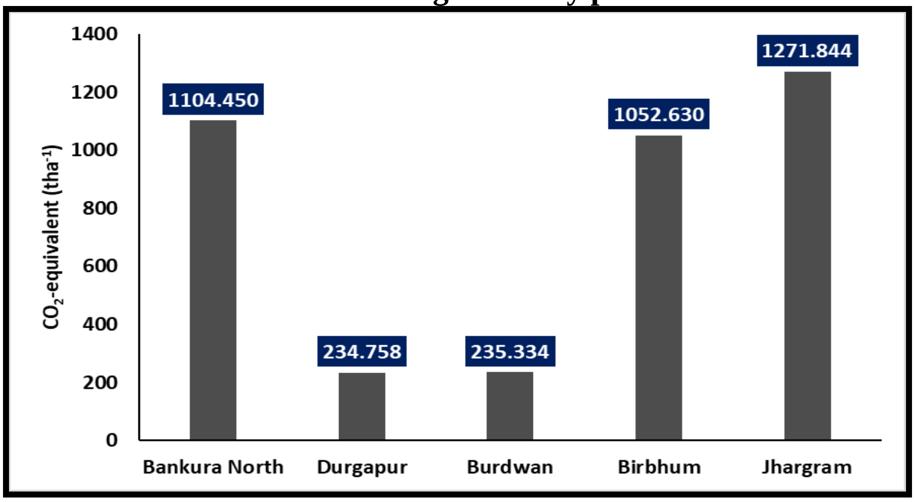


Fig. 15. CO_2-equivalent (in tha^{-1}) of Eucalyptus in the five selected forest divisions during the study period

Box 3: Pattern of biotic components for Sal (*Shorea robusta*)

Division-wise pattern/spatial pattern

1. We estimated the plot-wise AGB of Sal in all the five divisions, which exhibited the order Jhargram (656.787 tha^{-1}) > Bankura North (611.430 tha^{-1}) > Birbhum (395.359 tha^{-1}) > Burdwan (146.668 tha^{-1}) > Durgapur (115.611 tha^{-1}) (Fig. 16).

2. We estimated the plot-wise AGC of Sal in all the five divisions, which exhibited the order Jhargram (306.456 tha^{-1}) > Bankura North (285.291 tha^{-1}) > Birbhum (184.106 tha^{-1}) > Burdwan (67.402 tha^{-1}) > Durgapur (52.761 tha^{-1}) (Fig. 17).

3. BGB estimated through empirical ratio exhibited the order Jhargram (170.765 tha^{-1}) > Bankura North (158.972 tha^{-1}) > Birbhum (102.793 tha^{-1}) > Burdwan (77.549 tha^{-1}) > Durgapur (30.059 tha^{-1}) (Fig. 18).

4. We estimated the plot-wise sequestered carbon in AGB of Sal in all the five divisions, which exhibited the order Jhargram (20.430 tha^{-1}y^{-1}) > Bankura North (19.019 tha^{-1}y^{-1}) > Birbhum (15.342 tha^{-1}y^{-1}) > Burdwan (13.721 tha^{-1}y^{-1}) > Durgapur (12.042 tha^{-1}y^{-1}) (Fig. 19).

5. We estimated the plot-wise CO_2-equivalent of Sal in all the five divisions, which exhibited the order Jhargram (1124.695 tha^{-1}) > Bankura North (1047.019 tha^{-1}) > Birbhum (675.668 tha^{-1}) > Burdwan (247.367 tha^{-1}) > Durgapur (193.633 tha^{-1}) (Fig. 20).

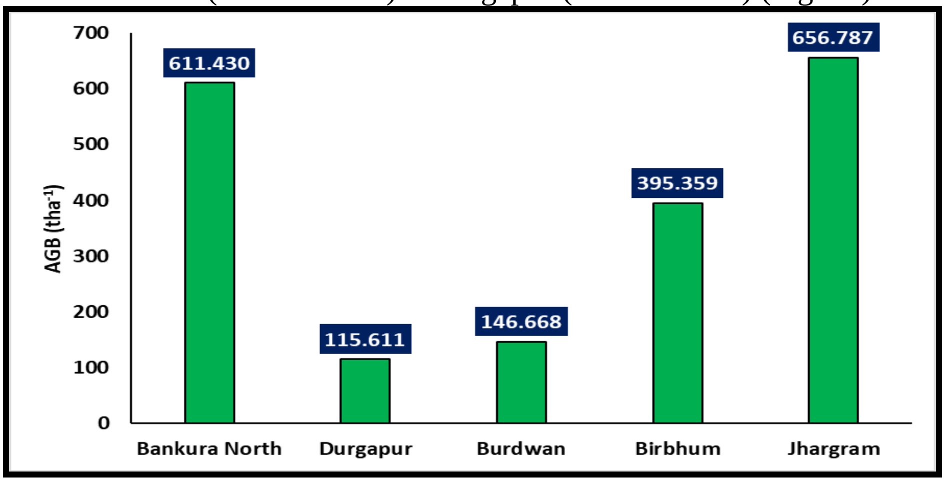


Fig. 16. AGB (in tha^{-1}) of Sal in the five selected forest divisions during the study period

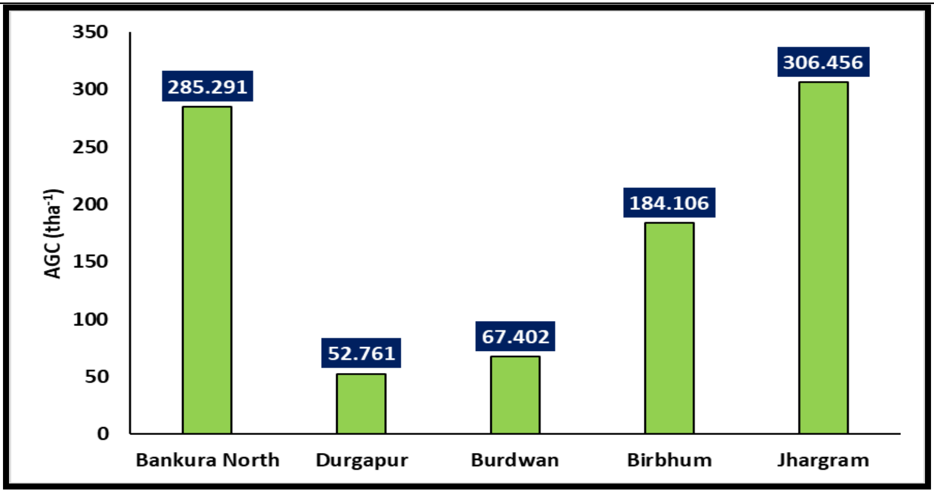


Fig. 17. AGC (in tha^{-1}) of Sal in the five selected forest divisions during the study period

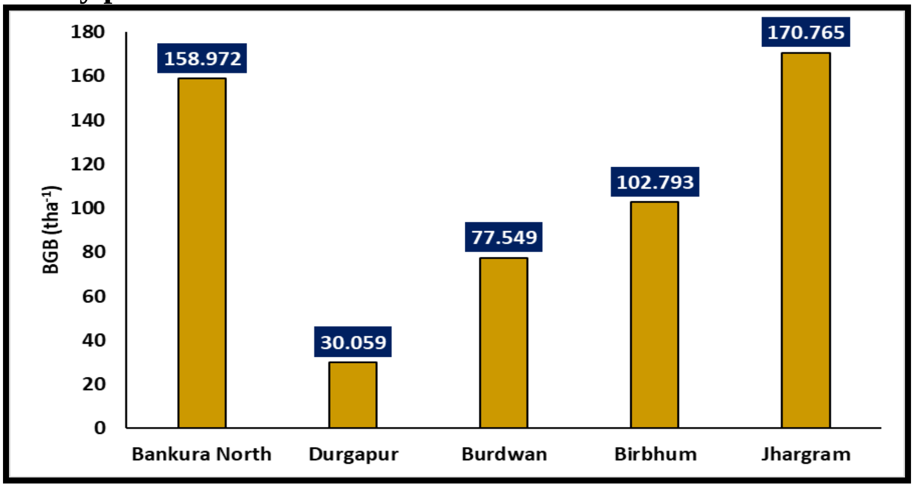


Fig. 18. BGB (in tha^{-1}) of Sal in the five selected forest divisions during the study period

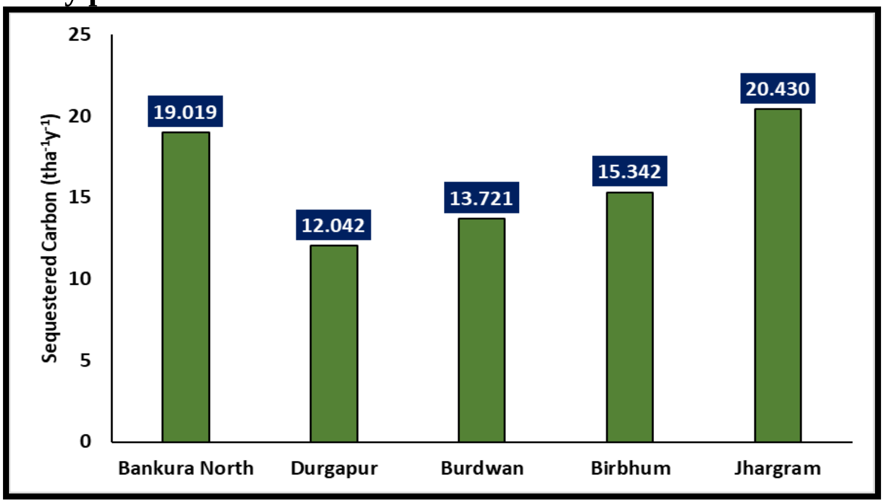


Fig. 19. Sequestered carbon (in tha^{-1}y^{-1}) in AGB of Sal in the five selected forest divisions during the study period

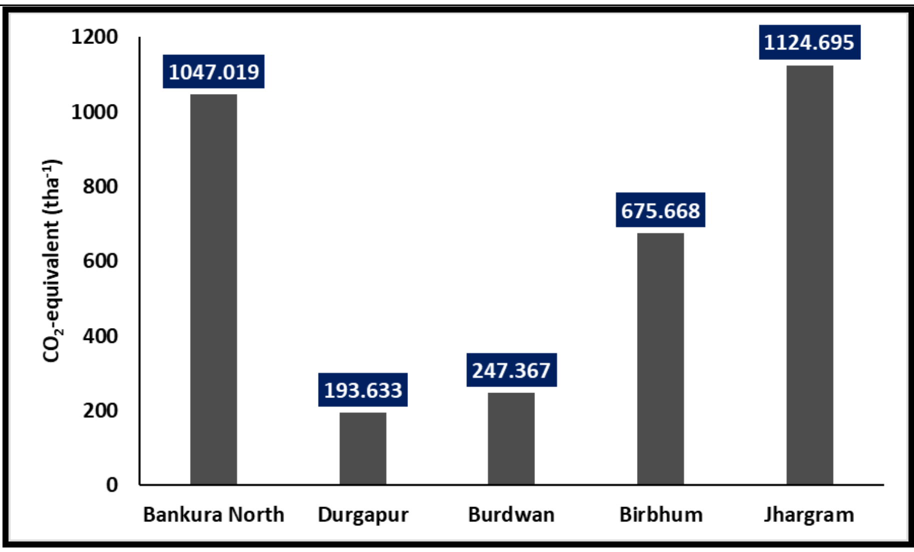


Fig. 20. CO_2-equivalent (in tha^{-1}) of Sal in the five selected forest divisions during the study period

For convenience, division – wise comparative accounts for the three candidate species are highlighted in tables 3, 4 and 5.

Table 3: Biotic Report Card in five selected forest divisions for Akashmoni tree

Divisions	Average AGB (tha^{-1})	Average AGC (tha^{-1})	Average BGB (tha^{-1})	Average Sequestered Carbon ($tha^{-1}yr^{-1}$)	Average CO_2-equivalent (tha^{-1})
Bankura North	191.245	84.189	49.724	7.016	308.975
Durgapur	50.401	23.140	13.104	4.028	84.924
Burdwan	51.247	23.437	13.324	5.217	86.013
Birbhum	171.167	77.984	44.504	5.347	286.200
Jhargram	271.046	125.100	70.472	9.116	459.117

Table 4: Biotic Report Card in five selected forest divisions of Eucalyptus tree

Divisions	Average AGB (tha^{-1})	Average AGC (tha^{-1})	Average BGB (tha^{-1})	Average Sequestered Carbon ($tha^{-1}yr^{-1}$)	Average CO_2-equivalent (tha^{-1})
Bankura North	654.024	300.940	170.046	25.078	1104.450
Durgapur	145.460	63.967	37.819	9.597	234.758
Burdwan	155.700	64.124	40.482	16.031	235.334
Birbhum	624.562	286.820	162.386	16.413	1052.630
Jhargram	751.887	346.552	195.491	28.879	1271.844

Table 5: Biotic Report Card in five selected forest divisions of Sal tree

Divisions	Average AGB (tha^{-1})	Average AGC (tha^{-1})	Average BGB (tha^{-1})	Average Sequestered Carbon ($tha^{-1}yr^{-1}$)	Average CO_2-equivalent (tha^{-1})
Bankura North	611.430	285.291	158.972	19.019	1047.019
Durgapur	115.611	52.761	30.059	12.042	193.633
Burdwan	146.668	67.402	77.549	13.721	247.367
Birbhum	395.359	184.106	102.793	15.342	675.668
Jhargram	656.787	306.456	170.765	20.430	1124.695

2. Abiotic Components

The abiotic components have great influence on the forest floral community *e.g.*, the edaphic factors like SOC, pH etc. regulate the survival and growth of the plants, which in turn pose a considerable impact on the ambient carbon dioxide level. Based on our ground-zero monitoring of abiotic components like near surface atmospheric carbon dioxide, SOC and soil pH, we frnish here the abiotic report cards in and around the habitats of the three floral candidate species separately for five forest divisions of South Bengal in Tables 6, 7 and 8.

2.1 Average Near Surface Atmospheric CO_2 (ppm)

In the present study, the average near surface atmospheric CO_2 level in **Akashmoni forest habitat** varied as per the order Durgapur (391 ppm) > Burdwan (386 ppm) > Birbhum (372 ppm) > Bankura North (348 ppm) > Jhargram (329 ppm); the average near surface atmospheric CO_2 level in **Eucalyptus clone habitat** varied as per the order Durgapur (397 ppm) > Burdwan (394 ppm) > Birbhum (378 ppm) > Bankura North (353 ppm) > Jhargram (336 ppm) and the average near surface atmospheric CO_2 level in **Sal forest habitat** varied as per the order Durgapur (388 ppm) > Burdwan (365 ppm) > Birbhum (351 ppm) > Bankura North (334 ppm) > Jhargram (318 ppm) (*Vide* Tables 6, 7 and 8; Figs. 21, 22 and 23).

Table 6: Abiotic Report Card of Akashmoni tree habitat in five selected forest divisions

Divisions	Average Near Surface Atmospheric CO_2 (ppm)	Average SOC	Average pH
Bankura North	348	1.43	6.70
Durgapur	391	1.14	6.79
Burdwan	386	1.39	6.76
Birbhum	372	1.4	6.70
Jhargram	329	1.56	6.67

Table 7: Abiotic Report Card of Eucalyptus tree habitat in five selected forest divisions

Divisions	Average Near Surface atmospheric CO_2 (ppm)	Average SOC	Average pH
Bankura North	353	1.18	6.74
Durgapur	397	1.06	6.91
Burdwan	394	1.1	6.89
Birbhum	378	1.15	6.85
Jhargram	336	1.23	6.71

Table 8: Abiotic Report Card of Sal tree habitat in five selected forest divisions

Divisions	Average Near Surface atmospheric CO_2 (ppm)	Average SOC	Average pH
Bankura North	334	1.72	6.72
Durgapur	388	1.28	6.81
Burdwan	365	1.54	6.8
Birbhum	351	1.69	6.76
Jhargram	318	1.87	6.69

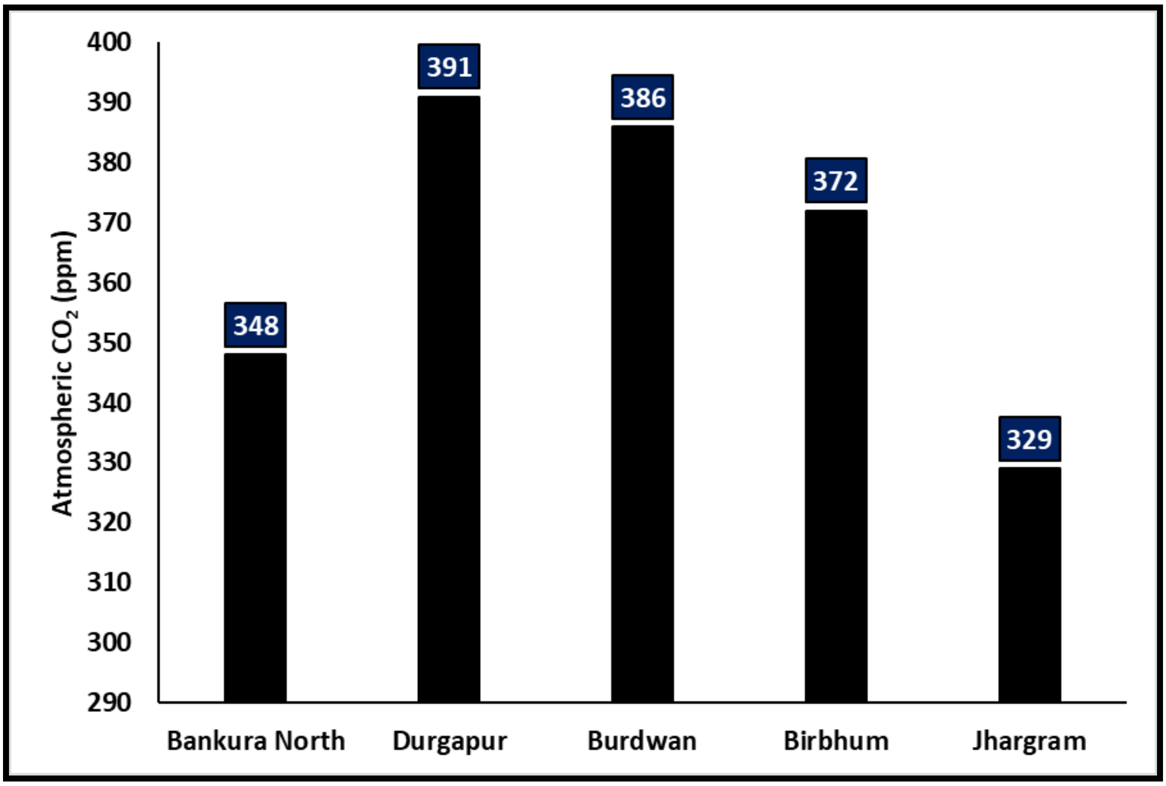


Fig. 21. Near surface atmospheric CO_2 (in ppm) in and around the Akashmoni forest habitat in the five selected forest divisions in South Bengal

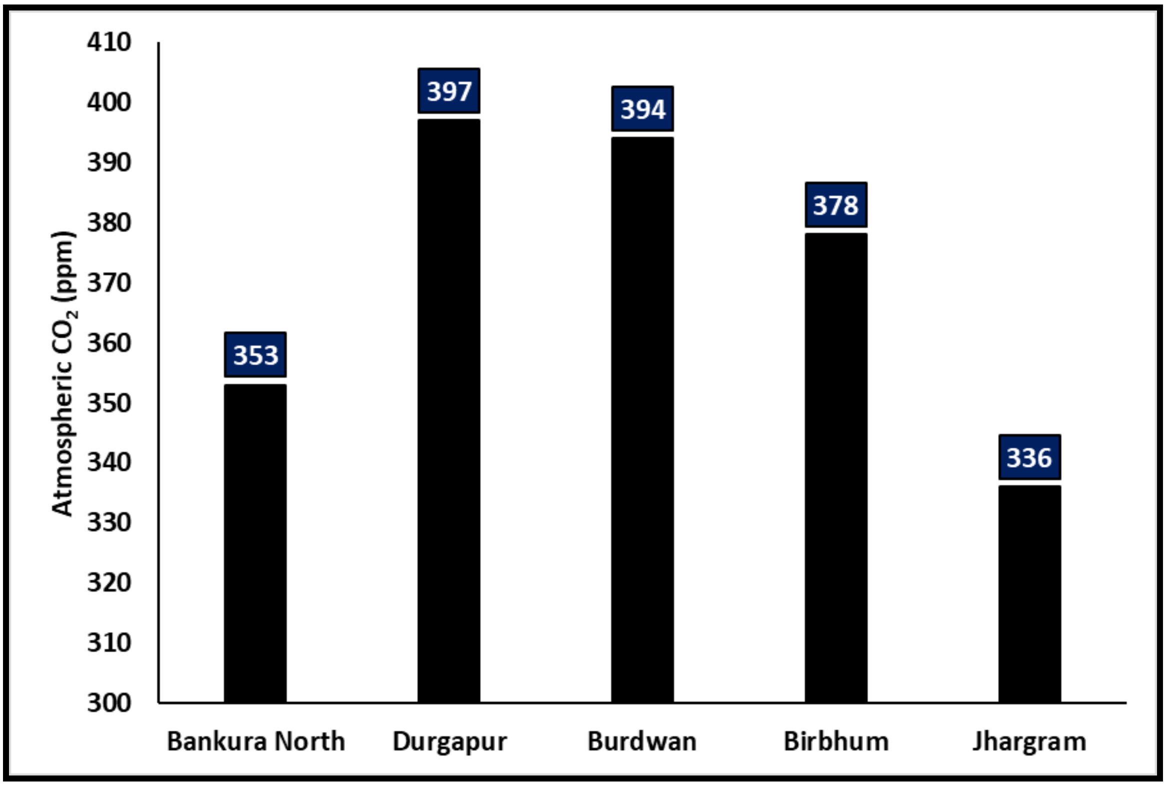


Fig. 22. Near surface atmospheric CO_2 (in ppm) in and around the Eucalyptus forest habitat in the five selected forest divisions in South Bengal

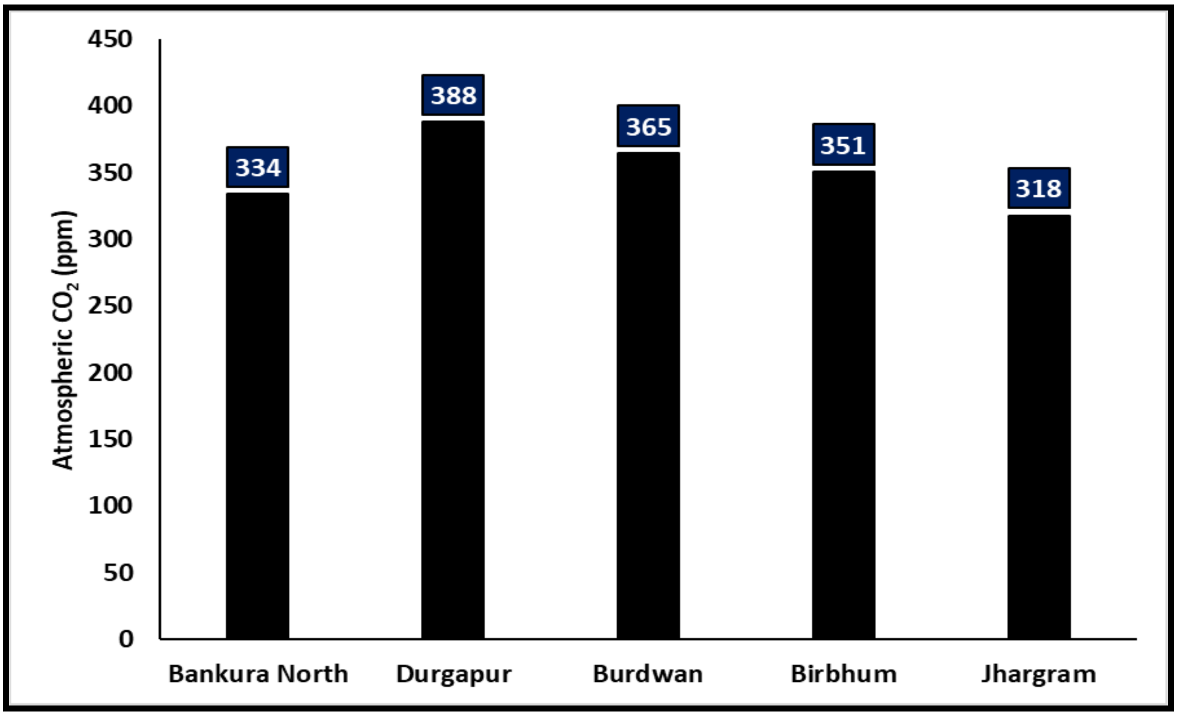


Fig. 23. Near surface atmospheric CO_2 (in ppm) in and around the Sal forest habitat in the five selected forest divisions in South Bengal

2.2 Soil Organic Carbon (SOC)

The average soil organic carbon in **Akashmoni forest habitat** varied as per the order Jhargram (1.56 %) > Bankura North (1.43 %) > Birbhum (1.40 %) > Burdwan (1.39 %) > Durgapur (1.14 %); the average soil organic carbon in **Eucalyptus clone habitat** varied as per the order Jhargram (1.23 %) > Bankura North (1.18 %) > Birbhum (1.15 %) > Burdwan (1.10 %) > Durgapur (1.06 %) and the average soil organic carbon in **Sal forest habitat** varied as per the order Jhargram (1.87 %) > Bankura North (1.72 %) > Birbhum (1.69 %) > Burdwan (1.54 %) > Durgapur (1.28 %) (*Vide* Tables 6, 7 and 8; Figs. 24, 25 and 26).

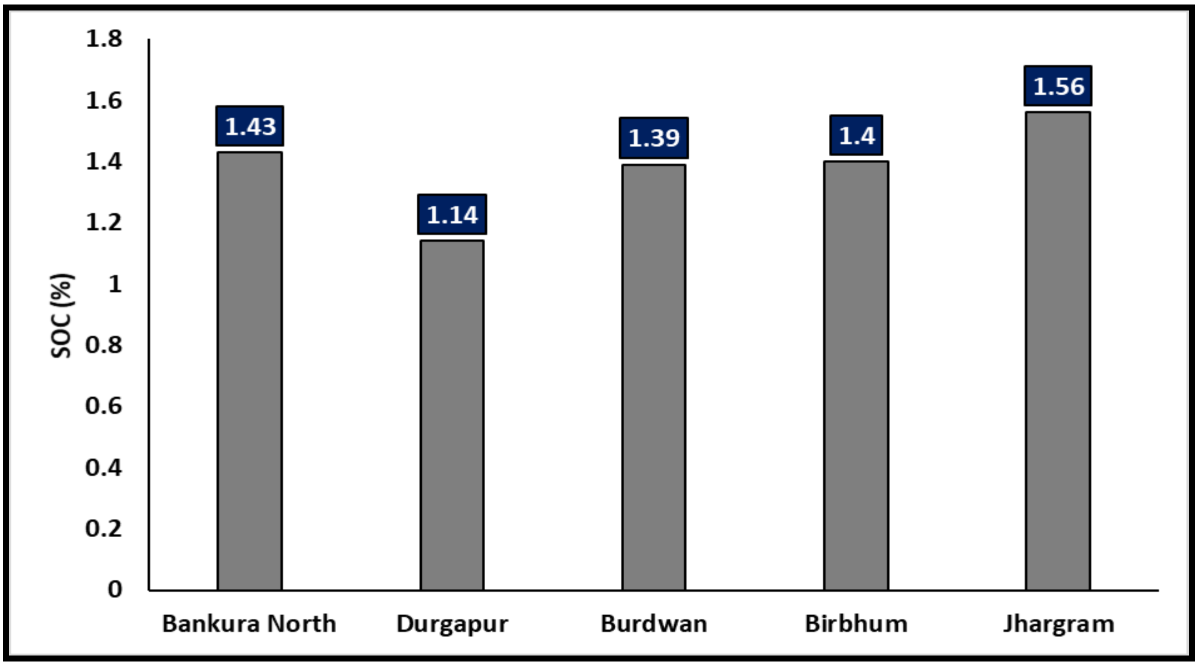


Fig. 24. Soil Organic Carbon (in %) in the Akashmoni forest habitat of five selected forest divisions in South Bengal

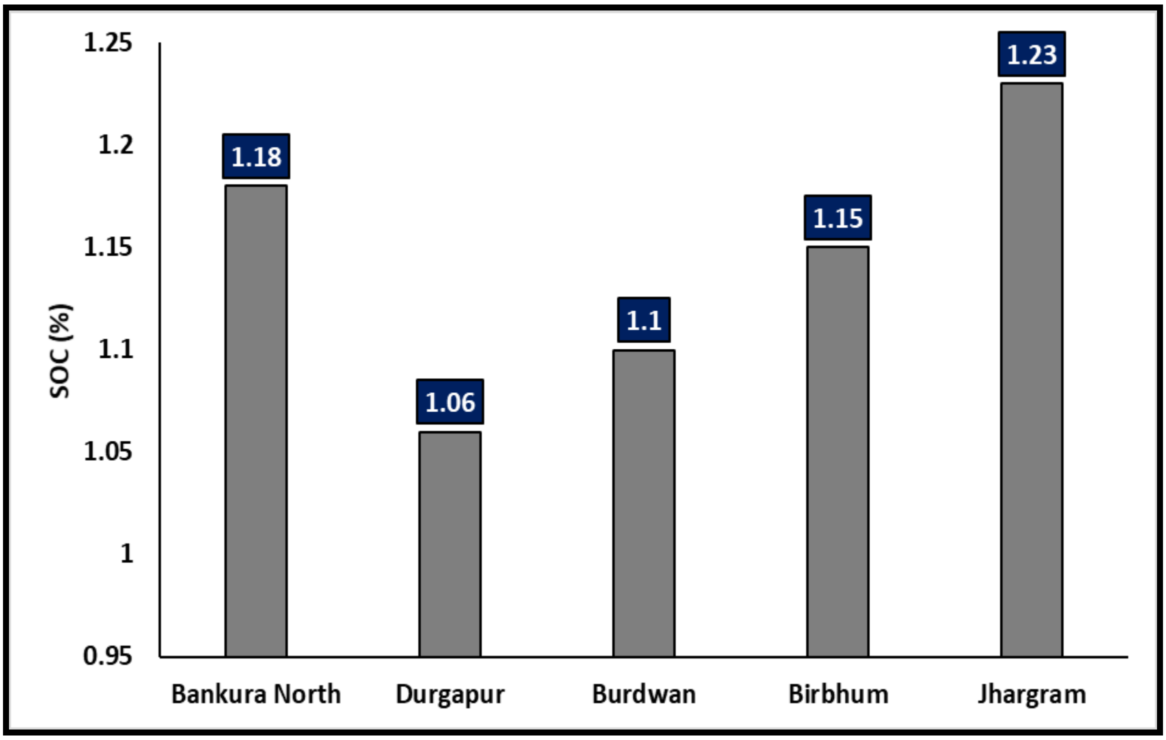


Fig. 25. Soil Organic Carbon (in %) in the Eucalyptus forest habitat of five selected forest divisions in South Bengal

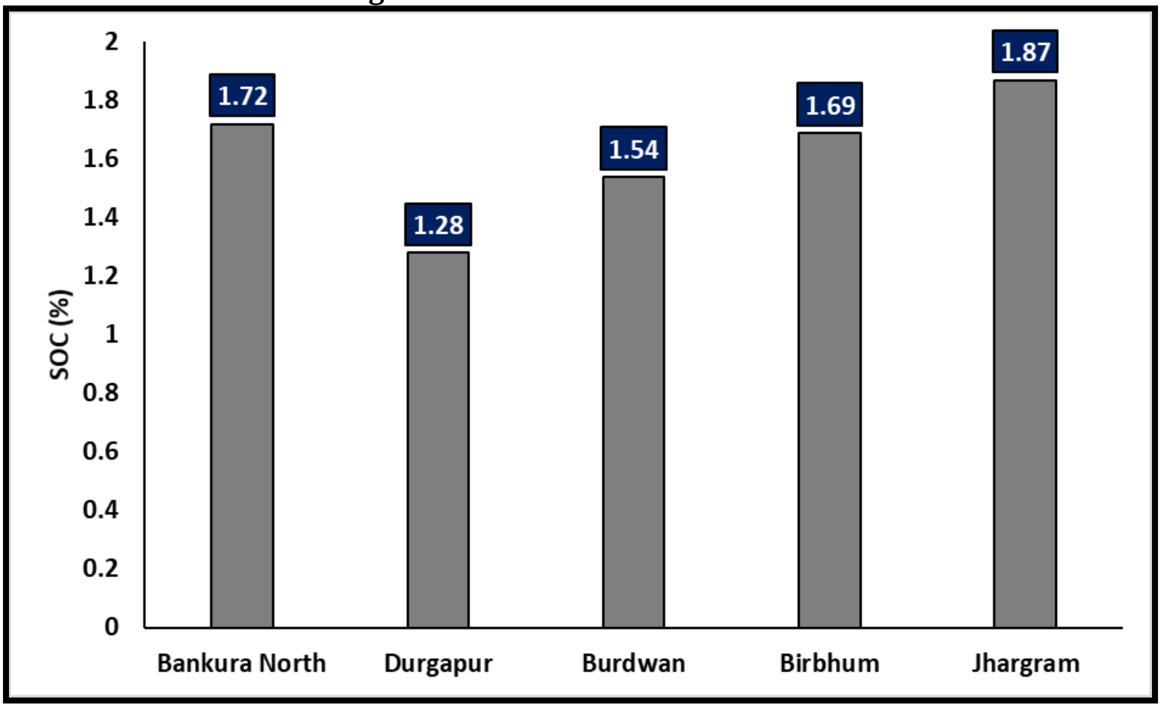


Fig. 26. Soil Organic Carbon (in %) in the selected Sal forest habitat during study period

2.3 Soil pH

The average pH in **Akashmoni forest habitat** varied as per the order Durgapur (6.79) > Burdwan (6.76) > Birbhum (6.70) = Bankura North (6.70) > Jhargram (6.67); the average pH in **Eucalyptus clone habitat** varied as per the order Durgapur (6.91) > Burdwan (6.89) > Birbhum (6.85) > Bankura North (6.74) > Jhargram (6.71) and the average pH in **Sal forest habitat** varied as per the order Durgapur (6.81) > Burdwan (6.80) > Birbhum (6.76) > Bankura North (6.72) > Jhargram (6.69) (*Vide* Tables 6, 7 and 8; Figs. 27, 28 and 29).

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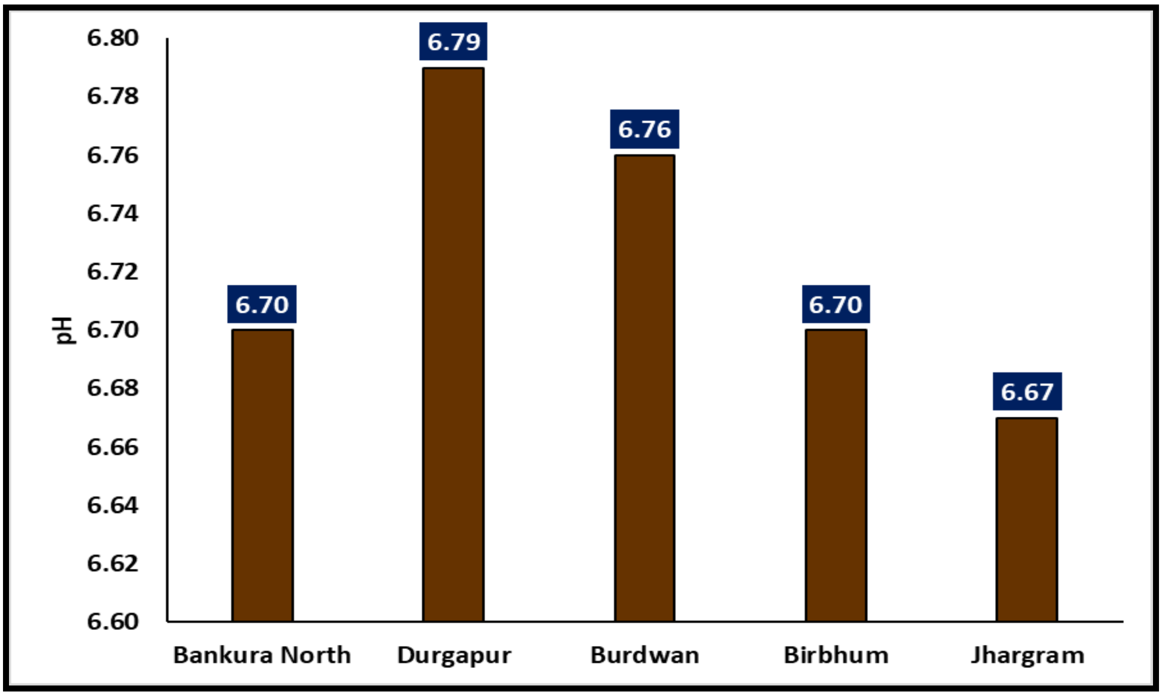

Fig. 27. Soil pH in the Akashmoni forest habitat of five selected forest divisions in South Bengal

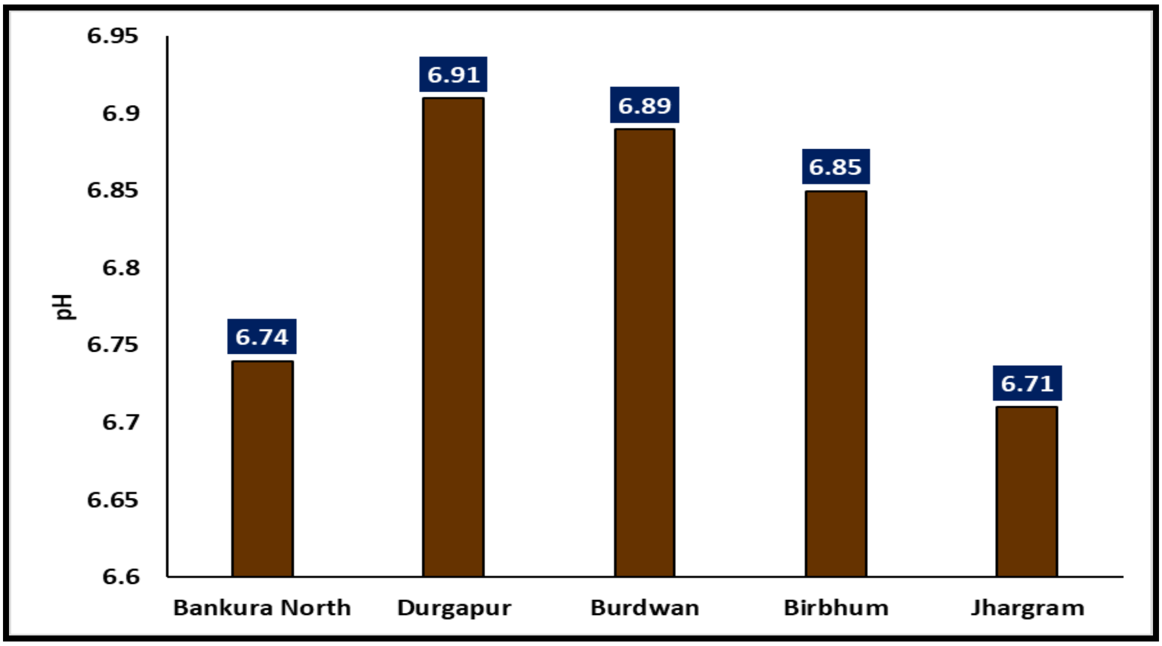

Fig. 28. Soil pH in the Eucalyptus forest habitat of five selected forest divisions in South Bengal

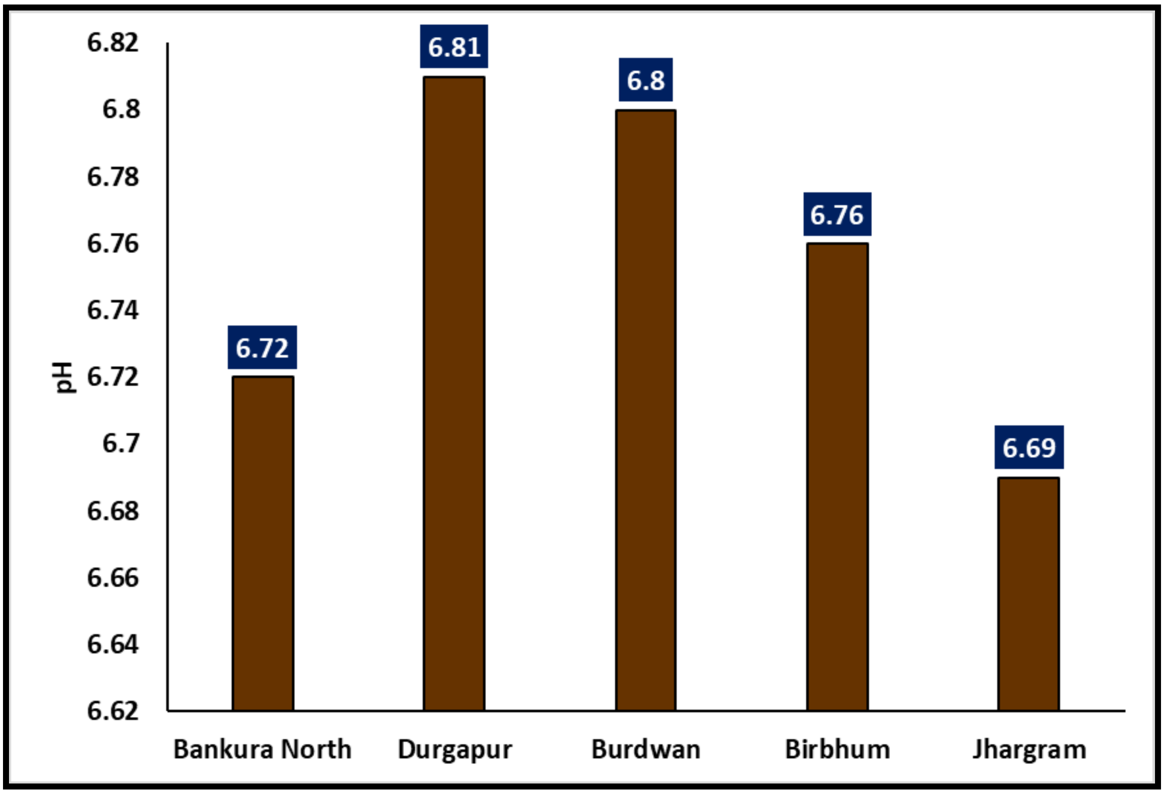

Fig. 29. Soil pH in the Sal forest habitat of five selected forest divisions in South Bengal

DISCUSSION

The results obtained through our survey in five divisions of South Bengal generated few core findings as listed here.

1. The values of AGB, AGC, CO_2 –equivalent (based on AGC), sequestered carbon and BGB exhibit spatial variation as per the order Jhargram > Bankura North > Birbhum > Burdwan > Durgapur

Probable reasons
1. Edaphic factors like SOC and soil pH are at optimum levels in Jhargram followed by Bankua North, Birbhum, Burdwan and Durgapur. 2. Anthropogenic pressure is highest in Durgapur followed by Burdwan and Birbhum, North Bankura and Jhargram. Areas with high anthropogenic activities have more SPM in the ambient air due to which the stomatal openings of the leaves get closed and carbon dioxide diffusion is obstructed subsequently leading to low values of the biotic variables (like AGB, AGC, CO_2-equivalent, sequestered carbon and BGB) in divisions like Durgapur.

2. Species- wise variations of AGB, AGC, CO_2-equivalent, sequestered carbon and BGB exhibit the order Eucalyptus > Sal > Akashmoni.

Probable reasons
1. The carbon stored in a particular species is a function of population density, height, DBH, number of branches, leaves and carbon percentage in the vegetative parts. The height of *Eucalyptus* is much more compared to other two species which may be the reason for variation. 2. The area of lamina is also another factor regulating the carbon storage in trees. With more number of stomatal apertures in broad leaves of Sal, the diffusion rate of carbon dioxide is more compared to *Acacia* which has placed Sal after Eucalyptus, although the height of the tree is relatively less

3. The near surface atmospheric carbon dioxide is highest in Durgapur followed by Burdwan > Birbhum > Bankura North > Jhargram

Probable reasons
1. The level of carbon dioxide depends on the urban and industrial activities, which is highest in Durgapur compared to other four divisions. Durgapur Steel Plant, 1.8 MT crude steel producing integrated steel unit of the Steel Authority of India Limited was set up in the late 50's. Its initial capacity was 1 million tonnes of crude steel per annum. It was subsequently enhanced to 1.6 million tonnes in the late sixties. Steel and iron production is reliant on coal, both as a feedstock and a fuel. Unlike cement, emissions arise at different points in the steel production process. Steel mills have a number of furnaces and subunits involved in the production process that emit carbon dioxide. The largest of these are the blast furnaces and the on-site power plant. This may be the reason for highest carbon dioxide level in the Durgapur division compared to other divisions. 2. The density, biomass and types of trees also regulate the ambient carbon dioxide level by way of carbon sequestration, which is highest in Jhargram followed by Bankura North > Birbhum > Burdwan > Durgapur. This is the reason why trees in Jhargram (for all species) exhibit maximum AGC and CO_2-equivalent compared to other four divisions.

For all the species, significant positive correlations were observed between sequestered carbon and the underlying SOC indicating considerable contribution of carbon of the trees to the soil compartment through litter and detritus. The significant negative relationships between sequestered carbon by the selected tree species and near surface atmospheric carbon dioxide confirm the potential of the trees as unique sink of carbon. The sequestered carbon is taken from the CO_2 reservoir of the ambient atmosphere due which the negative correlations have been generated as the output (Table 9).

Table 9: Inter-relationship between Sequestered carbon and abiotic components

Combination	Akashmoni	Eucalyptus	Sal
Sequestered Carbon × CO_2	-0.9740 ($p<0.01$)	-0.9469 ($p<0.01$)	-0.9894 ($p<0.01$)
Sequestered Carbon × SOC	0.7635 ($p<0.01$)	0.9098 ($p<0.01$)	0.9160 ($p<0.01$)
Sequestered Carbon × pH	-0.7925 ($p<0.01$)	-0.9202 ($p<0.01$)	-0.9899 ($p<0.01$)

CONCLUSION
&
RECOMENDATION

Few conclusive statements that are relevant in context to the present monitoring programme are stated here in points.

1. The floral species in the Jhargram forest division exhibited maximum biomass and subsequently more stored and sequestered carbon compared to other four sites. This may be the possible reason for maximum SOC level in the soil compartment of this division. The lowest CO_2 value in the atmosphere of this division confirms the absorption of atmospheric CO_2 by the forest vegetation.

2. The highest negative correlation values between sequestered carbon of Sal and atmospheric carbon dioxide ($r = -0.9894$; $p < 0.01$) points towards the broad leaves of the species as the natural tool to sequester carbon more efficiently compared to Eucalyptus and Akashmoni.

3. In all the divisions, the stored and sequestered carbon is directly proportional to plant biomass, which calls for an urgent need of upgrading the edaphic factors to keep up the plant health, preferably in terms of soil pH.

4. The direct correlations of SOC with AGB and AGC of the trees point towards the positive role of SOC in enriching the natural fertility of the soil.

From the entire observations few first order recommendations are listed here in points.

- A two - year seasonal study on carbon sequestration by trees of South Bengal forest divisions is recommended to evaluate the seasonal pattern of carbon storage by the candidate species in response to ambient environmental variables.

- The nursery adjacent to Arrah Forest Rest House (in Durgapur division), showed a soil pH around 5.82, where sprinkling of 2% lime at fortnightly interval is suggested for 6 months during the period of nursery raising, preferably in the premonsoon season

- Use of organic fertilizer (liquid form) is recommended. This may be sourced / manufactured from endemic floral species (Annexure A).

Annexure A: Composition of organic fertilizer

Ingredient	N	P_2O_5	K_2O	Ca	Mg	S	Comments
Blood (dried)	12-15	2-3	1	BDL	BDL	BDL	Good source of nutrients
Blood meal (steamed)	15	0.5-1	1	BDL	BDL	BDL	Good source of nutrients
Bone meal (steamed)	~ 1.8	10-20	0	18-30	0	0	Low nitrogen and moderate source of nutrients
Compost (garden)	V	V	V	V	V	V	Depending on the ingredients and technology, the composition varies
Cotton seed meal	6-7	2.5	1.5	BDL	BDL	BDL	Good source of nutrients
Cotton seed hull ash	0	0	27	BDL	BDL	BDL	Noted for high potassium level
Fish scrap (Acidulated)	8.5-9.5	1-2	0	BDL	BDL	2.0	Rich in nitrogen, but bioaccumulated heavy metals and pesticides are causes of concern
Dried fish meal	8.5-10.0	0	0	5.8	BDL	BDL	Rich in nitrogen, but bioaccumulated heavy metals and pesticides are causes of concern
Legume	2-3	2.4	2.4	1.2	0.2	0.3	Balanced nutrient level
Cattle manure	0.5-2	1.5	1.1-1.2	1.1	0.3	BDL	-
Broiler litter	2-3	3.0	2.0	1.6-1.9	0.4	0.3	Balanced nutrient level

V = Variable; BDL = Below Detectable level

PLATES

PLATES

Plate 1

Fig. A1: CFC location for Akashmoni in the South Bengal Forest Division

Fig. A2: CFC location for Eucalyptus in the South Bengal Forest Division

Plate 2

Fig. A3: CFC location for Sal in the South Bengal Forest Division

Fig. A4: Quadrate study (10 m × 10 m) for assessing carbon sequestration in Jhargram division (Drone view)

Plate 3

Fig. A5: Quadrate study (10 m × 10 m) for assessing carbon sequestration in Birbhum division (Drone view)

Fig. A6: Quadrate study (10 m × 10 m) for assessing carbon sequestration under Rampurhat range (Drone view)

Plate 4

Fig. A7: Tracking the coordinates by GPS

Fig. A8: Measuring the DBH at 1.37 meter height from the ground

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