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Tropical Deciduous Forests Possess High Carbon Storage Potential in High Lands of Eastern Ghats

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ABSTRACT

Understanding the vegetation, species distribution, biomass and carbon in forests can only pave the way for better forest health, productivity and protection with purification of the environment through removal of CO_2 from the atmosphere. In the present study, we analyzed the biomass and carbon in three sites of 250×250 m^2 plot area each in tropical dry deciduous forests of Nabarangpur district of Odisha. Diversity study was done by calculating relative abundance (%) and above ground biomass (AGB) was estimated from field inventory data. The pre-dominating trees during the study period of 2017-2021 were *Shorea robusta* (61.76%), *Pterocarpus marsupium* (13.60%), *Terminalia tomentosa* (11.40%), *Syzygium cumini* (10.71%) and *Schleichera oleosa* (7.07%) respectively. The species-wise average biomass and carbon in all the study sites in all the seasons showed the trend of *Shorea robusta* (0.37 Mg ha^{-1} ; 0.17 Mg ha^{-1}) > *Pterocarpus marsupium* (0.09 Mg ha^{-1} ; 0.04 Mg ha^{-1}) > *Terminalia tomentosa* (0.06 Mg ha^{-1}; 0.03 Mg ha^{-1}) > *Syzygium cumini* (0.03 Mg ha^{-1} ; 0.01 Mg ha^{-1}) > *Schleichera oleosa* (0.02 Mg ha^{-1}; 0.014 Mg ha^{-1}) respectively. Biomass is associated with tree DBH, height and basal area, which showed a strong positive correlation (R^2=0.59 - 0.92) between these parameters. Study reflected biomass has increased with the increase of DBH, height and basal area. The present study concluded that the study area is very congenial for the growth both in terms of biomass and carbon stock, which can serve as a baseline for planning and management of forest resources in mitigating climate change.

Key words : *Biomass, Carbon, Climatic parameters, Edaphic parameters, Tropical deciduous forest*

Introduction

Forests cover 4.03 billion hectare area all over the world which is about 30% area of the Earth, contributing 75% gross primary production (GPP), 80% total biomass including plant and soil carbon (Kindermann *et al.*, 2008; FAO, 2010; Beer *et al.*, 2010; Pan *et al.*, 2011). India ranks 10th among the 12 mega-diverse countries in the world with huge areas of forests accounting to 23.4% in India. As per the data of Global Forest Resources Assessment the rate of net forest loss declined from 7.8 m ha y^{-1} in the decade 1990-2000, 5.2 m ha y^{-1} in 2000-2010 and 4.7 m ha y^{-1} in 2010-2020 (FAO, 2020). This is a result of reduction in deforestation in some countries and simultaneous afforestation and natural expansion of the forest. It is being also reported that 93% (3.75 b ha) of the forest area worldwide is composed of naturally regenerated forest and 7% (290 m ha) is planted (FAO, 2020). The proportion of introduced and native species in planted forest accounts for 70% and introduced and 30% native species in Africa and vice-versa for Asia; 78% introduced and 22% native species in Europe, which is equals to Oceania; 3% introduced and 97% native species in North and Central America and vice-versa in South America. Overal 45% plantation in the world comprises of introduced species and 55% of native species (FAO, 2020).

The increased level of CO_2 *viz*. 410 ppm as per 2020 is an alarming signature and global environmental issue. Terrestrial forests constitute around 80% of carbon stock in their above ground biomass in the process of photosynthesis (Pan *et al.*, 2013). It is estimated that global forest carbon pool consists of 363 Pg C as per the field data. India ranks 5^{th} in the world in CO_2 emissions although it has high potentiality of carbon sequestration in the forest vegetation (Sathayea and Reddy, 2013). Carbon sequestration can be enhanced to mitigate this CO_2 emission with the changing land use pattern through afforestation or reforestation in the marginal areas.

Forest soil is also one of the important carbon storage sink, although this varies from place to place (Peichal *et al.*, 2006). Soil organic matter which is a direct function of organic carbon is a source of energy and influences the water holding capacity of the soil and improve plantation, Hence soil organic matter also provides economic benefits in terms of ecosystem services (Sparling *et al.*, 2006).

Above Ground Biomass (AGB) is considered important carbon sink along with the soil. The last report of Intergovernmental Panel on Climate Change (IPCC) has therefore focused on the determination of biomass and carbon in trees along with organic carbon (OC) in soil (Cihlar *et al.*, 2007). However, there is a large degree of uncertainty in the estimation of carbon spatially (Hese *et al.*, 2005). Regional studies of biomass estimation can be broadly classified in to different vegetation patterns like grasslands, primary forest and secondary forest. Calculation of AGB in primary and secondary forest seasonally gives potential biomass estimation because they are subjected to grazing and climatic variables (temperature and precipitation) (Scanlon *et al.*, 2005; San-Jose and Montes, 2007).

Mapping of Land Use Land Cover (LULC) changes with respect to forest classification and ground based AGB calculation help us to understand the changes in the forest cover vis-à-vis carbon assimilation or storage. In order to facilitate this process allometric equations of dependent variables like height (H), diameter at breast height (DBH) and basal area (BA) with biomass as independent variable are done from direct measurements. The present paper has highlighted this aspect of biomass estimation and its relationship with climatic and edaphic parameters in orders to pin-point the factors responsible for biomass enhancement in trees and its subsequent carbon stock enhancement in order to meet the consequences of global climate change.

Materials and Methods

Study area

The Nabarangpur district is located at 81°52' to 82°53' E Longitude and 19°09' to 20°05' N Latitude and covers over an area of approximately 5306.11 km^2. It shares its border with Kalahandi and Rayagada Districts in the East, Jagdalpur District in Chhattishgarh to the west, Kalahandi District to the North and Koraput District to the South. Out of the total geographical area of the district, total forest area is 1562.08 km^2, which constitutes about 29.44% of the total geographical area of the district (As per the USGS Landsat 8 satellite data of 2021 in the month of November - December).

The study area comprises of three sites where their elevations ranged from 620-640 m and are situated outside the Nabarangpur main town. The slope of the Site 1 (Bariguda) ranged from 2°-5° with North aspect, Site 2 (Majhiguda) has 5°-7° with South aspect and Site 3 (Kerduguda) has 2°-5° with North-East aspect. According to Champion and Seth Classification (1968) based on the rainfall and vegetation types, 18 forest types are present in Odisha and Nabarangpur forests that are under the category of 5A/C3 Southern Dry Mixed Deciduous Forests of Odisha. Sal (*Shorea robusta*) is the dominant plant making the top canopy of these forests. The forest floor is 85-90% covered by herbaceous layer in Site1, 70-80% in Site 2 and 75-85% in Site 3; about 2-5% of stoniness (stones, boulder and pebbles) and 1-4% of rock outcrop (exposed rocks) in Site 1, 5-10% stoniness and 2-5% of rock outcrop in Site 2 and 4-5% stoniness and 5-10% rock outcrop in Site 3. Soil type is alluvial, soil texture is loam and brown to black-brown in color. Brown-red to black- brown color humus with 1.5 to 2.5 cm thickness can be seen in the area. Qualitative assessment of canopy density for biomass estimation of forest has been done by visual assessment. 70-80% of crown density is present in Bariguda, 60-80% in Majhiguda and 50-75% in Kerduguda. Stand height (the average of the observations of 3-4 top and 3-4 co-dominant trees canopies in the plot with range finder) varies between 10-16 m in each plot (Fig. 1).

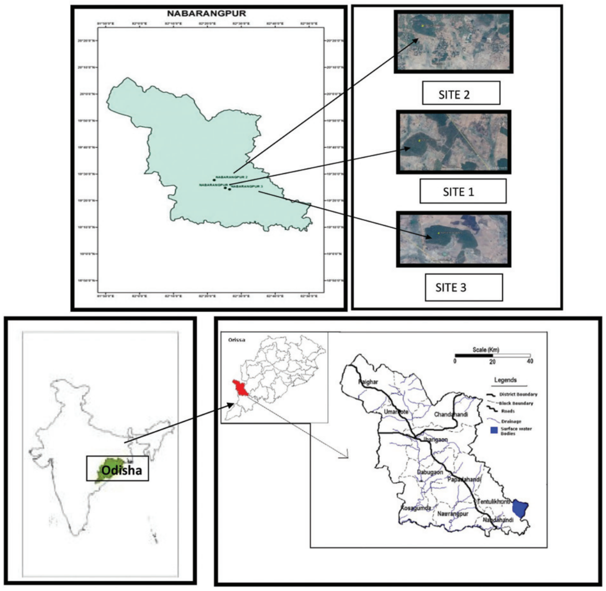

Fig. 1. Map of Nabarangpur District showing the three study sites

Vegetation study

The co-ordinates (latitude and longitude) provided by NRSC, Hyderabad of each site were transferred on topo-sheet first or satellite data from Google Earth. We surveyed 250 m × 250 m area of each site which is the main super-plot area and within these super-plot area 4 sub-plots were laid down in the 4 corners of the super-plot with a dimension of 31.6 m × 31.6 m for measuring individual tree species as per the methodology provided by NRSC, Hyderabad) (Fig. 2). The minimum size of the diameter at breast height (DBH) is ≥ 10 cm that was considered for carrying out this study. Quantitative assessment of vegetation was done by relative abundance (%) as per the standard formulae (Sahu *et al.*, 2016). Forest cover assessment was done using remote sensing data of Landsat 8 with 30 m resolution obtained from USGS.

Biomass and carbon studies

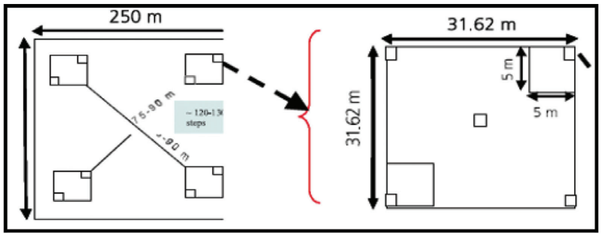

Fig. 2. Sampling design for vegetation structure analysis

We have measured diameter at breast height (DBH), i.e. circumference of the plant at 1.37 m above from the ground with the use of measuring tape. The height of the tree was measured using Bosch Range Finder DLE 40 professional instrument. The stem volume of each tree was measured by the following formula (Banerjee *et al.*, 2020)

$$V = \pi r^2 H$$

Where, V = volume of the plant, π = 3.14, r = radius of the plant H = height of the plant,

Specific gravity (g) of the wood was determined by taking the stem cores of 1 cm^3 (Chaturvedi *et al.*, 2010) which was further converted into stem biomass as per the expression of (Brown and Lugo, 1992).

$$B = g \times V$$

Where, B=Biomass, g=specific gravity and V=volume of stem

Tree basal area (BA) is the cross-sectional area at the breast height which is expressed in m^2 and measured by the following expression (Sahu *et al.*, 2016):

Stand basal area is the sum of the basal area of each tree in the plot. It was measured by the following formula:

$$\text{Stand basal area } (m^2\ ha^{-1}) = \frac{\text{Sum of the basal area of each tree in the plot}}{\text{area of the plot}}$$

Biomass values were converted to carbon stocks using default carbon conversion factor (=0.47) as per (IPCC, 2006).

Study of temperature and rainfall pattern

Temperature and rainfall data from 2019 to 2021 was obtained from Indian Meteorological Department, Bhubaneswar to find out the pattern of rainfall and temperature over the district and whether such variation is the cause for the changes in vegetation pattern and biomass of the forest patches.

Analysis of soil physico-chemical parameters

The soil temperature was measured by using digital thermometer (SIGMA). The soil pH was measured by using digital pH meter (SYSTRONICS). Soil Nitrogen was estimated through automatic distillation system (Model Classic DX). Soil phosphorus (P) in soil was determined by Olsen's method (Olsen *et al.*, 1954). Soil potassium (K) was measured by the standard flame photometry method. Soil organic carbon content of the soil samples were analyzed by the standard method (Walkley and Black, 1934).

Statistical analysis

The biomass values of trees were correlated with the soil physico-chemical parameters to understand their effects on biomass of trees. Regression equations were computed in order to find the relationship of biotic parameters on the biomass of trees.

Results

Vegetation structure and composition

In case of diversity study of tree species during 2017-2021, we enumerated 32 tree species including 27 genera and 20 families in all the three sites of tropical deciduous forests of Nabarangpur district of Odisha. Fabaceae was the highest dominating tree family followed by Anacardiaceae and Combretaceae as co-dominating families during the study period (Figs. 3 & 4).

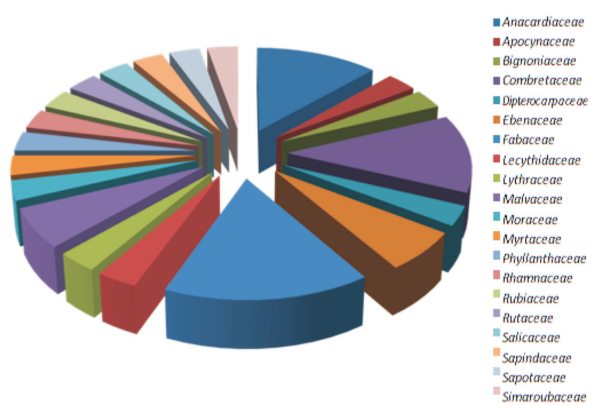

Fig. 3. Family-wise distribution of tree species at the study sites during 2017-2021

Relative abundance (RA) analysis of tree species in Site-1 showed the dominancy of *Shorea robusta with* 35.44% and co-dominating species was *Pterocarpus marsupium* (13.60%); in Site-2, the trend of RA was *Shorea robusta (36.56%) > Pterocarpus marsupium (12.26%) > Terminalia tomentosa (11.40%)* respectively; and in Site-3, *Shorea robusta* showed highest value of 61.76% with *Syzygium cumini (10.71%)* as co-dominating plant (Fig. 4).

Forest in the study area classified into Dense

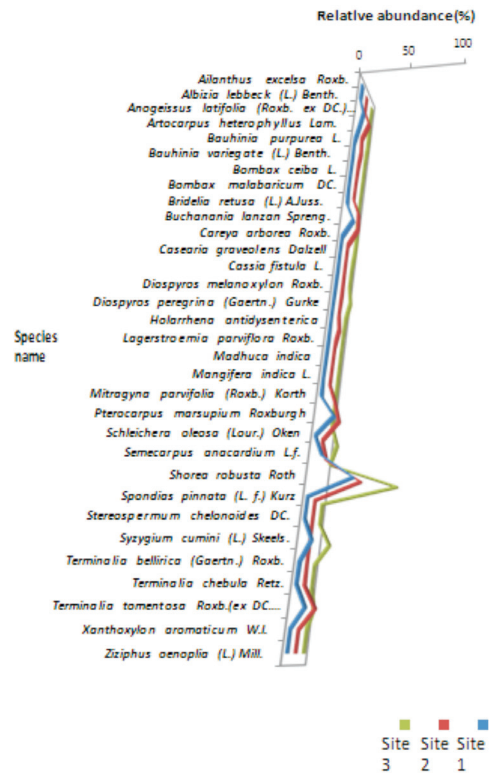

Fig. 4. Relative abundance (%) of all the tree species during 2017-2021

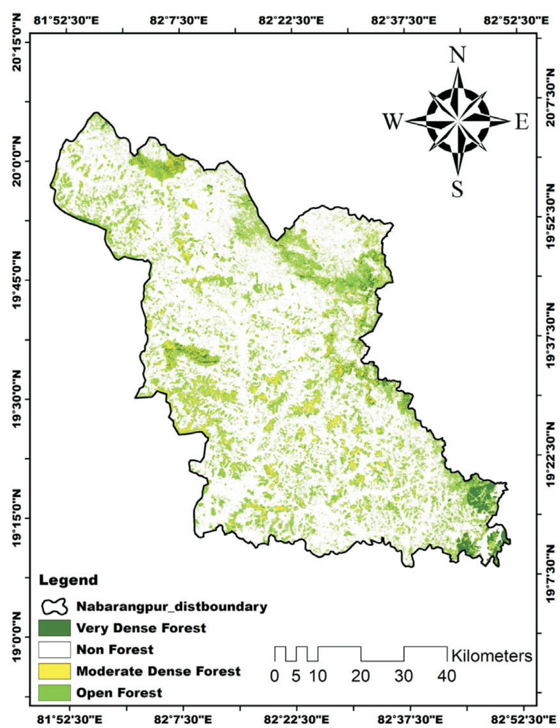

Fig. 5. Forest cover classification of the study site

Forest = 21,464 hectares (4.05%); Moderate Dense Forest = 25,099 hectares (4.73%); Open Forest= 10,9645 hectares (20.66%)] respectively (Fig. 5). The total forest constitutes 29.4% of the district and hence is thought to be potential source of carbon sink about 3, 74,402 hectares is non-forest area which is about 70.56 % of the total geographical area of the study site.

Above ground biomass and carbon

The study showed 728 number of trees from Site 1, 465 number of trees from Site 2 and 523 number of trees from Site 3 respectively during 2017-2021. The standing total tree biomass showed 1.51 Mg in Site 1, 1.3 Mg in Site 2 and 1.36 Mg in Site 3 respectively in the post-monsoon season. Pre-monsoon biomass values were 1.5 Mg in Site 1, 1.32 Mg in Site 2 and 1.37 Mg in Site 3 respectively. In monsoon season, estimated biomass showed the values of 1.53 Mg in Site 1, 1.33 Mg in Site 2 and 1.39 Mg in Site 3 respectively (Table 1 & Fig. 6). Species-wise biomass of trees at Site 1 during monsoon season showed maximum average biomass of *Shorea robusta* (0.77 Mg) and minimum in *Ziziphus oenoplia* (0.014 Mg). The trend of biomass as seen in Site 1 during monsoon was *Shorea robusta* (0.77 Mg) > *Pterocarpus marsupium* (0.23 Mg) > *Terminalia tomentosa* (0.13 Mg) > *Anogeissus latifolia* (0.11 Mg) > *Semicarpus anacardium* (0.1 Mg); in Site 2, Maximum average biomass was shown for *Shorea robusta* (0.58 Mg) and minimum for *Diospyros melanoxylon* (0.08 Mg) during post-monsoon. Species-wise biomass trend in Site 2 during post- monsoon was *Shorea robusta* (0.58Mg) >*Pterocarpus marsupium* (0.2 Mg) >*Terminalia tomentosa* (0.19 Mg) >*Anogeissus latifolia* (0.11 Mg); in Site 3, *Shorea robusta* (0.94 Mg) showed maximum average biomass and minimum showed for *Ailanthus excels* (0.001 Mg). Species-wise trend of biomass as seen in Site 3 during post-monsoon was *Shorea robusta* (0.94 Mg) > *Syzygium cumini* (0.13 Mg) > *Schleichera oleosa* (0.11 Mg) > *Diospyros peregrine* (0.06 Mg) > *Terminalia tomentosa* (0.03 Mg). Pre-monsoon and monsoon season of species-wise plant biomass also showed similar trend with little increasing trend.

Average diameter at breast height (DBH) in all the study sites during 2017-2019 for the five dominating species were *Shorea robusta* with a range of 0.20-0.21 m, *Pterocarpus marsupium* ranging from 0.11-0.20 m, *Terminalia tomentosa* ranging from 0.17-0.19 m, *Syzygium cumini* ranging from 0.15-0.19 m and *Schleichera oleosa* ranging from 0.18-0.19 m. The average tree height in all the study sites and in all the seasons showed *Shorea robusta* ranging from 14.42-14.74 m, *Pertocarpus marsupium* ranging from 9.00-13.52 m, *Terminalia tomentosa* ranging from 9.07-15.12 m, *Syzygium cumini* ranging from 12.07-13.88 m and *Schleichera oleosa* with 12.89 m. The average basal area (BA) and average stand basal area (SBA) of all the study sites during 2017-2021 also measured for *Shorea robusta* (average BA ranging from 0.33-0.36 $m^2 ha^{-1}$ and average SBA ranging from 59.16-110.19 $m^2 ha^{-1}$), *Pertocarpus marsupium* (average BA ranging from 0.09-0.32 $m^2 ha^{-1}$ and average SBA ranging from 0.38-31.32 $m^2 ha^{-1}$), *Terminalia tomentosa* (average BA ranging from 0.22-0.31 $m^2 ha^{-1}$ and average SBA ranging from 5.12-17.18 $m^2 ha^{-1}$), *Syzygium cumini* (average BA ranging from 0.19- 0.26 $m^2 ha^{-1}$ and average SBA ranging from 11.26-15.34 $m^2 ha^{-1}$) and *Schleichera oleosa* (average BA ranging from 0.27-0.30 $m^2 ha^{-1}$ and average SBA ranging from 9.39-10.50 $m^2 ha^{-1}$). The trend of species-wise average above ground biomass in all the sites of Nabarangpur district during 2017-2021 showed the dominating species as *Shorea robusta* (0.37 Mg ha^{-1}) > *Pterocarpus marsupium* (0.09 Mg ha^{-1}) > *Terminalia tomentosa* (0.07 Mg ha^{-1}) >

Table 1. Biomass (Mg ha^{-1}) of trees at the selected sites during the study period

Sites	Number of trees	Biomass (Mg ha^{-1}) Post-monsoon	Pre-monsoon	Monsoon
Site 1	728	1.51	1.52	1.53
Site 2	465	1.31	1.32	1.33
Site 3	523	1.36	1.37	1.39

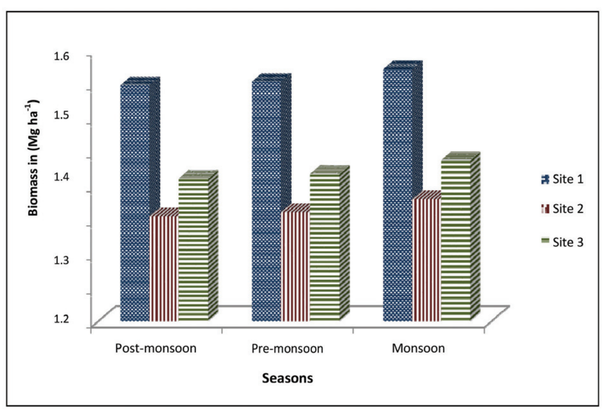

Fig. 6. Seasonal variation in total tree biomass per study site during 2017-2021

Syzygium cumini (0.03 Mg ha^{-1}) > *Schleichera oleosa* (0.02 Mg ha^{-1}).

The standing total tree carbon stocks showed 0.71 Mg in Site 1, 0.62 Mg in Site 2 and 0.64 Mg in Site 3 respectively in the post-monsoon season. Pre-monsoon carbon values were 0.71 Mg in Site 1, 0.62 Mg in Site 2 and 0.64 Mg in Site 3 respectively. In monsoon season, estimated carbon showed the values of 0.72 Mg in Site 1, 0.63 Mg in Site 2 and 0.65 Mg in Site 3 respectively (Table 1 & Fig. 6). Species-wise carbon of trees at Site 1 during post-monsoon season showed maximum average carbon of *Shorea robusta* (0.36 Mg) and minimum in *Ziziphus oenoplia* (0.0066 Mg). The trend of carbon as seen in Site 1 during post-monsoon was *Shorea robusta* (0.36 Mg) > *Pterocarpus marsupium* (0.12 Mg) > *Terminalia tomentosa* (0.06 Mg) > *Anogeissus latifolia* (0.052 Mg) > *Semicaepus anacardium* (0.047 Mg); in Site 2, maximum average biomass was shown by *Shorea robusta* (0.27 Mg) and minimum for *Diospyros melanoxylon* (0.038 Mg) during post-monsoon. Species-wise carbon trend in Site 2 during post- monsoon was *Shorea robusta* (0.27 Mg) > *Pterocarpus marsupium* (0.094 Mg) > *Terminalia tomentosa* (0.089 Mg) > *Anogeissus latifolia* (0.052 Mg); in Site 3, *Shorea robusta* (0.442 Mg) showed maximum average carbon and minimum was showed by *Ailanthus excels* (0.00047 Mg). Species-wise trend of carbon as seen in Site 3 during post-monsoon was *Shorea robusta* (0.442 Mg) > *Syzygium cumini* (0.061 Mg) > *Schleichera oleosa* (0.052 Mg) > *Diospyros peregrine* (0.028 Mg) > *Terminalia tomentosa* (0.014 Mg). Pre-monsoon and monsoon season of species-wise plant carbon also showed similar trend with biomass.

Variation in climatic and edaphic factors

The present study was carried out in the three seasons of 2017-2019, i.e. post-monsoon (November-February); pre-monsoon (March - June); and monsoon (July - September). The average annual temperature of 2018-2019 varies between 25.69-25.65 °C. Average annual precipitation varies between 261.65- 317.52 mm. The average post-monsoon, pre-monsoon and monsoon temperature and rainfall were 21.11 °C, 0.25 mm; 29.31 °C, 76.63 mm and 26.25 °C, 491.88 mm respectively over the district (Fig. 7)

Soil temperature in the selected sites showed maximum temperature at Site 2 (23.9±0.28 °C) and minimum during monsoon (21.4±0.15 °C) at Site 3 respectively. Soil pH on the other hand showed maximum pH at Site 1 during pre-monsoon (6.20±0.159) and minimum during monsoon at Site 2 (4.92±0.156) respectively (Table 2). Soil organic carbon, soil nitrogen, soil phosphorus soil and potassium showed uniform trend with higher values during monsoon at Site 1 and lower values

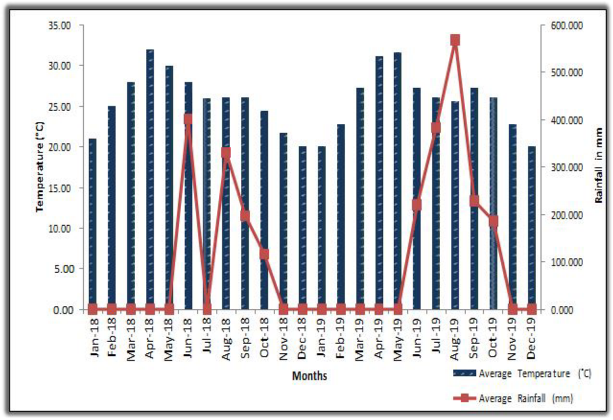

Fig. 7. Temperature and rainfall pattern of study site during 2017-2021

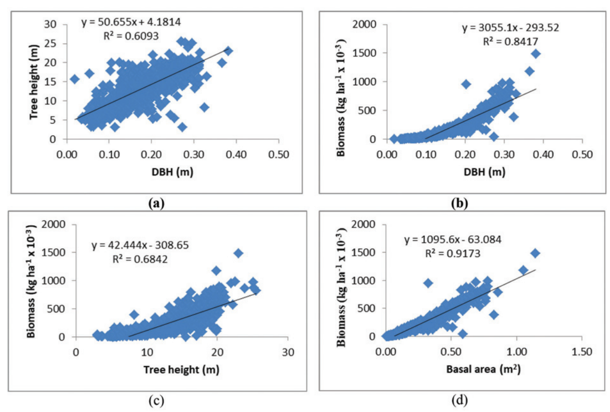

Fig. 8. The interrelationships between biomass, DBH, tree height and basal area of *Shorea robusta*

Table 2. Seasonal variations in soil physico-chemical parameters at the study sites

Soil parameters	Soil temperature (°C)			Soil pH		
	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon
Site 1	22.80±0.19	23.20±0.25	21.70±0.22	6.18±0.18	6.20±0.16	5.22±0.16
Site 2	22.40±0.18	23.90±0.28	21.90±0.16	6.12±0.15	6.11±0.16	4.92±0.16
Site 3	22.60±0.12	23.10±0.23	21.40±0.15	6.16±0.15	6.18±0.16	5.20±0.17

Table 3. Seasonal variations in soil nutrients at the study site

Soil parameters	Soil OC (%)			Soil Nitrogen (kg ha^{-1})			Soil Phosphorus (kg ha^{-1})			Soil Potassium (kg ha^{-1})		
	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon	Post-monsoon	Pre-monsoon	Monsoon
Site 1	0.38±0.02	0.36±0.01	0.48±0.03	139.22±2.28	137.06±3.21	144.62±3.45	0.019±0.0011	0.013±0.0021	0.029±0.0007	37.62±1.97	30.36±1.08	39.58±2.08
Site 2	0.30±0.02	0.28±0.01	0.42±0.02	130.24±3.05	124.61±3.86	140.16±3.05	0.005±0.0007	0.004±0.0011	0.014±0.0012	27.88±1.03	21.64±1.08	29.47±1.08
Site 3	0.35±0.02	0.32±0.02	0.45±0.02	136.48±4.03	131.78±4.40	142.12±4.06	0.012±0.0012	0.010±0.0013	0.021±0.0013	32.16±1.09	26.12±1.66	32.52±1.10

during pre-monsoon at Site 2 respectively. Soil organic carbon varied from 0.28±0.013 % to 0.48±0.031%, soil nitrogen varied from 124.61±3.86 kg ha^{-1} to 144.62±3.45 kg ha^{-1}, soil phosphorus varied from 0.004±0.0011 kg ha^{-1} to 0.029±0.0007 kg ha^{-1} and soil potassium varied from 21.64±1.075 kg ha^{-1} to 39.58±2.080 kg ha^{-1} respectively (Table 3).

Regression analysis between tree height and tree DBH, tree DBH and tree biomass, tree height and tree biomass, tree basal area and tree biomass were computed based on the dominance of the species combining all the sites. In combination *Shorea robusta*, *Pterocarpus marsupium*, *Terminalia tomentosa* were dominating compared to all the other species. Regression equation between tree diameter at breast height (DBH) and tree height showed an R^2 value ranging from 0.52-0.61, showing positive relationship between the tree DBH and tree height for all the species (Figs. 8, 9 & 10). Similar relationship between tree DBH and tree biomass were computed for all the selected species which showed R^2 value ranged from 0.78-0.87 showing positive relationship between all the selected sites and all the species (Figs. 8, 9 & 10). R^2 values for tree height and tree biomass of the selected species between the sites ranged from 0.60-0.68 showing a positive relationship between tree height and tree biomass (Figs. 8, 9 & 10). Biomass values also showed significantly positive relationship with basal area for the selected species in all the selected sites with R^2 value ranging from 0.87-0.92 (Figs. 8, 9 & 10). All the four parameters have shown significant interrelationships ($R^2 > 0.5$) with one another in the present study. However, the overall R^2 values were the best in case of *Shorea robusta* followed by *Pterocarpus marsupium* and *Terminalia tomentosa*. Tree height vs DBH has shown the least interrelationship with the lowest R^2 values for all the three species (Figs. 8, 9 & 10).

Discussion

Vegetation structure, species composition, forest

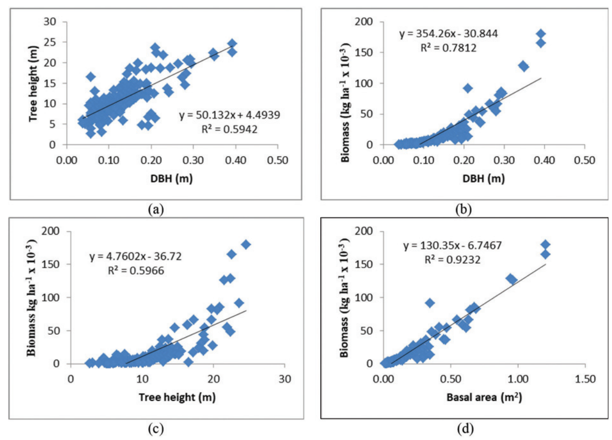

Fig. 9. The interrelationships between biomass, DBH, tree height and basal area of *Pterocarpus marsupium*

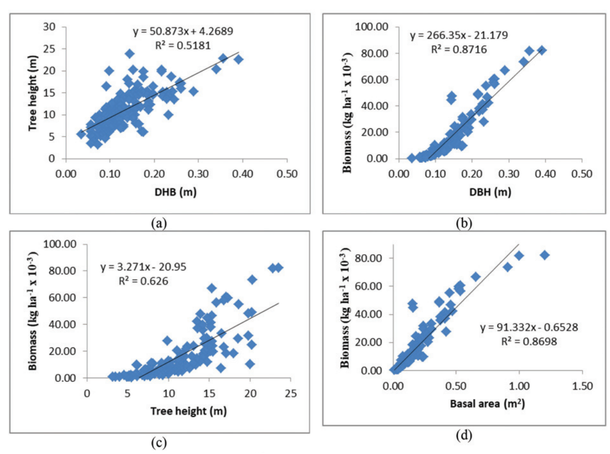

Fig. 10. The interrelationships between biomass, DBH, tree height and basal area of *Terminalia tomentosa*

Table 4. Species-wise comparison of biomass and carbon of tropical deciduous forests in different countries of the world

Name of the studied country	Name of the species studied	Biomass ($Mg\ ha^{-1}$)	Carbon ($Mg\ ha^{-1}$)	Reference
Northern Iran	*Acer velutinum*	90.03	45.015	Ostadhashemi *et al.* 2014
	Quercus castanifolia	72.82	36.41	
	Tilia begonifolia	71.88	35.94	
	Fraxinus excelsio	56.07	28.035	
	Prunus avium	37.92	18.96	
	Alnus subcordata	103.53	51.765	
	Pinus taeda	141.76	70.88	
	Pinus nigra	20.05	10.025	
China	*Picea spp.*	1.67	NA	Zeng Wei Sheng (2017)
	Abies spp.	1.82	NA	
	Betula spp.	1.67	NA	
	Quercus spp.	1.66	NA	
	Populus spp.	1.07	NA	
	Larix spp.	1.3	NA	
	Cunninghamia lanceolata	0.64	NA	
	Pinus massoniana	1.08	NA	
Sri Lanka	*Pinus caribaea*	NA	130.19	De Costa and Suranga (2012)
	Tectona grandis	NA	42.70	
	Eucalyptus grandis	NA	132.72	
	Eucalyptus camaldulensis	NA	26.25	
	Swietenia macrophylla	NA	97.59	
	Acacia auriculiformis	NA	87.14	
	Acacia mangium	NA	110.67	
	Eucalyptus robusta	NA	148.32	
	Eucalyptus tereticornis	NA	68.01	
	Pinus patula	NA	76.24	
	Eucalyptus microcorys	NA	116.15	
	Casuarina spp.	NA	58.11	
	Eucalyptus torelliana	NA	79.29	
	Eucalyptus pilularis	NA	182.27	
	Pinus oocarpa	NA	190.71	
	Acacia decurrens	NA	140.33	
	Cupressus sp.	NA	27.38	
	Eucalyptus citriodora	NA	86.81	
	Eucalyptus cloeziana	NA	70.56	
	Eucalyptus globulus	NA	63.85	
	Eucalyptus deglupta	NA	134.33	
	Acacia melanoxylon	NA	111.89	
Western Ghats, India	*Acacia mangium*	1.95	NA	Devagiri *et al.* 2019
	Acrocarpus fraxinifolious	9.54	NA	
	Aporosa lindleyana	7.08	NA	
	Atlantia spp.	9.1	NA	
	Baccourea courtallensis	10.18	NA	
	Bombax ceiba	5.3	NA	
	Cassia fistula	0.33	NA	
	Chionanthus malabarica	14	NA	
	Cinnamomum spp.	8.1	NA	
	Dalbergia latifolia	5.95	NA	
	Dalbergia latifolia	26.8	NA	
	Dillenia pentagyna	1.58	NA	
	Ficus bengalensis	20.73	NA	
	Flacourtia montana	3.9	NA	

Table 4. *Continued ...*

Name of the studied country	Name of the species studied	Biomass (Mg ha^{-1})	Carbon (Mg ha^{-1})	Reference
	Gliricidia sepium	0.58	NA	
	Grevillea robusta	18.66	NA	
	Grewia tiliaefolia	3.05	NA	
	Hevea brasiliensis	55.6	NA	
	Hopea parviflora	8.9	NA	
	Kingiodendron pinnatum	23	NA	
	Lagerstroemia lanceolata	24.4	NA	
	Lagerstroemia parviflora	0.45	NA	
	Macaranga peltata	1.1	NA	
	Mallotus philippensis	1.9	NA	
	Mangifera indica	3.6	NA	
	Myristica malabarica	2	NA	
	Olea dioica	10.24	NA	
	Pterocarpus marsupium	12.41	NA	
	Stereospermum spp.	12.4	NA	
	Syzigium cumini	0.34	NA	
	Syzigium lanceolatum	0.84	NA	
	Tectona grandis	175.3	NA	
	Terminalia bellerica	0.78	NA	
	Terminalia chebula	3.91	NA	
	Terminalia crenulata	42.5	NA	
	Terminalia paniculata	8.15	NA	
	Tetrameles nudiflora	1.6	NA	
	Trema orientalis	4.1	NA	
	Vataria indica	51	NA	
	Vitex altisima	0.23	NA	
	Xylia xylocarpa	34.23	NA	
East Godavari Region, Andhra Pradesh, India	*Terminalia arjuna*	186.13	104.44	Srinivas Kantipudi and Sundarapandian Somaiah (2018)
	Xylia xylocarpa	125.25	70.26	
	Lannea coromandelica	124.48	9.29	
	Anogeissus latifolia	15.62	8.76	
	Mangifera indica L.	14.133	7.92	
	Pongamia pinnata (L.)	13.62	7.64	
	Syzygium cumini (L.)	11.25	6.29	
	Schleichera oleosa (Lour.)	12.35	6.94	
	Bridelia retusa (L.)	8.98	5.04	
	Grewia tiliifolia	9.08	5.09	
	Bombax ceiba L.	8.03	4.51	
	Lagerstroemia parviflora Roxb.	7.94	4.46	
	Dillenia pentagyna Roxb.	7.11	3.99	
	Diospyros montana Roxb.	6.43	3.6	
	Terminalia bellirica (Gaertn.) Roxb.	5.62	3.14	
	Terminalia alata Heyne ex Roth	7.46	4.18	
	Miliusa tomentosa (Roxb.)	4.81	2.69	
	Diospyros melanoxylon Roxb.	5.53	3.1	
	Alangium salviifolium (L.f.)	2.87	1.61	
	Ficus exasperata	2.56	1.45	
	Dolichandrone atrovirens (Roth)	2.84	1.61	
	Diospyros sylvatica Roxb.	4.06	2.29	
	Mitragyna parvifolia (Roxb.) Korth.	2.94	1.64	
	Acacia auriculiformis Benth	1.98	1.11	
	Schrebera swietenioides Roxb.	1.993	1.12	

Table 4. *Continued ...*

Name of the studied country	Name of the species studied	Biomass (Mg ha^{-1})	Carbon (Mg ha^{-1})	Reference
Tropical Dry Forests of Eastern Ghats, India	*Adina cordifolia(Roxb.) Hook. f. ex Brand.*	2.01	1.008	Sahu *et al*. 2016
	Aegle marmelos (L.) Corr.	0.39	0.199	
	Albizzia lebbeck (L.) Benth.	0.21	0.106	
	Alstonia scholaris (L.) R.Br.	0.04	0.024	
	Anogessius latifolia (Roxb. Ex DC.) Wall.ex Guill. & Perr.	3.77	1.888	
	Antidesma acidum Retz.	0.01	0.005	
	Bauhinia purpurea L	0.14	0.074	
	Bauhinia variegate L.	0.07	0.037	
	Bombax ceiba L.	0.05	0.028	
	Bowsellia serrata Roxb.ex Colebr.	2.99	1.499	
	Bridellia retusa (L.) Spreng	0.24	0.121	
	Buchnania lanzan Spreng	2.85	1.428	
	Butea monosperma (Lam.) Taub.	0.08	0.040	
	Careya arborea Roxb.	0.61	0.307	
	Casearia graveolens Dalz	1.03	0.517	
	Cassia fistula L.	0.62	0.310	
	Chloroxylon swietiana DC.	1.37	0.688	
	Cleistanthus collinus (Roxb) Benth.ex.Hook.f.	1.36	0.684	
	Dalbergia latifolia Roxb.	1.46	0.730	
	Dalbergia paniculata Roxb.	0.83	0.418	
	Dalbergia sisoo Roxb.	0.03	0.018	
	Dillenia pentagyna Roxb.	0.86	0.434	
	Diospyros malabarica (Desr.) Kostel.	2.38	1.193	
	Diospyros melanoxylon Roxb.	5.27	2.637	
	Diospyros montana Roxb.	0.84	0.423	
	Erythrina variegate L.	0.26	0.131	
	Ficus tomentosa Roxb. Ex Willd.	0.08	0.044	
	Ficus benghalensis L.	3.61	1.806	
	Ficus racemosa L.	0.03	0.015	
	Ficus religiosa L.	0.24	0.123	
	Ficus semicordata Buch. Ham. ex J.E.Sm.	0.01	0.005	
	Gardenia latifolia Ait.	0.30	0.151	
	Glochidion velutinum Wight	0.20	0.103	
	Gmelina arborea Roxb.	0.31	0.155	
	Helecteres isora L.	0.04	0.020	
	xora pavetta Andr.	0.20	0.103	
	Lagerstroemia parviflora Roxb.	0.66	0.333	
	Lannea coromandelica (Houtt) Merr.	3.79	1.899	
	Macaranga peltata (Roxb.) Muell-Arg.	0.01	0.002	
	Madhuca indica Gmel.	9.44	4.722	
	Mangifera indica L.	8.36	4.184	
	Melastoma malabathricum L.	0.02	0.011	
	Mitragyna parviflora (Roxb.)	1.01	0.508	
	Morinda pubescens Sm. in Rees	0.70	0.351	
	Murraya paniculata (L.) Jack	0.01	0.002	
	Nyctanthes arbor-tristis L.	0.16	0.084	
	Ougenia ojeinensis (Roxb.) Hochr.	0.07	0.036	

Table 4. *Continued ...*

Name of the studied country	Name of the species studied	Biomass (Mg ha^{-1})	Carbon (Mg ha^{-1})	Reference
	Phyllanthus emblica L.	0.23	0.119	
	Polyalthia cerasoides (Roxb.) Bedd.	0.10	0.050	
	Protium seratum Wall ex Colebr	0.09	0.045	
	Pterocarpusmarsupium Roxb.	0.87	0.435	
	Pterospermum acerifolium (L.) Willd.	0.25	0.129	
	Pterospermum xylocarpum (Gaertn.) Sant & Wagh	0.10	0.050	
	Randia malabarica Lam.	0.01	0.005	
	Schleichera oleosa (Lour.) Oken	1.60	0.800	
	Semecarpus anacardium L.f.	0.30	0.153	
	Shorea robusta Gaertn.f.	20.62	10.311	
	Soymida febrifuga (Roxb.) A.Juss.	0.27	0.138	
	Sterculia urens Roxb.	0.10	0.050	
	Strychnos nux-vomica L.	0.02	0.012	
	Strychnos potatorum L.f.	0.71	0.355	
	Symplocos racemosa Roxb.	0.14	0.072	
	Syzygium cumini (L.) Skeels	1.26	0.632	
	Terminalia alata Heyne ex Roth.	8.32	4.162	
	Terminalia arjuna (Roxb.ex DC) Wight & Arn.	1.81	0.909	
	Terminalia bellirica (Gaertn.) Roxb.	0.69	0.346	
	Terminalia chebula Retz.	0.94	0.470	
	Trewia nudiflora L.	0.23	0.116	
	Wendlandia tinctoria (Roxb.) DC.	0.43	0.219	
	Xylia xylocarpa (Roxb.) Taub.	0.33	0.167	
	Ziziphus xylocarpus (Retz.) Willd.	0.10	0.054	
Major bauxite mine of Eastern Ghats, India	*Acacia auriculiformis Bent*	96.1	NA	Banerjee *et al.* 2020
	Syzygium cumini (L.) Skeels	27.4	NA	
	Pongamia pinnata (L.) Pierre	30.82	NA	
	Eucalyptus hibrid Maiden	667.39	NA	
	Grevillea robusta A.Cunn. ex R.Br	223.62	NA	
	Casuarina equisetifolia L	0.57	NA	
	Ailanthus excelsa Roxb	7.36	NA	
	Psidium guajava L	0.05	NA	
	Terminalia arjuna (Roxb. ex DC.) Wight & Arn	40.92	NA	
	Samanea saman L	48.48	NA	
	Mimusops elengi L	1.5	NA	
	Cofea robusta L.Linden	0.14	NA	
	Bauhinia purpurea L	1.4	NA	
	Pinus insularis L	471.96	NA	
	Cassia fstula L	5.1	NA	
	Mangifera indica L	269.16	NA	
	Ficus glomerata. L	40.93	NA	
	Tamarindus indica	35.29	NA	
	Ziziphus oenoplia L	17.84	NA	
	Acacia leucophloea (Roxb.) Willd	18.14	NA	
	Madhuca indica J.F.Gmel	68.64	NA	
	Terminalia chebula Retz	25.35	NA	
	Cleistanthus collinus Benth. exHook.f	23.49	NA	
	Semecarpus anacardium L.f	41.32	NA	
	Ailanthus excelsa Roxb	80.05	NA	

Table 4. *Continued ...*

Name of the studied country	Name of the species studied	Biomass (Mg ha^{-1})	Carbon (Mg ha^{-1})	Reference
Koraput district in Odisha (the first quarter) of Eastern Ghats of India	*Anacardium occidentale*	0.25	0.12	Banerjee *et al.* 2017
	Artocarpus heterophyllus	5.57	2.69	
	Magnifera indica	45.51	21.75	
	Bombax malabaricum	6.89	3.25	
	Pongamia glabra	27.23	13.04	
	Tamarindus indica	14.58	7.06	
	Eugenia jambolana	11.43	5.62	
	Shorea robusta	17.72	8.78	
	Santalum album	0.36	0.18	
Nabarangpur district of Odisha (Eastern Ghats of India)	*Shorea robusta*	0.37	0.174	Our study
	Pterocarpus marsupium	0.09	0.042	
	Terminalia tomentosa	0.06	0.028	
	Syzygium cumini	0.03	0.014	
	Schleichera oleosa	0.02	0.009	

cover, productivity etc. are the vital aspects of the ecosystem which shows the characteristics of the entire environment (Billings, 1952) and the whole complex of vegetation varies from season to season in a cyclic way, and over the years in a succession manner. These fluctuations suggest a response by each species population to the prevailing heat, moisture and light as modified by the vegetation itself (Heady, 1958). Plant growth has a mutual relationship among themselves and with the environment existing there (Mishra *et al.,* 1997).

Climatic and edaphic factors

Though there is direct relationship between atmospheric air temperature, annual rainfall and edaphic factors with plant species richness, growth, biomass production (reflects ecosystem capacity) and regeneration processes, present study shows seasonal fluctuations in plant species number, diversity and biomass. Soil temperature influences plant root growth, nutrient and water uptake and ultimately biomass production. Researchers have showed that both low and very high soil temperatures negatively correlate with root growth and nutrient uptake and affect below ground biomass more than the above ground biomass production. Low soil temperatures also increase water deficiency within plants (Pavel *et al.,* 1998). In the present study, soil temperature showed a variation between 21.4±0.15 ^{o}C to 23.9±0.28 ^{o}C comparing all the seasons and all the study sites which is a clear demarcation of tropical temperature prevailing over the area. Rainy season showed the lowest soil temperature which may be due to high precipitation rate. Post-monsoon showed moderate and pre-monsoon had highest value of soil temperature, owing to the direct recipient of sunlight during pre-monsoon period (Table 2).

Soil pH is an important indicator to identify the chemical nature of the soil (Shalini *et al.,* 2003) as it is the measurement of hydrogen ion concentration present in the soil which indicates whether the soil is acidic or alkaline in nature (Ravikumar and Someshekar, 2013). Soil pH facilitates plant growth by improving physical characteristics and nutrient availability for plants. However, low pH holds the soil nutrients tightly and makes the nutrients unavailable for the plants. The optimum pH range for plant nutrient uptake is 5.5-6.5 (Sonko *et al.,* 2016). Results of the present study showed the soil is slightly acidic in nature, i.e. 4.92 to 6.20 that could be due to non-weathering of rocks because weathering of rocks increases the pH of the soil (Salim *et al.,* 2015). Seasonal variation in soil pH may be high due to high litter degradation during monsoon as there is high moisture availability in the forest area. This facilitates litter decomposition and release of acids which decrease soil pH in rainy season. Because of dry weather of pre-monsoon, all the litters and humus become dry and decomposition rate is very slow in that time. So pH value is high in summer (Table 2). Similar studies on change in soil pH was also noticed by Salim *et al.,* (2015) in the natural forests of Haridwar- Uttarakhand showing the same trend of soil pH.

Phosphorus which is present in soil both in organic and inorganic forms, is the second most important macronutrient of plants growth and contributes more than 1% of the dry matter (Ravikumar and Someshekar, 2013). In the present study, available phosphorus content ranged from 0.004 to 0.029 kg ha^{-1} and higher values were shown for monsoon season. This may be due to high soil moisture content of monsoon which facilitates the decomposition rate of forest litters (Table 3).

Potassium is the third most important limiting element for plants and present abundantly in plant cell i.e. about 2-3% of dry weight. This element plays a key role in balancing of water in plants or osmoregulation (Singh and Tripathi, 1993). In the present study, the exchangeable potassium value varies from 21.64-39.58 kg ha^{-1} and rainy season showed higher values which may be because of high bacterial activity in presence of high soil moisture in this period (Table 3).

Soil nitrogen is most important limiting nutrient for plant growth. Plants absorb nitrogen as nitrates under aerobic conditions and as ammonium ions during anaerobic conditions. Excess amount of soil moisture is one of the important factors affecting nitrification in water logged soils and has major contribution to vary the process (Ravikumar and Someshekar, 2013). The present study area has dry soil and hence, bacterial metabolism rate and subsequent rate of biosynthesis of nitrogen is comparatively lower ranging from 124.61-144.62 kg ha^{-1}. The high amount of nitrogen content during monsoon is probably due to the availability of enough moisture for bacterial degradation of litters and more nitrogen in soil (Table 3).

Organic matter present in the soil recognizes its fertility or nutrient status and acts as a unique distinguishing character of soil from parent rock/ other non-fertile soils. It also checks erosion and runoff of soil and water. The percentage of organic carbon in the present study varied from 0.28%-0.48% indicating the good nutrient status of the soil (Table 3). Similar values on soil parameters like soil pH, soil NPK and organic carbon have also been documented by Ravikumar and Someshekar, (2013) while working in Varahi river basin of Karnataka, India. Since NPK and organic carbon concentration in the soil determines the chemical environment, hence the dynamicity of the nutrient elements is indispensible for continuous plant growth. The nutrient transformation and its availability in soils mainly depend upon pH of the soil (Reddy and Reddy, 2010). Hence, presence of dense vegetation affords the soil adequate cover. In the present study area, the dense forest vegetation with its understory clearly indicates the above statement in all the three sites and in all the three seasons. The low nutrient content in pre-monsoon (summer) and high in monsoon (rainy season) may probably due to warm temperature and high rainfall which results in soil weathering quickly. The natural weathering process makes the soil acidic and generally devoid of nutrients. It has been noted in all the sites that high organic carbon resulted in low pH because the decomposition of plant litter has led to increase in organic carbon and decrease in pH as has already been reported by earlier workers (Robertson and Vitousek, 1981; Adams and Sidle, 1987; Albrecht, 1995; Kirschbaum, 1995). Dick and Gregorich, (2004) compared the relative decomposition rates of organic matter in different climates like tropical (Nigeria) and cold dry climates (Canada), and concluded that the decomposition rates of organic matter were 10 times faster in tropical areas. Since the present study area is also located in the same climatic regime, the return of high amount of litter in natural forest which has led to more release of nutrients (NPK & OC) from litter decomposition. The results also revealed that natural forest's soil have maximum amount of nutrients in all the seasons and in all the sites. Similar works of soil temperature, soil pH and soil nutrients have also been studied by other researchers (Miller *et al.,* 2004; Bhattacharyya, 2008; Ravikumar and Somashekar, 2013; Salim *et al.,* 2015; Sonko *et al.,* 2016).

Vegetation structure and composition

Tropical forests are the richest biological communities on Earth which contribute significantly to global biodiversity (Myers *et al.,* 2000 and Baraloto *et al.,* 2013). These forests are noted for their ecosystem services that provides species habitat for plants and animals, prevention of soil erosion and protection from natural disasters (Connell, 1971). Over exploitation and rapid loss of forests are one of the biggest environmental problems around the world and studies have shown that tropical forests are disappearing at alarming rates worldwide reducing annually 1-4% of current area (Laurance, 1999). Another similar study done by Mandal and Joshi, (2014) in the dry deciduous forests of Doon valley in western Himalaya showed *Shorea robusta* RA values ranging from 35.44-61.76%. Similar values were also found within the limits by some earlier workers (Pande, 1999; Agni *et al.,* 2000; Chauhan, 2001; Gautametal, 2008). The dominancy of *Shorea robusta* in a forest mainly depends upon stand age, available resources, associate species, disturbance gradient and successional changes of the stand reported by Mandal and Joshi, (2014).

Relative abundance of trees studied in the present geographical locale has shown higher relative abundance during monsoon season owing to a favorable environmental condition like low soil pH, low soil temperature, high availability of soil nutrients for plant uptake. Similar works on floral diversity study in tropical forests have also been done by earlier workers (Champion and Seth, 1968; Knight, 1975; Jha *et al,* 1990; Neumann *et al.,* 2001; Huang *et al.,* 2003; Anitha *et al.,* 2010; Kumar *et al.,* 2010; Naidu *et al.,* 2016). The diversity indices and vegetation pattern are also a function of soil conditions, slope angle, altitude gradient, regional climate, topography, species composition, and biotic interferences as has been explained by Bliss, (1963), Douglas and Bliss, (1977) and Billings, (1979). The regional species richness is also the result of many interactions between plant productivity, competition, geographical area, environmental variables, and human activity (Eriksson, 1996; Zobel, 1997; Criddle *et al.,* 2003).

Biomass and carbon potential analysis

The green energy in the form of vegetation biomass of an ecosystem is driven by climatic conditions and edaphic factors to which the floristic diversity depends on. The presence of a species in a particular habitat depends not only upon its ecological adaptations but also on the associated species (particularly the understory) and the abiotic environment by Vijay and Negi, (2004). Within a given community, certain plant species are taken as forage by the herbivores, while others are ecologically important for maintaining biogeochemical cycles. The present study area has shown the pre-dominance of *Shorea robusta, Pterocarpus marsupium, Terminalia tomentosa, Syzygium cumini and Schleichera oleosa.*

The reason for maximum biomass and carbon in case of monsoon season may be due to excess amount of nutrients, adequate moisture, less temperature and low pH. In pre-monsoon season (summer) the plant species has shown reduction in biomass in case of trees. This has been reported by earlier workers that most of the plant parts dry in pre-monsoon season owing to stress of high temperature and low moisture leading to reduction in plant biomass (Pandey, 1997). The increase in biomass of certain dominating species may be due to the fact that they are often avoided by the grazers leading to their increase in biomass. There is very little or negligible difference in biomass and carbon between seasons which might probably be due to selection of a matured stand forest. However, there was significant variation between biomass and carbon with sites, which might probably be due to abiotic conditions of the site. The biomass and carbon of trees was comparatively less in Site 2 which might have been affected significantly by the anthropogenic disturbance, owing to the fringe population which is situated within 100 km of the forest patch. On contrary, the values of biomass and carbon were higher in case of Site 1 which proved that the site is anthropogenically undisturbed.

The regression relationships have established the fact that tree biomass is a function of tree DBH, tree height and tree basal area at any given location. These parameters contribute the above ground biomass which differs with sites, habitat, forest successional stage, composition of forest, species variability and varying tree density (Joshi and Ghose, 2014). The variation in biomass of trees at the various sites can be attributed to the climate and edaphic factors, site to site variation, anthropogenic disturbances and proximity to the site by fringe population. Comparing the regression it has been seen that *Shorea robusta* has shown the highest density in its population in all the selected sites which proves it to be an indicator species with greater tolerance and adaptability to the changing climate. The comparisons of biomass estimates of study sites with other workers are difficult because of variation in the methods employed for estimation of biomass in different studies. Our study results of average biomass of trees were 0.24 kg ha^{-1} in Site 1, 0.21 kg ha^{-1} in Site 2 and 0.22 kg ha^{-1} in Site 3. Similar studies on biomass estimation in tropical forests was done by earlier workers like Supriya Devi and Yadava, (2009), in north-eastern India; Salunkhe *et al.,* (2016), in central India; Sahu *et al.,* (2016) and Banerjee *et al.,* (2017 & 2020) in Eastern Ghats of India, etc.

Soil temperature did not play any significant role in the growth of the trees in case of monsoon season. On contrary, it showed significantly positive impact at 1% level of significance in post- monsoon season.

This might probably be due to favorable abiotic condition of the site which has led to the significant growth of the trees. In case of monsoon, the increase in biomass of trees might probably be due to the swollen girth of the tree because of high moisture accumulation. The biomass of present forest stand is lower than that of dry deciduous forests and sal forest (*Shorea robusta*) as described by Singh *et al.*, (1992), mixed Oak forest of Manipur, India (Singh *et al.* 1994) and lowland Dipterocarp forest (Kawahara *et al.*, 1981). The overall health of the forests in Nabarangpur District of Odisha is sound because the lower value of biomass may be due to different combination of tree size, tree diversity and the dominant tree species which is influenced by abiotic factors and the age of the dominating tree species.

Conclusion

It was concluded that the area is pristine in nature, free from anthropogenic disturbances, excepting few anthropogenic disturbances. The study recommends the conservation of these tropical dry forests stands for enhancing carbon stock for the sustainable future. However, the risk of ecosystem degradation, increasing water consumption and global warming up to some extent needs to be taken care of by the government, corporate entities and forest departments in order to increase carbon sequestration potential from the vegetation biomass. This study shall also work as complementary data for estimation of AGB with optical remote sensing data.

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