



# International Journal of Research in Agronomy

E-ISSN: 2618-0618  
P-ISSN: 2618-060X  
© Agronomy  
NAAS Rating (2026): 5.20  
[www.agronomyjournals.com](http://www.agronomyjournals.com)  
2026; SP-9(9): 57-62  
Received: 18-07-2026  
Accepted: 25-08-2026

**Viresh Alamel**  
M.Sc. Scholar, Department of  
FRM, College of Forestry, Sirsi,  
UAS, Dharwad, Karnataka, India

**Gopal V Dasar**  
Professor and Head, Department  
of Soil Science and Agricultural  
Chemistry, College of Agriculture,  
Vijayapura, Karnataka, India

**Girish B Shahapurmath**  
Scientist S1 (Agroforestry), AICRP  
on Agroforestry, Department of  
Forestry, UAS, Dharwad,  
Karnataka, India

**Hanumantha M**  
Assistant Professor and Head,  
Dept. of FPU, College of Forestry,  
Sirsi, UAS, Dharwad, Karnataka,  
India

**Upendra Muramatti**  
M.Sc. Scholar, Department of  
FPU, College of Forestry, Sirsi,  
UAS, Dharwad, Karnataka, India

**Corresponding Author:**  
**Viresh Alamel**  
M.Sc. Scholar, Department of  
FRM, College of Forestry, Sirsi,  
UAS, Dharwad, Karnataka, India

## Assessment of biomass production and carbon stock in Moist deciduous and Semi- evergreen forest types of Hulekal Range, Sirsi forest division

**Viresh Alamel, Gopal V Dasar, Girish B Shahapurmath, Hanumantha M  
and Upendra Muramatti**

**DOI:** <https://www.doi.org/10.33545/2618060X.2026.v9.i9Sa.6488>

### Abstract

The present study was conducted to assess biomass production and carbon stock in moist deciduous and semi-evergreen forests of Hulekal Forest Range. The study area is located in the central Western Ghats. Field data were collected using quadrat sampling with 61 randomly selected quadrats measuring 20 m×20 m. All trees with a girth at breast height (GBH) of  $\geq 30$  cm was enumerated and their girth and height were recorded. Basal area and stand volume were estimated from field measurements. Aboveground biomass was calculated using tree volume and wood specific gravity, while belowground biomass was estimated as 27 per cent of aboveground biomass. Total carbon stock was estimated by considering 47 per cent of total biomass as carbon content. The results revealed that marked differences in forest structure, biomass accumulation and carbon storage between the two forest types. The semi-evergreen forest recorded higher basal area ( $50.20 \text{ m}^2 \text{ ha}^{-1}$ ) and stand volume ( $523.26 \text{ m}^3 \text{ ha}^{-1}$ ) than the moist deciduous forest, which recorded  $34.02 \text{ m}^2 \text{ ha}^{-1}$  and  $343.30 \text{ m}^3 \text{ ha}^{-1}$ , respectively. Aboveground biomass was also higher in the semi-evergreen forest ( $349.27 \text{ Mg ha}^{-1}$ ) as compared to moist deciduous forest ( $244.03 \text{ Mg ha}^{-1}$ ). Similarly, belowground biomass and total biomass were higher in the semi-evergreen forest, with values of  $94.30$  and  $443.57 \text{ Mg ha}^{-1}$ , respectively, as compared with  $65.89$  and  $309.92 \text{ Mg ha}^{-1}$  in the moist deciduous forest. Carbon stock was higher in the semi-evergreen forest ( $208.48 \text{ Mg ha}^{-1}$ ) than in the moist deciduous forest ( $145.66 \text{ Mg ha}^{-1}$ ). The findings indicated that semi-evergreen forests possess greater biomass accumulation and carbon sequestration potential.

**Keywords:** Biomass, carbon stock, semi-evergreen forest, moist deciduous forest, Hulekal forest range, western Ghats, carbon sequestration

### Introduction

Forests form an essential component of the Earth's land-based ecosystems, occupying about 30 per cent of the world's land area (Anon, 2011) <sup>[1]</sup>. Research indicates that forests store a large share of the Earth's carbon, with more than 80 per cent of aboveground carbon and nearly 40 per cent of belowground carbon contained within forest ecosystems (Dixon *et al.*, 1994) <sup>[6]</sup>. On a global scale, forests absorb approximately 29 per cent of the carbon dioxide released from fossil fuel combustion (Harris *et al.*, 2021) <sup>[9]</sup>. Recent assessments estimate that forests currently hold around 400 peta grams of carbon (PgC) in their biomass and under favourable conditions, this storage potential could rise to about 772 PgC (Pan *et al.*, 2011) <sup>[16]</sup>. The main driver is the release of greenhouse gases, particularly carbon dioxide ( $\text{CO}_2$ ), from the combustion of fossil fuels such as coal, petroleum and natural gas. These gases retain heat in the atmosphere, intensifying the greenhouse effect and leading to global temperature rise. In response to this issue, the idea of carbon sequestration was introduced in the 1980s. During the 1990s, tropical deforestation released approximately 1–2 billion tonnes of carbon each year and accounted for nearly 15–25 per cent of total global greenhouse gas emissions (Malhi and Grace, 2000) <sup>[14]</sup>. India, the fourth-largest emitter of carbon dioxide ( $\text{CO}_2$ ) globally, still possesses an extensive forest cover of nearly 712249 square kilo meters, which stores about 7124.6 million tonnes of carbon. International climate agreements have acknowledged the seriousness of this issue.

The Kyoto Protocol called on developed countries to lower their greenhouse gas emissions, based on the idea that nations historically responsible for higher emissions should take the lead in climate mitigation efforts. Subsequently, the Doha Amendment and the Paris Agreement (2015) strengthened international collaboration, with the Paris Agreement obtaining emission reduction commitments from both developed and developing countries. India's total forest above-ground biomass and below-ground biomass contributed 2374.4 Mt and 735.2 Mt, respectively, highlighting the substantial role of forest biomass in carbon storage. (Anon, 2023) <sup>[2]</sup>.

### Materials and Methods

The study was carried out in Hulekal Forest Range of Uttara Kannada district, Karnataka, located in the central Western Ghats at approximately 14.69° N latitude and 74.74° E longitude. The region receives an average annual rainfall of about 2500–3000 mm, creating favourable conditions for the occurrence of diverse forest ecosystems, including evergreen, semi-evergreen and moist deciduous forests. The landscape is also of considerable ecological and cultural importance, characterized by sacred groves, ecotourism locations and traditional practices associated with forest resources and ecosystems (Fig. 1).

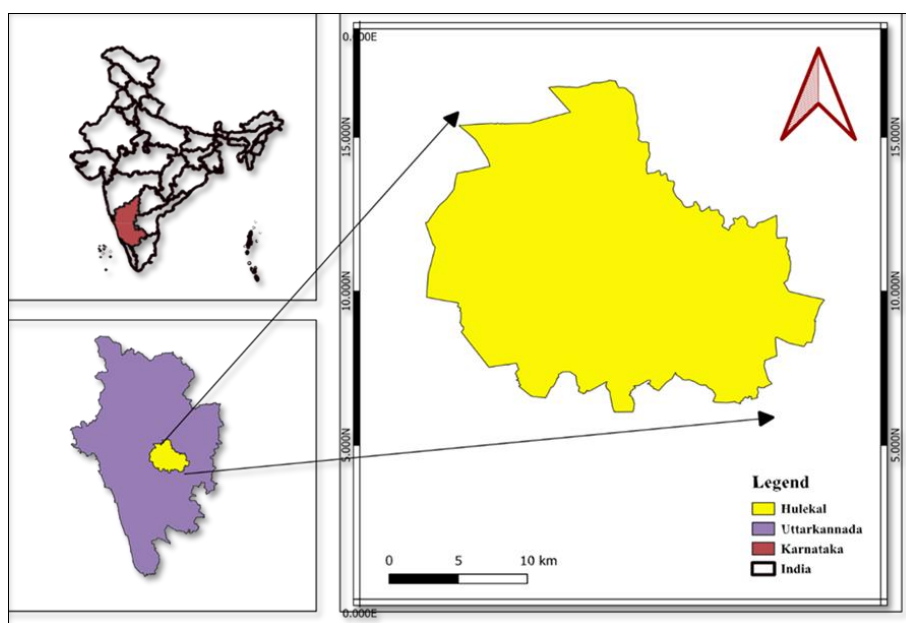


**Fig 1:** Geographical location of the study area in the Hulekal Range, Uttara Kannada district

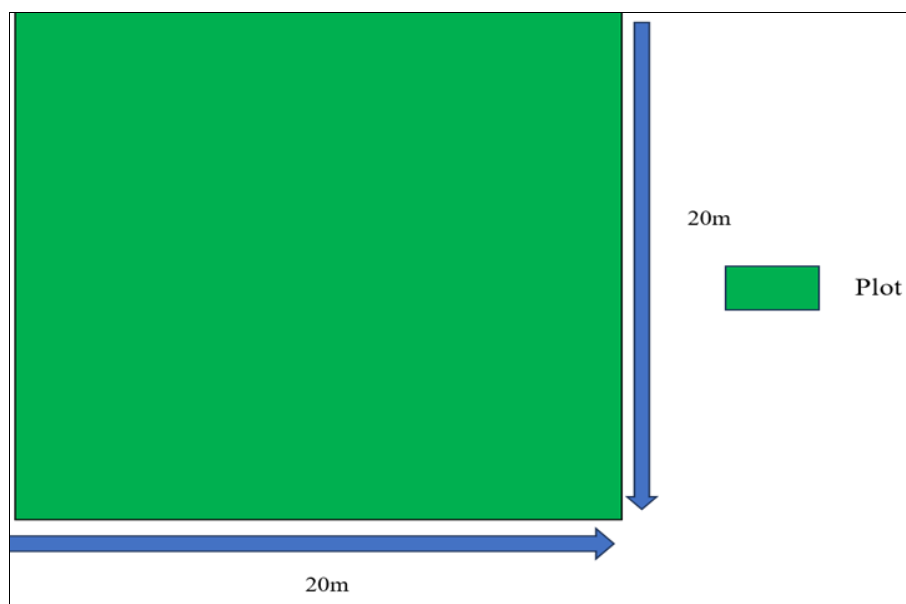


**Fig 2:** Pictographic representation of quadrat sampling plot

The study was carried out in the Hulekal Forest Range using the quadrat sampling technique. In each selected forest type, sampling plots measuring 20 m × 20 m were laid out, corresponding to a sampling intensity of 0.01 per cent. A total of 61 quadrats were established across the study area (Fig. 2). Random sampling was followed to obtain representative information on the tree community. All trees having a girth of

30 cm or more were identified and enumerated within each quadrat. Data on species identity, girth and tree height were recorded for every sampled individual. Girth at breast height (GBH) was determined at 1.37 m above ground level using a girth tape. Tree height was estimated from the ground level to the terminal point of the tree with the help of a Ravi Altimeter. For each sampling plot, geographical and topographical

information, including latitude, longitude, altitude and slope, was recorded using a GPS device.

## 2.1 Biomass production and carbon sequestration

A non-destructive method was used for the estimation of Biomass and Carbon stock the steps involved are as follows:

**Basal area (m<sup>2</sup>):** Basal area of tree species was derived from diameter at breast height by using formula,

$$\text{Basal area} = G^2 / 4\pi$$

Where G is the girth at breast height and expressed in meter.

**Volume (m<sup>3</sup>):** The total volume was calculated using formula mentioned below

$$\text{Volume (m}^3\text{)} = \text{Basal area (m}^2\text{)} \times \text{Height (m)} \times \text{Form factor}$$

Estimation of above ground biomass (AGB): Biomass of trees obtained from each quadrat was used to estimate total AGB (Mg ha<sup>-1</sup>).

$$\text{Above ground Biomass} = \text{Volume} \times \text{Specific gravity}$$

Specific gravity of different trees was obtained from the list given by Forest Research Institute (FRI) Dehradun.

### Estimation of below ground biomass (BGB)

IPCC (2007) <sup>[10]</sup> suggest that below ground biomass is close to 27 per cent of the total above ground biomass.

In the present study BGB was obtained by multiplying AGB with factor of 0.27

$$\text{BGB (Mg ha}^{-1}\text{)} = \text{AGB} \times 0.27$$

Hence, total tree biomass density is the sum of the aboveground biomass and belowground biomass (Chandra *et al.*, 2010) <sup>[5]</sup>.

### 3.3.2.8 Carbon stock estimation:

The biomass in each of the sites was converted into per hectare and 47 per cent of the biomass was taken as the carbon content. The total carbon stock was determined by multiplying the total tree biomass with a factor 0.47 as suggested by IPCC (2007) <sup>[10]</sup> and expressed in Mg ha<sup>-1</sup>.

$$\text{Total biomass} = \text{AGB} + \text{BGB (Mg ha}^{-1}\text{)}$$

$$\text{Carbon stock} = 0.47 \times \text{Total biomass (Mg ha}^{-1}\text{)}$$

This methodology ensured precise estimation of biomass accumulation and carbon stock in potential in moist deciduous and semi-evergreen forest ecosystems.

## Results and Discussion

Forest growth and productivity are strongly influenced by climatic factors such as rainfall, temperature, relative humidity

and soil moisture. Among these, rainfall is considered one of the most important environmental factors because it regulates soil water availability and creates favorable conditions for tree growth and stand development (Dwivedi, 1992) <sup>[7]</sup>. For biomass estimation, all trees having a girth at breast height (GBH) of 30 cm or greater within each sample plot were inventoried. During the field survey, each tree was identified to species level and its girth at breast height (m) and total tree height (m) were measured. These measurements formed the basis for estimating stand biomass, carbon stock potential.

**Table 1:** Composition of tree species in the Semi evergreen Forest of Hulekal Range

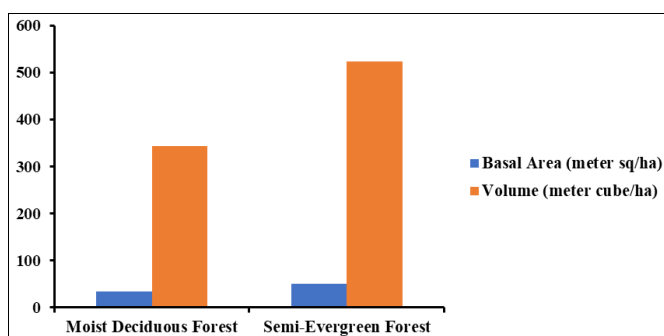
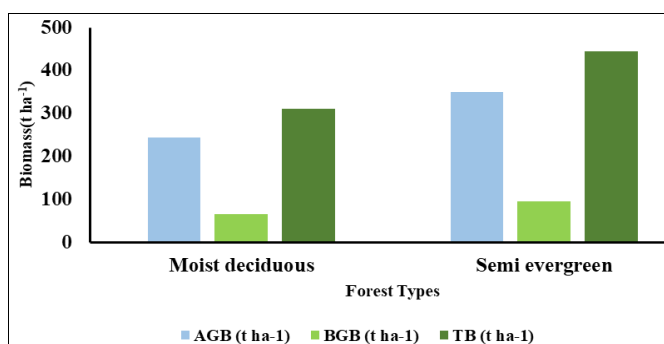
| Sl. No. | Species                          | No. of Individuals |
|---------|----------------------------------|--------------------|
| 1       | <i>Aporosa lindleyana</i>        | 87                 |
| 2       | <i>Hopea ponga</i>               | 74                 |
| 3       | <i>Syzygium cumini</i>           | 68                 |
| 4       | <i>Artocarpus hirsutus</i>       | 67                 |
| 5       | <i>Olea dioica</i>               | 65                 |
| 6       | <i>Garcinia indica</i>           | 60                 |
| 7       | <i>Knema attenuata</i>           | 57                 |
| 8       | <i>Holigarna arnottiana</i>      | 46                 |
| 9       | <i>Garcinia gummi-gutta</i>      | 36                 |
| 10      | <i>Vitex altissima</i>           | 26                 |
| 11      | <i>Flacourtia montana</i>        | 22                 |
| 12      | <i>Schleichera oleosa</i>        | 20                 |
| 13      | <i>Terminalia tomentosa</i>      | 19                 |
| 14      | <i>Diospyros buxifolia</i>       | 18                 |
| 15      | <i>Terminalia paniculata</i>     | 17                 |
| 16      | <i>Terminalia bellirica</i>      | 17                 |
| 17      | <i>Myristica malabarica</i>      | 16                 |
| 18      | <i>Lophopetalum wightianum</i>   | 15                 |
| 19      | <i>Knema attenuata</i>           | 14                 |
| 20      | <i>Diospyros sylvatica</i>       | 13                 |
| 21      | <i>Dysoxylum binectariferum</i>  | 12                 |
| 22      | <i>Garcinia talbotii</i>         | 11                 |
| 23      | <i>Garcinia morella</i>          | 10                 |
| 24      | <i>Carellia brachiata</i>        | 10                 |
| 25      | <i>Alsedaphne semicarpifolia</i> | 9                  |
| 26      | <i>Xylia xylocarpa</i>           | 9                  |
| 27      | <i>Diospyros candolleana</i>     | 9                  |
| 28      | <i>Terminalia chebula</i>        | 8                  |
| 29      | <i>Saraca asoca</i>              | 7                  |
| 30      | <i>Calamus sps</i>               | 7                  |
| 31      | <i>Alstonia scholaris</i>        | 6                  |
| 32      | <i>Caryota urens</i>             | 6                  |
| 33      | <i>Polyalthia fragrans</i>       | 5                  |
| 34      | <i>Mimusops elengi</i>           | 5                  |
| 35      | <i>Hydnocarpus pentandra</i>     | 4                  |
| 36      | <i>Elaeocarpus serratus</i>      | 3                  |
| 37      | <i>Cleidion spiciflorum</i>      | 2                  |
| 38      | <i>Syzygium laetum</i>           | 2                  |
| 39      | <i>Euonymus indicus</i>          | 1                  |

**Table 2:** Composition of tree species in the Moist Deciduous Forest of Hulekal Range

| Sl. No. | Species                           | No. of Individuals |
|---------|-----------------------------------|--------------------|
| 1       | <i>Terminalia paniculata</i>      | 83                 |
| 2       | <i>Terminalia tomentosa</i>       | 54                 |
| 3       | <i>Xylia xylocarpa</i>            | 45                 |
| 4       | <i>Careya arborea</i>             | 41                 |
| 5       | <i>Lagerstroemia lanceolata</i>   | 36                 |
| 6       | <i>Dillenia pentagyna</i>         | 33                 |
| 7       | <i>Terminalia bellirica</i>       | 32                 |
| 8       | <i>Adina cardifolia</i>           | 25                 |
| 9       | <i>Terminalia chebula</i>         | 21                 |
| 10      | <i>Lagerstroemia speciosa</i>     | 20                 |
| 11      | <i>Flacourtia montana</i>         | 18                 |
| 12      | <i>Butea monosperma</i>           | 15                 |
| 13      | <i>Alstonia scholaris</i>         | 12                 |
| 14      | <i>Madhuca longifolia</i>         | 8                  |
| 15      | <i>Sygzium cumini</i>             | 7                  |
| 16      | <i>Gmelina arborea</i>            | 6                  |
| 17      | <i>Sygzium caryophyllatum</i>     | 5                  |
| 18      | <i>Anogeissus latifolia</i>       | 5                  |
| 19      | <i>Macaranga peltata</i>          | 4                  |
| 20      | <i>Diospyros melanoxylon</i>      | 4                  |
| 21      | <i>Aporosa lindleyana</i>         | 3                  |
| 22      | <i>Bauhinia purpurea</i>          | 3                  |
| 23      | <i>Lannea coromandelica</i>       | 2                  |
| 24      | <i>Buchanania lanzana</i>         | 2                  |
| 25      | <i>Ficus racemosa</i>             | 1                  |
| 26      | <i>Madhuca latifolia</i>          | 1                  |
| 27      | <i>Emblica officinalis</i>        | 1                  |
| 28      | <i>Dalbergia latifolia</i>        | 1                  |
| 29      | <i>Zanthoxylum rhetsa</i>         | 1                  |
| 30      | <i>Alseodaphne semicarpifolia</i> | 1                  |

**Table 3:** Biomass and carbon stock estimation in Moist deciduous and Semi evergreen forest of Hulekal Range

| Forest type     | Basal area (m <sup>2</sup> ha <sup>-1</sup> ) | Volume (m <sup>3</sup> ha <sup>-1</sup> ) | AGB (Mg ha <sup>-1</sup> ) | BGB (Mg ha <sup>-1</sup> ) | TB (Mg ha <sup>-1</sup> ) | Carbon stock (Mg ha <sup>-1</sup> ) |
|-----------------|-----------------------------------------------|-------------------------------------------|----------------------------|----------------------------|---------------------------|-------------------------------------|
| Moist deciduous | 34.02                                         | 343.30                                    | 244.03                     | 65.89                      | 309.92                    | 145.66                              |
| Semi evergreen  | 50.20                                         | 523.26                                    | 349.27                     | 94.30                      | 443.57                    | 208.48                              |

**Fig 3:** Comparison of Basal Area (m<sup>2</sup> ha<sup>-1</sup>) and Volume (m<sup>3</sup> ha<sup>-1</sup>) among different forests type of Hulekal Range**Fig 4:** Biomass comparison among different forest types of Hulekal Forest Range

The basal area varied significantly between the two forest types with the semi-evergreen forest recording a higher basal area (50.20 m<sup>2</sup> ha<sup>-1</sup>) than the moist deciduous forest (34.02 m<sup>2</sup> ha<sup>-1</sup>). Basal area is an important structural attribute of forest stands as it reflects the cumulative cross-sectional area of tree stems and provides an indication of stand maturity, growing stock and biomass accumulation. A higher basal area generally represents the presence of larger trees with greater girth, which contribute substantially to the overall stand volume and carbon storage. Although the semi-evergreen forest also recorded a higher tree density (613 stems ha<sup>-1</sup>) than the moist deciduous forest (490 stems ha<sup>-1</sup>), the greater basal area cannot be attributed solely to the number of trees. The findings of the present study are consistent with those of Jayakumar and Nair (2013) <sup>[11]</sup>, who reported a basal area of 47.21 m<sup>2</sup> ha<sup>-1</sup> in evergreen forests of the Western Ghats. Joshi and Dhyani (2019) <sup>[13]</sup> highlighted that species composition, tree age and individual growth patterns explain such differences, while Baliram (2019) <sup>[4]</sup> reported basal areas of 28.41–39.53 m<sup>2</sup> ha<sup>-1</sup> in natural forests of Kodagu. The present study revealed a substantial difference in stand volume between the two forest types. The semi-evergreen forest recorded higher stand volume (523.26 m<sup>3</sup> ha<sup>-1</sup>) as compared to moist deciduous forest (343.30 m<sup>3</sup> ha<sup>-1</sup>). The findings of the present investigation are in agreement with those of Ramachandra *et al.* (2019) <sup>[18]</sup>, who reported that semi-evergreen and evergreen forests of the Western Ghats possess considerably higher stand volumes (259–446 m<sup>3</sup> ha<sup>-1</sup>) than moist deciduous

forests ( $157 \text{ m}^3 \text{ ha}^{-1}$ ). Jose *et al.* (2025) <sup>[12]</sup> also emphasized that stand volume is closely associated with basal area, tree size distribution and structural maturity in tropical forests.

The significant variation was observed in aboveground biomass (AGB) between the two forest types. The semi-evergreen forest recorded a higher AGB ( $349.27 \text{ Mg ha}^{-1}$ ) than the moist deciduous forest ( $244.03 \text{ Mg ha}^{-1}$ ), indicated its superior capacity for biomass production and carbon storage. Baishya *et al.* (2009) <sup>[3]</sup> recorded  $323.9 \text{ Mg ha}^{-1}$  in humid tropical forests of northern India. Swamy *et al.* (2010) <sup>[20]</sup>, who reported aboveground biomass ranging from 416 to  $552.9 \text{ Mg ha}^{-1}$  in tropical evergreen forests of the Western Ghats. Ramachandran *et al.* (2007) <sup>[19]</sup>, who reported an aboveground biomass of  $307.30 \text{ Mg ha}^{-1}$  in evergreen forests and  $251.65 \text{ Mg ha}^{-1}$  in deciduous forests of the Eastern Ghats.

IPCC (2007) <sup>[10]</sup> suggest that below ground biomass is close to 27 per cent of the total above ground biomass. Belowground biomass differed between the two forest types. The semi-evergreen forest recorded a higher belowground biomass ( $94.30 \text{ Mg ha}^{-1}$ ) compared to the moist deciduous forest ( $65.89 \text{ Mg ha}^{-1}$ ). Panda *et al.* (2013) <sup>[17]</sup> similarly reported that tropical evergreen forests exceeded  $85 \text{ Mg ha}^{-1}$  BGB owing to deeper root networks, whereas deciduous systems typically stored less due to seasonal leaf fall and shallower rooting patterns.

The present study demonstrated significant variation in total biomass (TB) between the two forest types. The semi-evergreen forest recorded the highest total biomass ( $443.57 \text{ Mg ha}^{-1}$ ), whereas the moist deciduous forest accumulated  $309.92 \text{ Mg ha}^{-1}$ . Swamy *et al.* (2010) <sup>[20]</sup>, who estimated total biomass ranging from 439 to  $587 \text{ Mg ha}^{-1}$  in tropical evergreen forests of the Western Ghats.

### Carbon Stock

The total carbon stock was determined by multiplying the total tree biomass with a factor 0.47 as suggested by IPCC (2007) <sup>[10]</sup> and expressed in  $\text{Mg ha}^{-1}$ . The differences in carbon stock between the two forest types. The semi-evergreen forest recorded the highest carbon stock ( $208.48 \text{ Mg ha}^{-1}$ ), whereas the moist deciduous forest stored ( $145.66 \text{ Mg ha}^{-1}$ ). Nayak *et al.* (2022) <sup>[15]</sup>, reported an average carbon stock of  $88.84 \pm 2.90 \text{ Mg ha}^{-1}$  in natural forests, supporting the observation that undisturbed tropical forests serve as significant carbon reservoirs. Haripriya (2000) <sup>[8]</sup>, while estimating biomass and carbon stocks of Indian forests, reported an average carbon density of  $34 \text{ Mg C ha}^{-1}$ .

Overall, the semi-evergreen forests exhibited greater basal area, stand volume, biomass accumulation and carbon storage than the moist deciduous forests. The observed variation can be attributed to differences in species composition, richness, forest structure, stand development and ecological conditions. The findings emphasize the significant contribution of semi-evergreen forests to biodiversity conservation and climate-change mitigation through their greater capacity for biomass production and carbon sequestration. Therefore, effective protection and sustainable management of these forests are essential for maintaining ecological stability and enhancing long-term carbon storage.

### Conclusion

Forest ecosystems are indispensable for maintaining biodiversity, regulating regional and global climate and mitigating climate change through carbon sequestration. Evaluating the ecological characteristics of different forest types is essential for developing sustainable forest management

practices and effective conservation strategies. The present study demonstrated clear differences in stand structure, biomass production and carbon storage between the semi-evergreen and moist deciduous forests of Hulekal Forest Range. The semi-evergreen forest exhibited greater basal area ( $50.20 \text{ m}^2 \text{ ha}^{-1}$ ), stand volume ( $523.26 \text{ m}^3 \text{ ha}^{-1}$ ), aboveground biomass ( $349.27 \text{ Mg ha}^{-1}$ ), belowground biomass ( $94.30 \text{ Mg ha}^{-1}$ ) and total biomass ( $443.57 \text{ Mg ha}^{-1}$ ) as compared to moist deciduous forest, which recorded  $34.02 \text{ m}^2 \text{ ha}^{-1}$  basal area,  $343.30 \text{ m}^3 \text{ ha}^{-1}$  volume and  $309.92 \text{ Mg ha}^{-1}$  total biomass. The higher carbon storage capacity of the semi-evergreen forest, with  $208.48 \text{ Mg ha}^{-1}$  compared with  $145.66 \text{ Mg ha}^{-1}$  in the moist deciduous forest, indicated its greater contribution to long-term carbon sequestration. The observed differences are associated with variations in tree density, stand structure, tree size, species composition, forest development and prevailing ecological conditions. Overall, conservation of both forest types is essential for maintaining ecosystem productivity, biodiversity and ecological stability.

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