

## CLIMATES EFFECT OF CLIMATE CHANGE ON CARBON SEQUESTRATION OF CEDRUS DEODARA (ROXB. EX D. DON) IN DRY AND MOIST TEMPERATE OF KHYBER PAKHTUNKHWA

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### Abstract

The study assessed the carbon stock and soil properties of *Cedrus deodara* forests in the moist temperate regions of Galiyat and Chitral, Pakistan. For comparison of *Cedrus deodara* performance in terms of carbon stocking and biomass production in order to determine the severity of climate change in two different climatic conditions i.e. moist and dry temperate regions. The research focused on evaluating the above-ground (AG), below-ground (BG) and total biomass along with carbon stocks of *Cedrus deodara* and with analyzing soil properties such as bulk density, pH, and soil organic carbon (SOC). Plot-wise data were collected, and mean Diameter at Breast Height (DBH), Tree volume, Growth patterns, development and tree height were measured to estimate biomass and carbon stocks. The results revealed significant variations in biomass and carbon stocks across different experimental units in moist and dry temperate climatic zones. The highest total biomass (362.91 t/ha in Chitral and 350.45 t/ha in Galiyat) recorded at high elevation in mature trees. The lowest biomass values were observed in low elevation stands or those affected by anthropogenic disturbances. Soil analysis indicated that bulk density increased with depth, while SOC decreased, consistent with findings from other temperate forests. The soil pH ranged from slightly acidic to slightly alkaline (7.0–8.5), suitable for the growth of *Cedrus deodara*. The findings shows that *Cedrus deodara* has a slight better performance in terms of carbon stocking in dry temperate forests as compared to moist temperate forests. The study also finds out that with higher elevations in the same zone *Cedrus Deodara* shows better performance in terms of carbon stocking and less effectivity by climate change and vice versa, which indicates that climate change is more evident at lower elevations than higher elevations and because of the density of greenhouse gasses (GHG) they are more evident at lower elevations. The study highlights the significant carbon sequestration potential of *Cedrus deodara* forests and underscores the need for their conservation and sustainable management to mitigate climate change. This study provides a foundation for future research on carbon dynamics and forest management in temperate regions the study also provides foundation for forest managers and policy makers for making of forest working plans and management plans for climate change mitigations and adaptations.

## Introduction

The changing ecology since the industrial revolution has been influenced due to the growing generation of greenhouse gases (GHGs). Over the past few decades, carbon dioxide (CO<sub>2</sub>) in the atmosphere has been rising yearly at a rate of 1.91 parts per million due to a variety of human activities. This is because as of 2018, the atmospheric CO<sub>2</sub> concentration had increased to 410 ppm from 317 ppm in 1958 (NOAA, 2017). Variations in CO<sub>2</sub> concentration have ultimate effects on the change in temperature which in turn has great effects on social, economic, and ecological systems. Environmental biologists get worried about environmental changes or climate changes due to carbon imbalance and excessive high rate of greenhouse gases (Ardo and Olsson, 2004).

Thus, the elevated amount of carbon dioxide must be taken out of the atmosphere and stored in terrestrial ecosystems as carbon. Zhang *et al.*, (2013) states that forests are the predominant portion of the carbon cycle, and the amount of carbon stored in forest could be more. In forests, carbon is worth 20–50 times what it is worth in the atmosphere (Houghton and Hackler, 1995). Forest covers 4.06 billion hectares, 31% of the earth's land surface and accountable for 2.4 gigatons of carbon stored annually (FAO, 2020; Ni *et al.*, 2016). They are major carbon sinks since 44% of their living biomass (above and below ground); 8% of their dead wood, and 5% of their leaf litter are stored in soil and the other part is stored in the atmosphere (Pan *et al.* 2011; Sun and Liu, 2020).

The northwest Khyber Pakhtunkhwa (KP) province, where around 40% of Pakistan's natural forests are located, is an important stock of Pakistan's forest ecosystems (Khan *et al.*, 2021). These temperate Himalayan Forest, characteristic of the keystone species *Cedrus*

*deodara* cover about 1.133–1.504 million hectares (Ali, 2017; Bukhari *et al.*, 2012). Acknowledging that the tree has a 2 m diameter in 140 years in desert valleys, it only requires 110 years in monsoon fed regions, shows the remarkable growth plasticity (Gamble, 1922). In addition, climatic pathways of range contraction are available: with *Abies* pindrow in wet sites and then blue pine at higher xeric sites at higher elevations (Champion & Seth 1968), and with drought resistant *Pinus roxburghii* at lower elevations (Zobel *et al.* 2001). As such, this crucial study is needed into the carbon sequestration capacity across moisture gradients, because the species distribution models predict very worrying population decreases (Gilani *et al.*, 2020). This study will greatly help for the understanding of *Cedrus deodara*'s capacity to sequester carbon in the dry and wet temperate atmosphere of Khyber Pakhtunkhwa under changing climatic conditions. It adds to better understand that how climate influences carbon storage and thus what changes can be made in national and regional climate mitigation policies. Where the stakeholder's can earn enough money on their carbon credit and ultimately conserve the forest and protect the biodiversity. Moreover, putting these methods into practice keeps the healthy woods of the reserve for the sake of biodiversity, water, and tourism, all key to the regional economy and people's wellbeing.

## MATERIAL AND METHODS

Deodar (*Cedrus deodara*) forests are widely distributed across northern Pakistan, including Kaghan, Kohistan, Dir, Chitral, Hazara, Abbottabad, Swat, Azad Kashmir, and Murree. The species primarily occurs in dry temperate forests but is also found in isolated stands within subalpine and moist temperate regions (Champion *et al.*, 1965; Ahmed *et al.*, 2006). The study focuses on two contrasting forest

zones: the moist temperate zone of Galiyat and the dry temperate zone of Chitral. Galiyat lies at approximately 1,500–2,992 m elevation, with an average annual temperature of 11.2 °C and annual rainfall of about 1,448 mm (Satti et al., 2024). Its forests are dominated by coniferous species such as *Cedrus deodara*, *Pinus wallichiana*, *Picea smithiana*, and *Abies pindrow*. Chitral represents a comparatively dry temperate environment characterized by rugged mountainous terrain, limited monsoonal influence, and coniferous vegetation including *Cedrus deodara*, *Juniperus excelsa*, *Pinus wallichiana*, and *Picea smithiana* (Sheikh et al., 2015; Ali & Qaiser, 2006).

Field data were collected using a stratified random sampling design. Fifteen circular plots of 0.1 ha were established across the study areas, and GPS was used to record elevation and geographical coordinates. Tree diameter at breast height (DBH) was measured using diameter tapes or calipers, while tree height was determined using a Haga altimeter. Trees below 6 cm DBH were excluded from biomass estimation. Within each plot, 1 m<sup>2</sup> subplots were used to assess understory vegetation, litter, dead wood, and other forest-floor components. Soil samples were collected from 0–15 cm and 15–30 cm depths to determine bulk density and soil organic carbon. Aboveground and belowground biomass and carbon stocks were estimated from tree, understory, litter, dead wood, and soil components. The collected data were statistically analyzed using Jamovi to compare biomass and carbon storage of *Cedrus deodara* stands across the moist and dry temperate zones.

### 3.7 MEASUREMENT OF VOLUME

Using standard forest inventory technique, the sample plot (m<sup>3</sup>/ha) was measured. For this purpose, Haga altimeter was used for the tree height and measuring tape or caliper for

determining the diameter of tree in cm at a height of 1.3 m (2004).

$$V = \pi/4 d^2 \times h \times f \dots\dots\dots \text{Eq. 01}$$

Whereas, V = volume of tree (m<sup>3</sup> d<sup>2</sup>) = Sq. of tree diameter

h = Height f = Form Factor, while  $\pi = 3.14$

### 3.8 EXAMINATION AND MEASUREMENT OF ABOVE GROUND BIOMASS

Trees's leaves, branches, primary stems are the aboveground biomass. Information concerning the total biomass, tree density, stem biomass, stem volume, stem height and diameter were collected to determine the amount of carbon stock in the plantation area (Kucuker & Tuyoglu, 2022). Hence, biomass prediction of single tree stems was made by multiplying volume (m<sup>3</sup>) by fundamental wood density. The same was established through the methods discussed by Haripriya (2003).

$$\text{Stem volume (m}^3\text{)} \times \text{Basic wood density (kg/m}^3\text{)} = \text{stem biomass (t ha}^{-1}\text{)} \dots\dots\dots \text{Eq.02}$$

This sum is because the biomass of the tree accounts for the stem, the branches, the twigs, along with the roots. The above ground biomass was estimated to multiply the stem biomass with the Biomass Expansion Factor (BEF; commercial biomass to the above ground biomass). As per Haripriya (2003), the total biomass was calculated using the following equation.

$$\text{Total Biomass (t ha}^{-1}\text{)} = \text{Stem biomass (t ha}^{-1}\text{)} \times \text{BEF} \dots\dots\dots \text{Eq 03}$$

$$\text{Below ground Biomass} = \text{AGB} \times \text{Root Stem Ratio (0.20 for pines)} \dots\dots\dots \text{Eq 04}$$

### 3.9 CARBON STOCK ESTIMATION

Total biomass was converted to carbon using a global factor of 0.5 (Nizami, 2012).

$$\text{Carbon Stock (t/ha)} = \text{Total Biomass} \times 0.5 \dots\dots\dots \text{Eq 05}$$

### 3.10 SOIL SAMPLING AND ANALYSIS

Soil samples (0–15 cm depth) and (15–30 cm depth) were collected from plots. Bulk density, pH, and SOC were analyzed as per Amir et al. (2018).

Bulk Density = Dry Soil Weight / Core Volume..... Eq 06

Soil Carbon (t/ha) = Horizon Thickness × Bulk Density × SOC % × 100..... Eq 07

### 3.11 STATISTICAL ANALYSIS

Standard deviation and standard error were computed as statistical measurements. An attempt was also made to use Sigma Plot Version 12.5 to construct regression models to determine the association between tree diameter (cm) and stem density ( $\text{ha}^{-1}$ ). To add, the stand basal area was regressed to the total biomass ( $\text{t ha}^{-1}$ ) and stem volume ( $\text{m}^3 \text{ha}^{-1}$ ). Furthermore, organic carbon stock ( $\text{t ha}^{-1}$ ) was

estimated from models of mean height and mean basal area by means of the same software.

## RESULTS AND DISCUSSIONS

### 4.1 VOLUME OF CEDRUS DEODARA IN GALIYAT

Table 4.1 contains plots number, elevation and geographic coordinates of *Cedrus deodara* trees and average diameter at breast height (DBH) and height at different elevations in Galiyat. To find the DBH and the mean height of these averages, all trees in a 0.1-hectare area were averaged. The slope with the lowest DBH (26.5 cm) was at an elevation of 2371 m and with the maximum (72 cm) at 2577 m additionally, the average tree height at 2577 m was 32.5 m and at 2371 m it was 16.8 m.

**Table 4.1:** *Mean DBH and Tree Height of Cedrus deodara in Galiyat*

| Elevation (m) | Latitude  | Longitude | Mean DBH (cm) | Mean Height (m) |
|---------------|-----------|-----------|---------------|-----------------|
| 2300          | 34.092642 | 73.347936 | 38.2          | 22.5            |
| 2320          | 34.080564 | 73.376143 | 36.8          | 21              |
| 2345          | 34.073240 | 73.367294 | 30.5          | 18.2            |
| 2360          | 34.073141 | 73.379168 | 40.1          | 23              |
| 2371          | 34.067717 | 73.372961 | 26.5          | 16.8            |
| 2390          | 34.090086 | 73.355394 | 50.3          | 26.5            |
| 2410          | 34.082635 | 73.323444 | 65.4          | 31              |
| 2425          | 34.084730 | 73.386784 | 60.2          | 29.5            |
| 2443          | 34.055862 | 73.389028 | 55.8          | 28              |
| 2467          | 34.064589 | 73.356632 | 67.3          | 31.5            |
| 2488          | 34.088266 | 73.369755 | 58.6          | 29              |
| 2505          | 34.069500 | 73.396858 | 62.1          | 30              |
| 2521          | 34.053394 | 73.380731 | 45.5          | 24              |
| 2546          | 34.054880 | 73.396023 | 32            | 18.5            |
| 2577          | 34.060276 | 73.369987 | 72            | 32.5            |

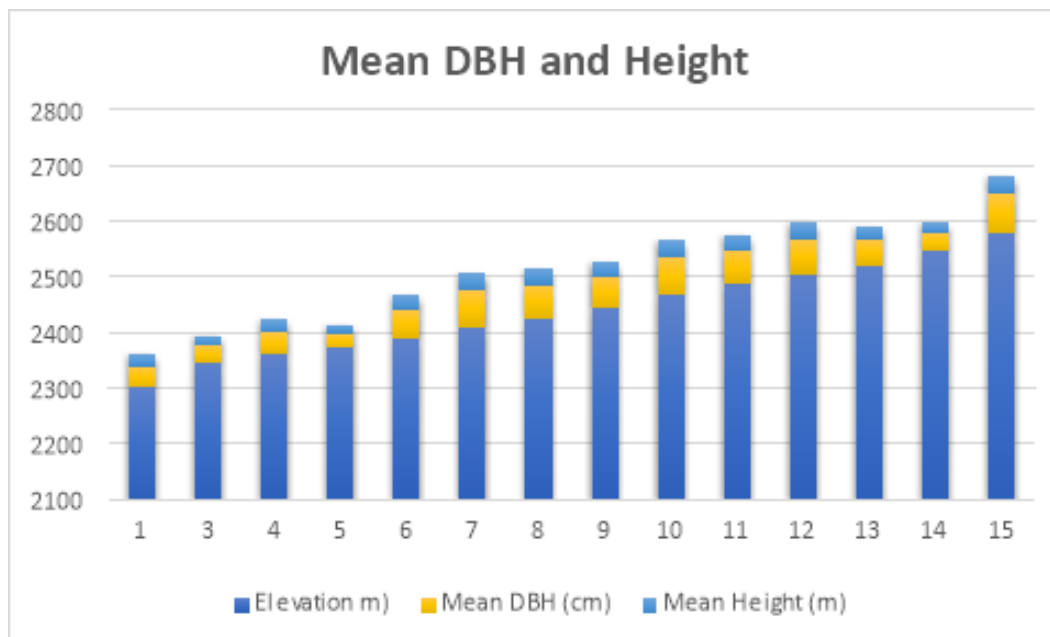


**Figure 4.1** *Elevation Wise Mean DBH and Height*

#### 4.1.1 ELEVATION-WISE BIOMASS ANALYSIS OF *CEDRUS DEODARA* IN GALIYAT

An overview of the estimated above (AGB), below (BGB) and total biomass of the *Cedrus deodara* trees at different altitudes of Galiyat is given in Table 4.2. The total biomass was the

greatest with highest 350.45 t/ha—1 biomass comprising of 70.09 t/ha—1 of belowground biomass and 280.36 t/ha—1 of aboveground biomass at an altitude of 2577 m. Since the total biomass at 2371 meters was lowest, 10.50 t/ha, AGB and BGB were subsequently determined to be 8.40 t/ha and 2.10 t/ha

**Table 4.2:** *Elevation wise Biomass Accumulation of Cedrus deodara in Galiyat*

| Elevation (m) | AGB (t/ha) | BGB (t/ha) | Total Biomass (t/ha) |
|---------------|------------|------------|----------------------|
| 2300          | 90.25      | 22.56      | 112.81               |
| 2320          | 160.45     | 40.11      | 200.56               |
| 2345          | 65.5       | 16.38      | 81.88                |
| 2360          | 180.5      | 45.13      | 225.63               |
| 2371          | 8.4        | 2.1        | 10.5                 |
| 2390          | 58.3       | 14.58      | 72.88                |
| 2410          | 64.8       | 16.2       | 81                   |
| 2425          | 35.2       | 8.8        | 44                   |
| 2443          | 29.5       | 7.38       | 36.88                |
| 2467          | 85.6       | 21.4       | 107                  |
| 2488          | 46.8       | 11.7       | 58.5                 |
| 2505          | 56.2       | 14.05      | 70.25                |
| 2521          | 275.3      | 68.83      | 344.13               |
| 2546          | 80.5       | 20.13      | 100.63               |

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2577                      280.36                      70.09                      350.45

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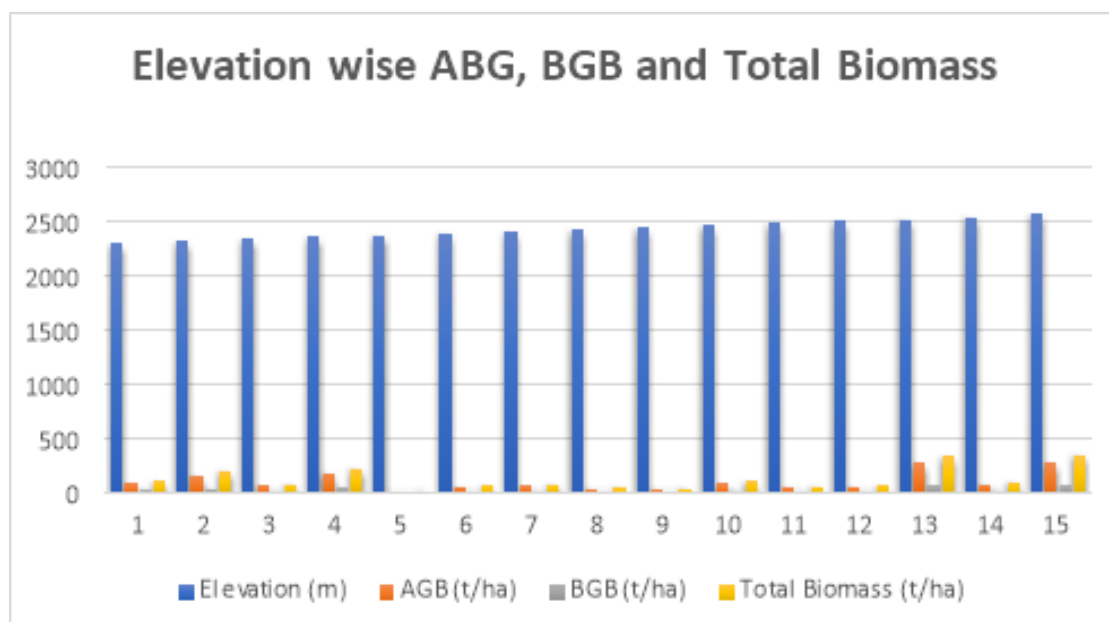


**Figure 4.2**      *Elevation wise AGB, BGB and Total Biomass*

#### 4.1.2 ELEVATION-WISE TOTAL CARBON OF CEDRUS DEODARA IN GALIYAT, BELOW-GROUND CARBON (BGC), AND ABOVE-GROUND CARBON (AGC)

Table 4.3 presents the carbon stocks for *Cedrus deodara* in Galiyat. Therefore, 2577m Elevation displayed the highest total carbon stock with values of 132.17 t/ha, 33.04 t/ha and 165.21 t/ha for AGC, BGC and TCS, respectively. 2371m elevation has the lowest relative amount

of carbon stock (4.95 t / ha; AGC = 3.96 t / ha; BGC = 0.99 t / ha).

#### 4.1.3 CEDRUS DEODARA'S TOTAL BIOMASS AND TOTAL CARBON IN GALIYAT

Table 4.3 is compilation of total biomass and total carbon stocks of *Cedrus deodara* in Galiyat. At 2577m, the total biomass (350.45 t ha<sup>-1</sup>) and total carbon (165.21 t ha<sup>-1</sup>) were highest and was lowest at 2371m (10.50 t ha<sup>-1</sup>) and 4.95 t ha<sup>-1</sup>).

**Table 4.3:**      *Elevation-wise Carbon Analysis of Cedrus deodara in Galiyat*

| Elevation (m) | AGC (t/ha) | BGC (t/ha) | Total Carbon (t/ha) |
|---------------|------------|------------|---------------------|
| 2300          | 42.42      | 10.60      | 53.02               |
| 2320          | 75.41      | 18.85      | 94.26               |
| 2345          | 30.79      | 07.70      | 38.49               |
| 2360          | 84.84      | 21.21      | 106.05              |
| 2371          | 03.96      | 0.99       | 04.95               |
| 2390          | 27.40      | 06.85      | 34.25               |
| 2410          | 30.46      | 07.61      | 38.07               |
| 2425          | 16.54      | 04.14      | 20.68               |
| 2443          | 13.87      | 03.47      | 17.34               |

|      |        |       |        |
|------|--------|-------|--------|
| 2467 | 40.23  | 10.06 | 50.29  |
| 2488 | 22.00  | 05.50 | 27.5   |
| 2505 | 26.41  | 06.60 | 33.01  |
| 2521 | 129.39 | 32.35 | 161.74 |
| 2546 | 37.84  | 09.46 | 47.30  |
| 2577 | 132.17 | 33.04 | 165.21 |

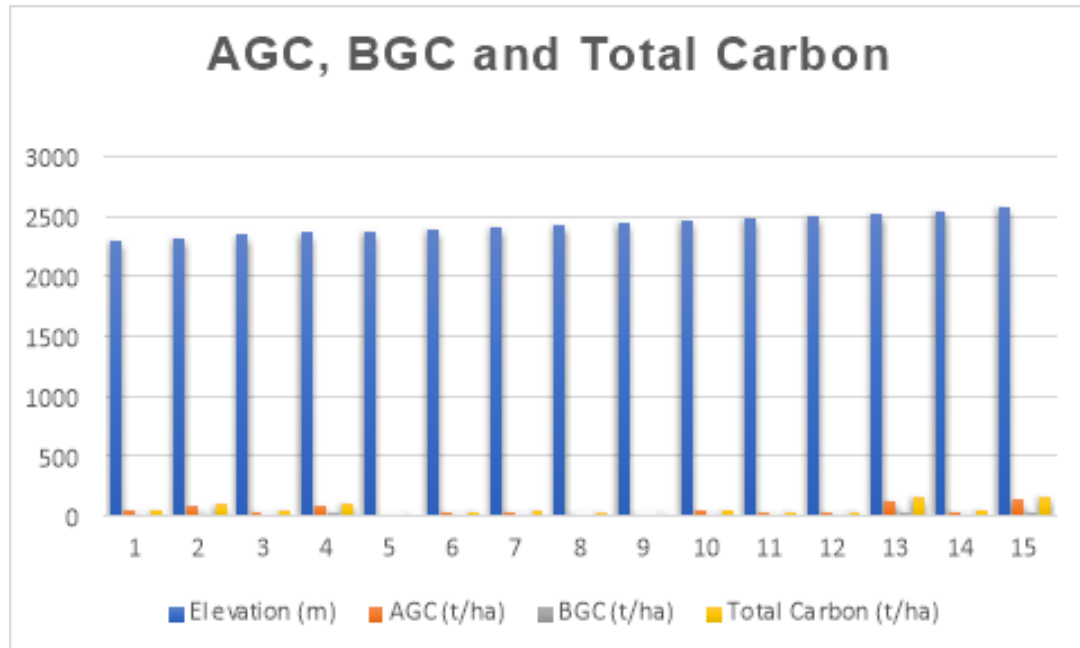


**Figure 4.3** Elevation wise AGC, BGC and Total Carbon

#### 4.1.4 BULK DENSITY IN GALIYAT

At different altitudes and depths, the bulk density of Galiyat soil has been evaluated. The

bulk density between the lowest (2320 m height) to the highest (2546 m elevation) ranged from 0.70 g/cm<sup>3</sup> to 1.30 g/cm<sup>3</sup>.

**Table 4.4:** Soil Bulk Density in Galiyat

| Plot No | Elevation (m) | Bulk Density (g/cm <sup>3</sup> ) |
|---------|---------------|-----------------------------------|
| 1       | 2320          | 0.70                              |
| 2       | 2371          | 0.90                              |
| 3       | 2425          | 1.10                              |
| 4       | 2488          | 1.20                              |
| 5       | 2546          | 1.30                              |
| Mean    | 2430          | 1.04                              |

Soil pH in Galiyat is slightly alkaline from 7.0 to 8.5. The lowest pH (8.5) was recorded at 2320m elevation and highest pH (7.0) recorded at 2546m elevation.

#### 4.1.5 SOIL pH IN GALIYAT

**Table 4.5:** Soil pH in Galiyat at different Elevations

| Plot No | Elevation (m) | Soil pH |
|---------|---------------|---------|
| 1       | 2320          | 7.0     |
| 2       | 2371          | 7.5     |
| 3       | 2425          | 8.0     |
| 4       | 2488          | 8.2     |
| 5       | 2546          | 8.5     |
| Mean    | 2430          | 7.84    |

#### 4.1.6 SOIL ORGANIC CARBON (SOC) IN GALIYAT

Measurement of soil organic carbon (SOC) was performed at the two depths of 0-15cm

and 15-30 cm in the Galiyat. The SOC ranged from 0-15 cm: 30.50-55.00 g/kg and 15-30 cm: 22.00-50.00 g/kg.

**Table 4.6:** Soil Organic Carbon (SOC) in Galiyat

| Plot No | Elevation (m) | SOC (0-15 cm) (g/kg) | SOC (15-30 cm) (g/kg) |
|---------|---------------|----------------------|-----------------------|
| 1       | 2320          | 40.50                | 32.00                 |
| 2       | 2371          | 45.00                | 35.00                 |
| 3       | 2425          | 50.00                | 40.00                 |
| 4       | 2488          | 55.00                | 45.00                 |
| 5       | 2546          | 30.50                | 22.00                 |
| Mean    | 2430          | 44.2                 | 34.8                  |

#### 4.2 CARBON STOCK ASSESSMENT OF CEDRUS DEODARA IN DRY TEMPERATE OF CHITRAL

##### 4.2.1. VOLUME OF CEDRUS DEODARA.

Table 4.1 summarizes plot number, elevation and geographic coordinates, the average Diameter at Breast Height (DBH) and mean tree height of all plots. Averages were calculated for the DBH and height of the

entire areas, measured from the DBH and height of every tree in each 0.1-hectare area. At 3395 meters lowest mean DBH was measured (74 cm) while at 3007 meters, the lowest was 28.66 cm. The same was observed, in which the highest average tree height was 33.91 m at 3395 m and the lowest was 17.25 m at 3007 m.

**Table: 4.7** Elevation wise DBH and Height of *Cedrus deodara*. At Chitral

| Elevation (m) | Latitude | Longitude | DBH (cm) | Height (m) |
|---------------|----------|-----------|----------|------------|
| 2876          | 35.5338  | 71.4115   | 68.67    | 32.47      |
| 2924          | 35.5337  | 71.4134   | 31.76    | 18.99      |
| 2965          | 35.5329  | 71.4139   | 34.33    | 20.43      |
| 2990          | 35.533   | 71.4135   | 37.53    | 21.38      |
| 3007          | 35.5344  | 71.4132   | 28.75    | 17.27      |
| 3060          | 35.5341  | 71.4116   | 68.75    | 32.55      |

|      |         |         |       |       |
|------|---------|---------|-------|-------|
| 3100 | 35.5329 | 71.4139 | 52.24 | 27.38 |
| 3140 | 35.5324 | 71.4165 | 58.23 | 29.19 |
| 3190 | 35.5334 | 71.4136 | 37.34 | 21.48 |
| 3200 | 35.5333 | 71.4133 | 37.85 | 21.64 |
| 3250 | 35.534  | 71.4151 | 64.33 | 31.11 |
| 3300 | 35.5341 | 71.4152 | 60.01 | 29.95 |
| 3320 | 35.5346 | 71.4149 | 31.78 | 18.17 |
| 3360 | 35.5342 | 71.414  | 44.67 | 23.69 |
| 3395 | 35.5355 | 71.4121 | 74    | 33.83 |

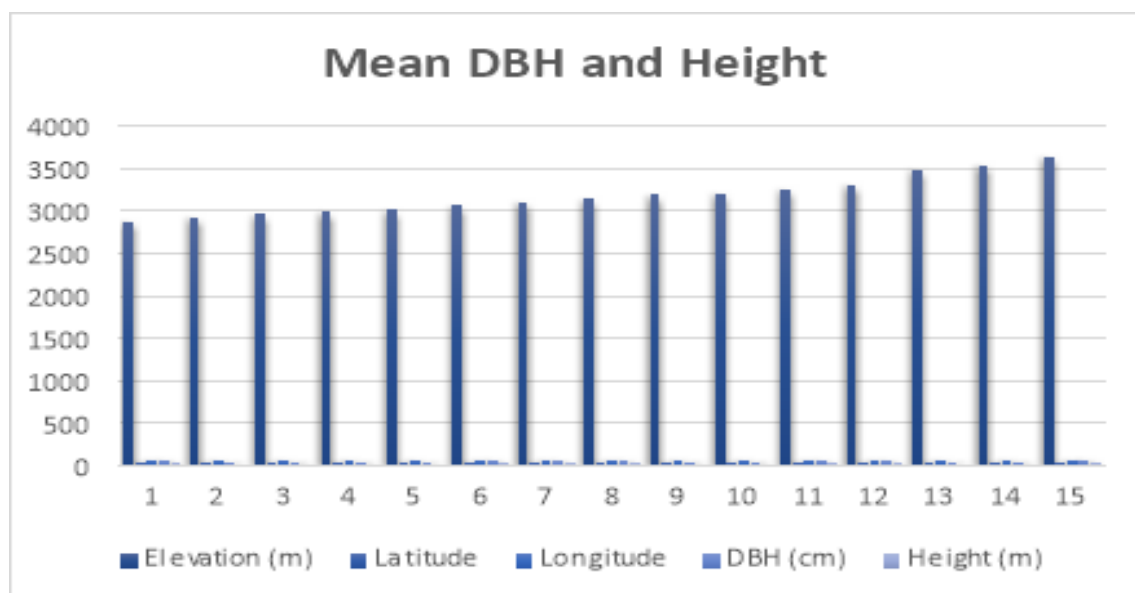


**Figure 4.4 Elevation wise Mean DBH and Height**

#### 4.2.2 ELEVATION WISE BIOMASS ANALYSIS OF CEDRUS DEODARA IN CHITRAL

The overview of total biomass (t/ha), below-ground biomass and above-ground biomass (t/ha) at different altitudes is projected in (Table 4.2). However, at 3395 m elevation the highest total biomass of 362.91 t ha<sup>-1</sup> was

recorded (214.68 t ha<sup>-1</sup> of above ground biomass and 148.23 t ha<sup>-1</sup> of below ground biomass). On the other hand, at 3060 m, the highest total biomass of 11.24 t/ha was comprised of 2.43 t/ha in total below ground biomass and 9.12 t/ha in total above ground biomass.

**Table 4.8: Elevation wise Biomass and Carbon Analysis of *Cedrus deodara* in Chitral at different strata's**

| Elevation (m) | AGB (t/h) | BGB (t/h) | TBM (t/h) | AGC (t/h) | BGC (t/h) | TC (h/h) |
|---------------|-----------|-----------|-----------|-----------|-----------|----------|
| 2876          | 66.1      | 18.18     | 82.29     | 31.10     | 9.01      | 38.82    |
| 2924          | 167.71    | 42.89     | 209.29    | 78.39     | 21.27     | 97.69    |
| 2965          | 94.09     | 22.39     | 118.38    | 44.82     | 12.33     | 56.01    |

|      |        |       |        |        |       |        |
|------|--------|-------|--------|--------|-------|--------|
| 2990 | 184.71 | 47.08 | 233.09 | 86.43  | 23.07 | 108.98 |
| 3007 | 53.43  | 14.65 | 67.06  | 23.67  | 7.69  | 33.48  |
| 3060 | 9.12   | 2.43  | 11.24  | 4.35   | 1.65  | 5.4    |
| 3100 | 66.18  | 17.37 | 84.07  | 31.35  | 8.27  | 39.57  |
| 3140 | 36.64  | 9.55  | 46.13  | 17.28  | 4.47  | 21.63  |
| 3190 | 30.87  | 8.28  | 38.06  | 14.63  | 3.77  | 18.21  |
| 3200 | 88.45  | 23.61 | 111.51 | 41.43  | 10.83 | 52.81  |
| 3250 | 48.15  | 8.53  | 41.32  | 15.4   | 4.00  | 19.49  |
| 3300 | 58.29  | 15.41 | 73.39  | 27.39  | 7.11  | 34.48  |
| 3320 | 49.09  | 12.94 | 62.73  | 23.68  | 6.37  | 29.42  |
| 3360 | 82.78  | 21.74 | 103.65 | 38.15  | 10.09 | 48.09  |
| 3395 | 288.43 | 74.17 | 362.91 | 135.02 | 35.19 | 170.59 |

#### 4.2.3 ABOVE GROUND OR VEGETATIVE BIOMASS OF CEDRUS DEODARA.

The estimated above-ground or aerial biomass of *Cedrus deodara* at various sites is shown in

Table 4.2. At 3060 meters, the lowest value was 9.12 t/ha and the highest 288.43 t/ha at 3395 meters. These values are depicted graphically on a few sites in Figure 2.

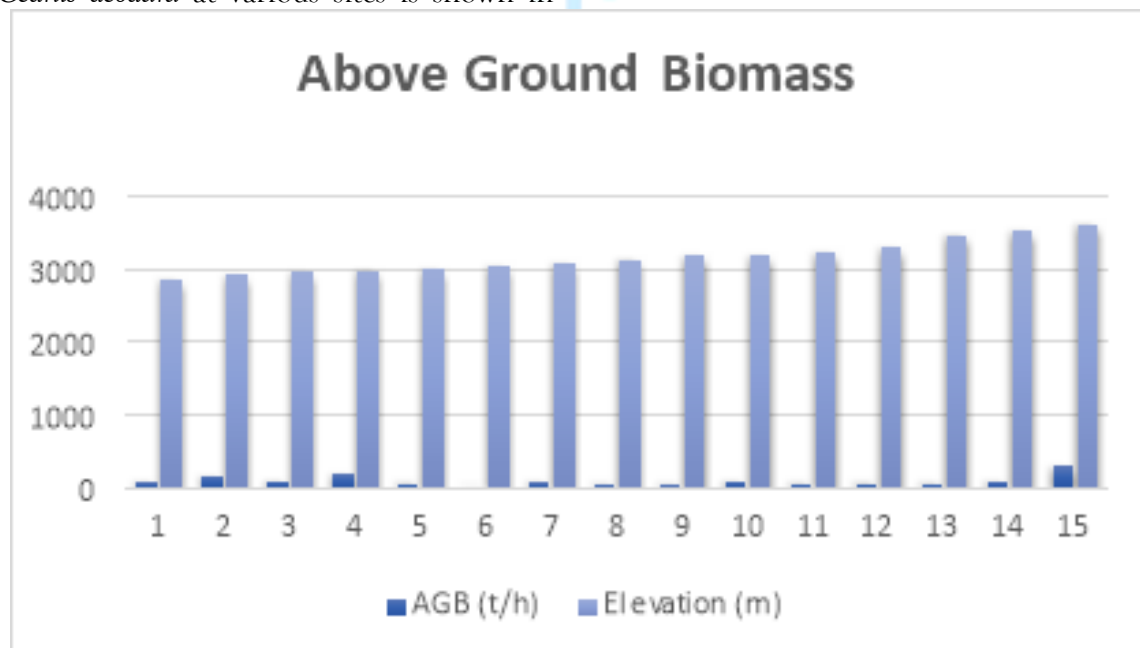


Figure 4.5: Plot wise AGB (t/ha) *Cedrus deodara* in Chitral

#### 4.2.4 BELOW GROUND OR ROOT BIOMASS OF CEDRUS DEODARA

Table 4.2 lists the biomass of *Cedrus deodara* below ground at various locations. The figures

ranged from 2.43 t/ha for 3060m elevation to 74.17 t/ha for 3395m elevation. Figure 3 shows these differences between in (belowground) and locations.

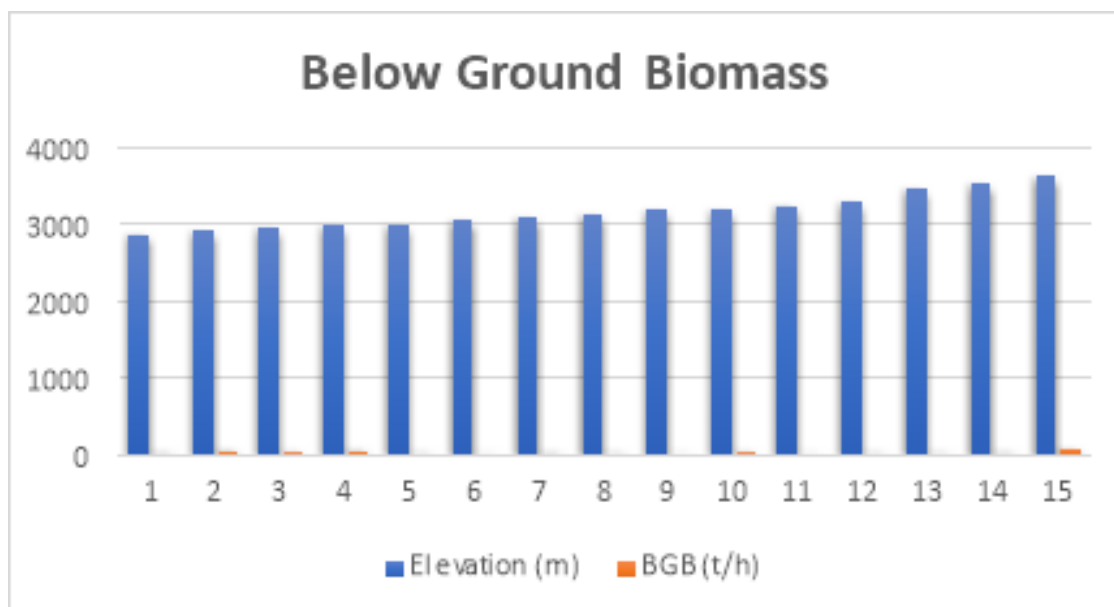


**Figure 4.6:** Plot wise BGB (t/ha) of *Cedrus deodara* in Chitral.

#### 4.2.5 TOTAL BIOMASS OF CEDRUS DEODARA

Table 2 shows the estimated aboveground biomass of *Cedrus deodara* at various places. At 3395m elevation, 362.91 t/ha was observed

in the maximum biomass and 11.24 t/ha in the minimum biomass from 3060 m elevation. Figure 5 shows the total biomasses of *Cedrus deodara* at different sample locations.

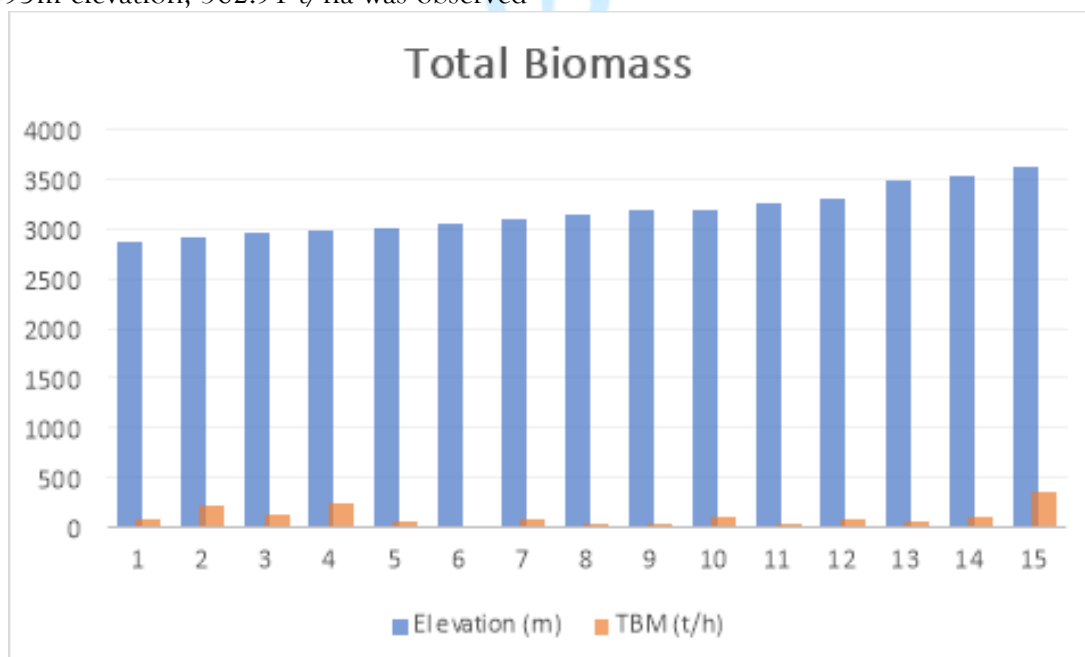


**Figure 4.7:** Plot wise Total Biomass (t/ha) of *Cedrus deodara* in Chitral

#### 4.2.6 ELEVATION WISE CARBON ACCUMULATION OF CEDRUS DEODARA

Thus, the graph shows (AGB) of *Cedrus deodara* at some places. Whereas, the highest amount of total carbon was found in 3395 m elevation i.e., 170.59 t/ha. Above ground, it totaled 135.02 t/ha and below ground 35.19

t/ha. *Cedrus deodara* was showing compatibility at different heights when analyzed for biomass and carbon stocks. The values decreased down to 3060 m where it was found lowest, 4.66 t/ha, 4.35 t/ha above ground and 1.65 t/ha below.

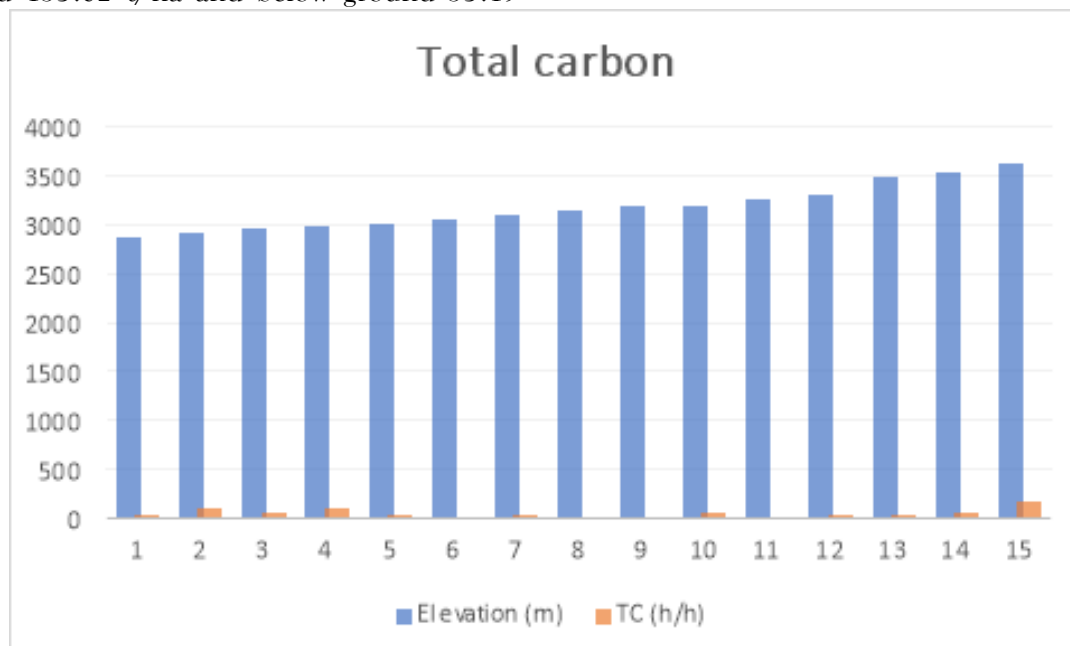


**Figure 4.8:** Plot wise Total Carbon (t/ha) of *Cedrus deodara* in Chitral

#### 4.2.7 TOTAL BIOMASS AND TOTAL CARBON OF CEDRUS DEODARA

Figure 4.7 shows the analysis of biomass and carbon accumulation of *Cedrus deodara* at various elevations it was recorded highest at 3395m Elevation at Chitral i.e (362.91 t/ha) whereas it was recorded lowest at 3030 m elevation (11.24 t/ha). The total carbon content at 3395m elevation was (170.59 t/ha) whereas lowest was at 3060m elevation i.e., (5.4 t/ha)

#### 4.2.8 Bulk Density

As soil depth increased, soil bulk density increased too. Increase in bulk density is

attributed to a drop in organic carbon with soil depth. Bulk density was highest at 3360 meters and the depth of soil was recorded from 15 to 30 cm (1.28 g/cm<sup>3</sup>), and lowest at 3060 meters (0.69 g/cm<sup>3</sup>). The results obtained are in line with results of pine soils done by Minhas *et al.* (1997), Kumar (2003), Minj (2008), Goswami (2009), Masoodi (2010), Devi (2011).

**Table 4.9: Height wise bulk density of soil at different sites.**

| S. No. | X       | Y       | Height (m) | Bulk Density (g/cm) |
|--------|---------|---------|------------|---------------------|
| 1      | 35.5337 | 71.4134 | 2876       | 1.09                |
| 2      | 35.5334 | 71.4136 | 2924       | 0.92                |
| 3      | 35.5330 | 71.4135 | 2965       | 0.90                |
| 4      | 35.5333 | 71.4133 | 2990       | 1.01                |
| 5      | 35.5329 | 71.4139 | 3007       | 1.09                |
| 6      | 35.5329 | 71.4139 | 3060       | 0.69                |
| 7      | 35.5338 | 71.4115 | 3100       | 1.08                |
| 8      | 35.5322 | 71.4179 | 3140       | 1.09                |
| 9      | 35.5324 | 71.4165 | 3190       | 0.93                |
| 10     | 35.5341 | 71.4116 | 3200       | 1.06                |
| 11     | 35.5341 | 71.4152 | 3250       | 1.26                |
| 12     | 35.5340 | 71.4151 | 3300       | 1.09                |
| 13     | 35.5342 | 71.4140 | 3320       | 1.03                |
| 14     | 35.5346 | 71.4149 | 3360       | 1.28                |
| 15     | 35.5346 | 71.4119 | 3395       | 0.79                |

#### 4.2.9 Soil pH

The pH of the soil mentioned in the table gives an overlook of the plot-wise. The pH is reported to be in the range of 7.4 to 8.5. That is within the range that implies that the soil is

neutral to slightly basic, and within the range that permits the variety of plants and animals of the park. At a height of 2990 meters, the lowest pH is 7.4 and at 3250 meters the highest pH is 8.4.

**Table4.10: Height wise pH of soil at different sites.**

| S. No. | X       | Y       | Height (m) | Soil pH |
|--------|---------|---------|------------|---------|
| 1      | 35.5337 | 71.4134 | 2876       | 7.7     |
| 2      | 35.5334 | 71.4136 | 2924       | 7.9     |
| 3      | 35.5330 | 71.4135 | 2965       | 7.8     |
| 4      | 35.5333 | 71.4133 | 2990       | 7.4     |
| 5      | 35.5329 | 71.4139 | 3007       | 8.2     |
| 6      | 35.5329 | 71.4139 | 3060       | 8.0     |
| 7      | 35.5338 | 71.4115 | 3100       | 7.5     |
| 8      | 35.5322 | 71.4179 | 3140       | 8.3     |
| 9      | 35.5324 | 71.4165 | 3190       | 7.8     |
| 10     | 35.5341 | 71.4116 | 3200       | 7.10    |
| 11     | 35.5341 | 71.4152 | 3250       | 8.4     |
| 12     | 35.5340 | 71.4151 | 3300       | 8.3     |
| 13     | 35.5342 | 71.4140 | 3320       | 8.1     |
| 14     | 35.5346 | 71.4149 | 3360       | 7.9     |
| 15     | 35.5346 | 71.4119 | 3395       | 7.6     |

### 5.2.10 Organic carbon of Soil

Table 4.10 gives overview of Plot-wise Organic Carbon of soil. The range in SOC's value is 30.62 to 57.8 (0-15 cm). At 3300 meters, Plot 12 had the least value for height at 30.62, while Plot 09 had the highest at 57.8 at 3190 meters of altitude. Average value of SOC (15-30 cm) was 37.61 and in the range of 23.75-51.46. The highest value was 51.46 in plot number 09 whose elevation was 3190 meters while the lowest was 23.75 in plot number 12 with an elevation of 3300 meters.

**Table 4.11: Soil Organic Carbon values at different Elevation**

| S. No. | X       | Y       | Height (m) | SOC (0-15cm) | SOC (15-30cm) |
|--------|---------|---------|------------|--------------|---------------|
| 1      | 35.5337 | 71.4134 | 2876       | 41.34        | 32.94         |
| 2      | 35.5334 | 71.4136 | 2924       | 40.21        | 34.62         |
| 3      | 35.5330 | 71.4135 | 2965       | 52.83        | 43.25         |
| 4      | 35.5333 | 71.4133 | 2990       | 46.69        | 42.80         |
| 5      | 35.5329 | 71.4139 | 3007       | 38.78        | 34.80         |
| 6      | 35.5329 | 71.4139 | 3060       | 54.66        | 43.08         |
| 7      | 35.5338 | 71.4115 | 3100       | 33.32        | 26.74         |
| 8      | 35.5322 | 71.4179 | 3140       | 43.83        | 39.25         |
| 9      | 35.5324 | 71.4165 | 3190       | 57.80        | 51.46         |
| 10     | 35.5341 | 71.4116 | 3200       | 53.12        | 39.94         |
| 11     | 35.5341 | 71.4152 | 3250       | 36.48        | 29.12         |
| 12     | 35.5340 | 71.4151 | 3300       | 30.62        | 23.75         |
| 13     | 35.5342 | 71.4140 | 3320       | 44.87        | 37.05         |
| 14     | 35.5346 | 71.4149 | 3360       | 36.41        | 31.59         |
| 15     | 35.5346 | 71.4119 | 3395       | 42.80        | 37.98         |

### 4.3 DISCUSSION

Thus, there is a need for a study on the carbon stock assessment of *Cedrus deodara* in Galiyat and Chitral moist temperate forest regions, to evaluate the biomass, carbon sequestration potential, soil characteristics and potential of this species as a source for biomass for energy generation projects.

*Cedrus deodara* had high variation for mean tree height and diameter at breast height (DBH) among Galiyat and Chitral plots. The first two altitudes showed highest maximum mean DBH (74.0 cm) and tree height (33.90 m) at 3395 m and lowest at 3060 m (28.66 cm and 17.25 m, respectively). Also, in Galiyat, DBH (72 cm), and tree height (32.5 m) reached a maximum at 2577 m and went down to 2371 m (26.5 cm and 16.8 m, respectively).

This variance in DBH and tree height, which is also observed in this study, may be caused by some of the changes in the elevation, soil quality, microclimatic conditions, and human activities such as logging and fuelwood harvesting. Because both tree growth and the accumulation of biomass are highly variable and varied by many different environmental factors, plots with higher DBH and tree height mean that these are in typically better growing conditions, with deeper soils, more available nutrients, and less anthropogenic disturbance. This agrees with the previous works conducted in other temperate forests (Nautiyal and Singh, 2013; Jina *et al.*, 2009).

The plot started to differ in the overall biomass of *Cedrus deodara*, in biomass above the ground (AGB) and biomass below the ground (BGB). At an elevation of 3395 m, Chitral had the maximum total biomass of (362.91 t/ha) having following values for above ground and below ground respectively i.e 288.43 t/ha and 74.17 t/ha. But at 3060 m the total biomass

Both the results found agree with similar studies which have been performed in the same ecosystem and show how *Cedrus deodara* has a key role to play in combating climate change and sequestering carbon. These are the main conclusions from this conversation, and they are further explained, contrasted with the body of existing literature, and prescriptions for further study and more forest management are provided.

was minimal (11.24 t/ha), although AGB and BGB were 9.12 t/ha and 2.43 t/ha, respectively. Furthermore, the highest total biomass (350.45 t/ha) were recorded at 2577m elevation in Galiyat while lowest biomass (10.50 t/ha) was recorded at 2371m elevation. The reason for the larger biomass encountered in these plots could be attributed to the fact that it contains older trees (mature trees) that contribute significantly to AGB and BGB with increased DBH and height. Other plots might have lower soil conditions, and, most extreme and unnoticed, human disturbances, especially illegal logging and fuelwood harvesting, as the reason for lower biomass estimates as they have younger stands than the plots where biomass was high. These findings are in keeping with the central Himalayan studies on carbon stocks in pines and oak forests (Jina *et al.*, 2009; Singh *et al.*, 2009). *Cedrus deodara* has high potential to sequester carbon due to its longevity and thick wood but has enormous potential for threats, especially illegal harvest, which jeopardizes the potential for carbon sequestration.

Carbon stored by *Cedrus deodara* has been evaluated using the maximum carbon stocks provided for Chitral, Chitral at 3395m and Galiyat at 2577m. Carbon stored was lowest in the plots with lowest biomass (4.66 t/ha in Galiyat and 4.95 t/ha in Chitral). *Cedrus deodara* has sizable ability to sequester carbon in mature forests with great biomass buildup.

This is like temperate forests studies, where *Pinus gerardiana* and *Cedrus deodara* are found to possess enough level of carbon storage (Nautiyal and Singh, 2013). Yet, the study also points out how much the forests are at risk and what extent of human impact could hinder their ability to sequester carbon. Proper conservation and management plans for these forests should therefore be developed to preserve them and make the most of their contribution to climate change mitigation.

#### **4.7 BULK DENSITY, PH AND ORGANIC CARBON IN SOIL**

In this research, the bulk density, pH, and organic carbon (SOC) of the soil were also examined. Like reported earlier studies Minhas *et al.* (1997), Kumar (2003), bulk density increased with depth in Chitral and Galiyat. The decrease of organic carbon with depth is probably coupled to the increase of bulk density with depth since the organic carbon content decreases with depth.

The pH of the soil was ranging from slightly acidic to slightly alkaline (7.0–8.5) in all the locations. It is just the beauty and the warmth of the range, which is ideal for the development of *Cedrus deodara* and other temperate forest species. It is the usual practice to reduce the SOC content at deeper depths of soil because organic matter accumulates in the upper layers of these forest ecosystems (Banerjee and Badola 1980; Gupta *et al.* 1991). The leaf litter is constantly added and takes exceptionally long to break down thereby raising the soil organic carbon in the top layer which makes the surface layers more abundant of greater SOC contents.

#### **4.8 IMPLICATIONS FOR FOREST MANAGEMENT AND CONSERVATION**

These results have huge conservation and management implications for forests in the humid temperate areas of Chitral and Galiyat. In the case of preservation and sustainable

management of *Cedrus deodara*, the carbon sequestering ability of this species is great. These woods are facing the main hazards such as illegal logging and fuelwood collecting and they should be stopped with some practical steps.

The study equally explains the necessity of keeping the forest soil healthy for the advancement of sustainable forest development. Afforestation, reforestation, and managed grazing are techniques that reduce erosion and promote an increase in organic carbon content of the soil. Analysis of carbon storage shows that conservation of *Cedrus deodara* should include mature stands.

#### **4.9 EVALUATION IN RELATION TO OTHER RESEARCH**

The findings of the study are congruent with other regions with similar systems. For instance, a lot of studies found that the Central Himalayan oak forests hold more carbon than pine forests (Jina *et al.*, 2009; Singh *et al.* Analogously, studies in the Garhwal Himalayas, which indicate the capability of broad-leaved species to sequester carbon (Nautiyal and Singh, 2013), are available in the literature which demonstrate the equivalent capability amongst tree species of other Himalayan regions. In addition to this, this research contributes to the growing body of data which demonstrates that temperate forests, especially those marked by *Cedrus deodara*, assume a significant role in the mechanism of global carbon cycling. Moreover, the research found that the dry-deciduous *Cedrus deodara* is more effective in carbon storage in a dry temperate climate as compared to wet one.

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