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Biomass estimation and carbon sequestration potential of gymnosperms in the unique ecological milieu of Kalash valley Chitral, Pakistan

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Key words: Biomass estimation, Carbon sequestration potential, Gymnosperms, Ecological milieu, Kalash valley, Chitral, Pakistan

Abstract

This study is to thoroughly investigate biomass and to gain comprehensive insights into the carbon sequestration dynamics of Gymnosperm trees in three sub-valleys within the Kalash region: Bumburate, Rambur, and Birir. The study honed in on conifers distributed above an elevation of 1800 meters above sea level. The species selected were *Cedrus deodara, Juniperus excelsa, Pinus gerardiana,* and *Pinus wallichiana*. Remote sensing using NDVI indicates that conifers constitute an expanse of 11,251 hectares and 3.325% of the total 1,048 square kilometres selected for this study. The total biomass contribution of the four Gymnosperm species in the area is recorded at 30.22 tonnes per hectare, sequestering 136,171 tonnes of carbon and emitting a carbon dioxide equivalent of 499,297 tonnes. The Shannon diversity index was determined to be 1.57, while Simpson's Diversity Index (D) stood at 0.78. The study found notable contribution of Gymnosperms in carbon sequestration and long term sink of carbon both AGB and BGB.

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Introduction

The concentration of CO_2 in the atmosphere has exponentially risen to dangerous range of 800 ppm (Byrne, 2023) it makes environmental concerns as a modern top most issue. The pivotal role played by forest vegetation in storing biomass and carbon (C) stock and primary solution to mitigate the impacts in rising CO_2 Concentration (Haq, 2023). To counter this issue Forest ecosystems have the capability to provide crucial carbon sinks contributing to global carbon neutrality (Xu *et al.*, 2023). It is unquestionable that Forests play an important role in carbon storage, known as carbon biomass. They serve as massive carbon repositories and and potential sink of carbon in the atmosphere (Bae *et al.*, 2004) by sequestering and removing carbon from the atmosphere and stores it as biomass in green plants (Chavan and Rasal, 2012) and valuable and viable solution for mitigating climate change. They hold 92% of all land-based biomass and store about 400 billion tons of carbon (Pan, 2013). Carbon Biomass is stored in plants and other plant material (Ostadhashemi, 2014). The IPCC classifies biomass carbon pools into AGB, BGB, litter, woody debris, and soil organic matter (Nunoo *et al.*, 2006). Assessing biomass and carbon budgets is essential for assessing productivity, sustainability, and carbon sequestration capacity but assessments primarily rely on accurate biomass estimations (Salunkhe *et al.*, 2023)

Biomass estimation is key to evaluate the status and flux carbon and dynamics of the ecosystem. Biomass can be estimated in various ways like Destructive or harvesting method, remote sensing method and non-destructive allometric equation. The equations tailored to find biomass of trees can provide more accurate estimates of biomass particularly if validated with the help of remote sensing (Navar, 2009). The estimation of biomass and C stock based on accurate local/regional allometric models is suitable method to large-scale falling of forest tree (Salunkhe *et al.*, 2023) and better mathematical approach as compared to destructive and manual methods. As per the IPCC, terrestrial ecosystems encompass five carbon pools related to biomass: above-ground biomass, below-ground biomass, litter, and woody debris, and soil organic matter. AGB is the predominant component of the carbon pool, serving as the most significant and conspicuous reservoir within the terrestrial forest ecosystem (Haq *et al.*, 2023). Aboveground biomass (AGB) in particular serves as a crucial indicator of ecosystem structure and functionality, playing a significant role in the estimation of forest carbon stocks (Fig. 1).

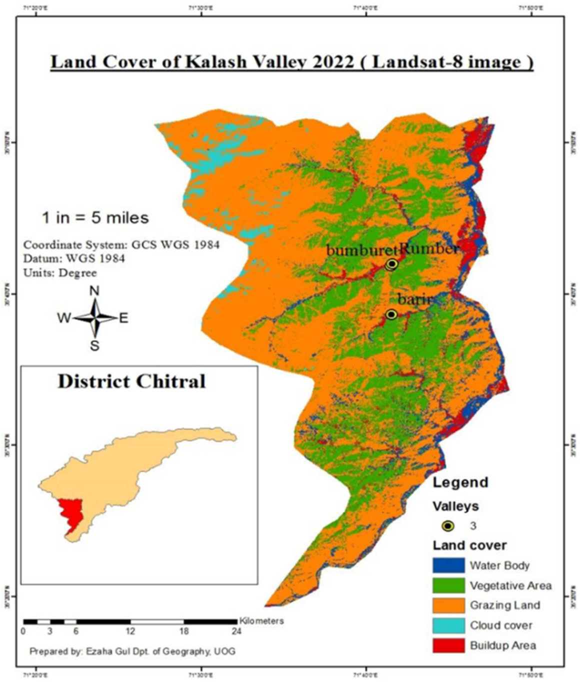

Fig. 1. Land cover of Kalash valley 2022 (Landsat-8 image)

Pakistan not dissimilar from the world, is facing an imminent risk of increased deforestation and forest degradation by anthropogenic activities and exacerbated by the adverse effects of climate change (Hussain and Fatima, 2015). Luckily Pakistan has significant potential for carbon sequestration, i.e., forests, rang elands, and agricultural lands sequester up to 225 million tons of CO_2 per year (Khilafat, 2022). According to FAO 2020, Biomass rreservoir of Pakistan is approximately 213 million tonnes of carbon including total forest area of 4.2 million hectares (Mahmood, 2011) 4.57 million ha according to Bhatti, 2011. Numerous studies in Pakistan, such as Nizami *et al.* (2009) on subtropical pine forests in Murree hills, Shaheen *et al.* (2016) on subtropical

Himalayan forests (Ghafoor, 2020; Nizami *et al.*, 2009; Shaheen *et al.*, 2016; Khan *et al.*, 2021; Hamayoon Jallat; Amir *et al.*, 2018; Ali *et al.*, 2020a; Sheikh *et al.*, 2012; Nizami, 2012; Ali and Anwar, 2020; Martin *et al.*, 2013; Arif *et al.*, 2017; Akbar *et al.*, 2023; Raqeeb, 2020) help us to understand Carbon sequestration in Pakistan.

Materials and methods

Study area

The area centred For Biomass study was Kalash Valley was on three research sites, i.e., Bumburet, Rambur and Birir, wherein the investigation delved into the biomass and carbon stock specifically pertaining to Gymnosperms, aiming for understanding of Carbon sequestration of the Area. *Cedrus deodara*, *Juniperus exelsa*, *Pinus gerardiana* and *Pinus wallichiana* were Gymnosperm trees of the area.

Chitral, a mountain locked land, situated between 35° 15/ to 36° 55/ North latitudes and 71°11/ to 73°51/ East longitudes. It covers an area of 14,850 km² (DCR, 1998) (Ali and Qaiser, 2009) while Lower Chitral (established in 2018) is a district in the Malakand division covering 6,458 km² and located between 35° and 37° N latitudes and 71° and 22° to 74° E longitudes (GoP). 40 km downstream from Chitral city lies Kalash Valley, positioned within 35° 70/ to 35°42/ North Latitude and 71°69/ or 71°41/ East Longitude. The elevation ranges from 1900 to 2200 (DCR, 1998), (Open Location Code 8J7 HPM6H). The valley comprises three sub-valleys and research site in this study are Bumburet, Rumbor, and Birir. They are bblessed with diverse flora, of oak and coniferous forests, rich biodiversity and indigenous culture. Kalash are believed to be descended from Alexander the Great's army (Hadi and Ibrar, 2015; Ullah *et al.*, 2014; Zeb, 2019). Rambur, positioned at a higher elevation than Bumburet, is renowned for its feeding glaciers and alpine meadows. Bumburet, the largest valley among the Kalash valley is situated at coordinates 35° 41' N and 71° 38' E. The area is characterized by rugged topography and steep slopes. Rambur is positioned between coordinates 35° 46' N and 71° 40' E, situated to the north of Bumburet in proximity of about 8 kilometres. Birir valley is located at the southernmost end of Chitral city. In contrast to the other two valleys, it has narrower width, at coordinates 35° 40' N and 71° 45' E and an elevation of 1360 meters (Zeb, 2019). Inhabitants of the area rely hugely on forest and forestry products for their livelihood. According to Aziz and Nadira (2003), approximately 25 thousand metric tons of forest wood is used as a source of fuel for 13% of the population (Irum *et al.*, 2014).

The valley experiences harsh and snowy winters, sometime as low as -20°C in certain areas and summer ranging from 15 to 25°C. The monsoon season contributing significantly to annual precipitation from 1500 to 2500 mm per year (Ali, 2010). In Gymnosperms *Cedrus deodara*, *Juniperus* sp., *Pinus gerardiana* and *Pinus wallichiana* along with *Quercus* spp. dominate the natural forest of the area (Hadi *et al.*, 2014; Sher *et al.*, 2003; FAO, 2010).

Sampling and field campaign

Circular plots, with a radius of 17.84 meters (equivalent to 0.1 hectares), were deployed within the expanse of gymnosperm forest of Kalash valley using geographic coordinates obtained through random sampling as used by Ismail *et al.*, 2017. The refinement of plot radius was achieved by applying slope correction factors. For measurement of Diameter at Breast Height (DBH), trees with diameters exceeding 5 centimetres and height surpassing 2 meters were recorded within the confines of each designated plot. For this purpose Diameter Tape (D-Tape) was used. For tree height Haga Altimeter was used. Reading was penned down along with Coordinates recorded by GPS. Forest imagery was captured using a digital camera. For better comparison Image of SAT 8 were also taken.

Occurrence and distribution of tree species/ Tree evenness and diversity index

Trees and community were identified followed by Vegetation analysis i.e., Tree height, DBH, Basal Area (BA), Relative Frequency (RF), Relative Density (RD), Relative Abundance (RA), Relative Cover, and Importance Value Index (IVI) using the formulae used by Ismail *et al.*, 2017. Regression model of Heights and DBH were calculated for each tree and sites. Tree species diversity index, i.e., Shannon Diversity Index (H') (Equation 1) and Simpson Diversity Index (Equation 2).

$$H = \sum_{i=1}^{s} -(Pi \times \ln Pi) \quad \text{Eq. 1}$$

Where H/ is Shanon Diversity Index, Pi is Fraction of entire population made up of species i, and s is number of species encountered and ln is natural algorathm.

$$D = \sum(n/N)2 \quad \text{Eq. 2}$$

Where D is Simpson Diversity Index, n is total number of particular species and N is number of total trees. The value of D ranges from 0- 1. 0 means infinite diversity and 1 means no diversity.

Tree allometric equations for biomass estimation

To estimate the above-ground tree biomass (AGTB), Tree allometric equations specific to the selected species, developed by previous researchers were employed. These equations are, i.e., M= Ln $(D^2 H)^n$

Cedrus deodara = $0.0491(D^2H)^{0.9167}$ Eq. 3

Pinus roxburghii = $0.0224(D^2H)^{0.9767}$ Eq. 4

Pinus gerardiana = $0.0253D^{2.6077}$ Eq. 5

Juniperus exelsa = 0.1645 × (p × D^2 × H)^0.8586 Eq. 6 (Ali *et al.*, 2015)

Where M is Dry biomass of the tree in kilogram; D is Diameter at Breast Height in centimetre; H is Total height of tree in m; Ln is Natural Logarithm and p is wood density. Used by Ali (2020).

Below Ground Biomass, above ground Carbon, below ground carbon andCO_2 equivalent were calculated using exiting literature as following.

BGB=AGB*R/S (BGB is below ground Biomass R is root and S is shoot. R/ S= 0.27 Eq. 7 (Ali *et al.*, 2017)

AGC=0.47*AGB (AGC is Above Ground Carbon) Eq. 8 (Ali *et al.*, 2020a)

BGC=0.26*AGB (BGC is below ground carbon) Eq. 9 (IPCC, 2008)

e Value=CStock*44/12 (CO_2 equivalent) Eq. 10 (Pearson *et al.*, 2007)

Validation of conifer forest by through remote sensing and imagery

To validate field studies satellite imagery of gymnosperms of August 2023 of Kalash Valley was taken from from the Land-sat 8 Operational Land Imager (OLI) on 08-12-2023. Boundaries drawn based on GPS USGS Earth Explorer. Multi temporal satellite images 2023 were downloaded from United State of Geological Survey website http://glovis.usgs.gov/). Remote sensing software, such as ENVI or QGIS, were used to visualize the satellite. The LULC classification is a clustering algorithm known as ISO Data Analysis Techniques; self-organizing (ISO) A (ISODATA), which was used for the purpose as used by Khan *et al.*, 2016. The methodology used by Taufik 2016; Huang, 2021 and Hartoyo, 2022. The data was prior confirmed by Questionnaire method and hectic field survey from 2021-2023 in various season.

Results

Gymnosperms trees *Cedrus deodara*, *Juniperus excelsa*, *Pinus gerardiana*, and *Pinus wallichiana*, focused in this study, were observed to play a substantial role in carbon sequestration with ecological contribution encompassing 11,251 hectares out of the total 104,800 hectares (Fig. 2). The elevation of these trees are 1,830 - 2,745 masl, 2,700 masl, 2,000 - 3,500 masl and above 2, 900 masl respectively. *Quercus dilata* and *Qercs baloot* were found to overlap in lower altitude and dominate below 1,800 masl in the area as studied by (Khan *et al.*, 2010). Data of FAO shows conifer forest spread in the area of 11251 hacters while remote sensing shows 3.325% of 1048 km^2 total area selected for this study. Over all the area is barren and vegetation is chiefly dominated by *Quercus dilata* and *Qercus baloot*.

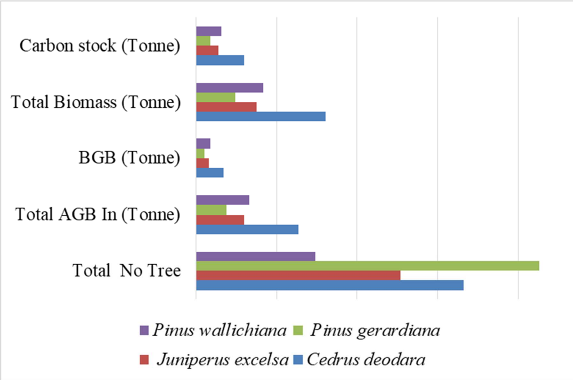

Fig. 2. Carbon stocking by conifer trees

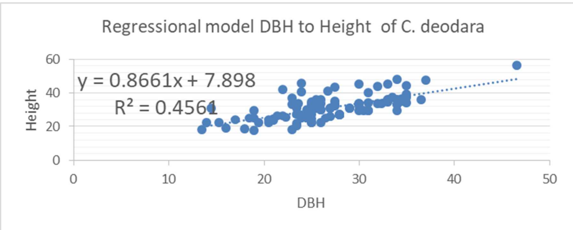

Fig. 3. Regressional model DBH to height of *C. deodara*

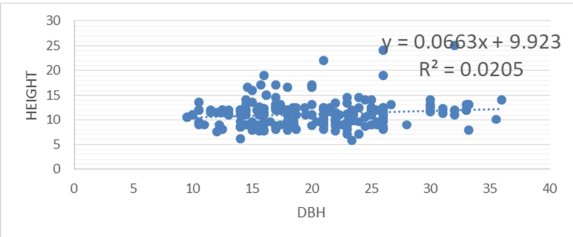

Fig. 4. Regressional model DBH to height of *J. exelsa*

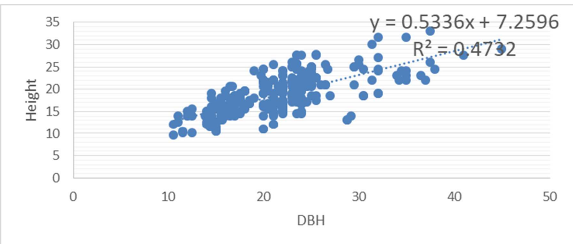

Fig. 5. Regressional Model DBH to height of *P. gerardiana*

Cedrus deodara, totalling 126,845 tonne in biomass of the areas and contributing to a carbon stock of 59,617 tonnes and sequestering approximately 218,596 tonnes of equivalent carbon dioxide (e-CO_2). It also stands tall with an average diameter at breast height (DBH) of 20.25 cm and height of 26.95 m, BA of 2.45 m², RA at 28.63%, RF of 50% and RD of 29.57%, signifying its ecological prominence. Regression of DBH and height for *Cedrus deodara* was 0.4561 (Fig. 3). While *Juniperus excelsa* exhibited total biomass 75,171 tonnes and lower in proportion (Fig. 4). It presents a comparatively smaller profile with average DBH of 19.64 cm and a shorter average height of 11.22 and regression trajectory of R^2 equal to 0.0205 it showed BA of 2.29 m², RA of 21.89%, RF of 47.5%, and RD of 22.61%. *Pinus gerardiana*, characterized by an average DBH of 21.64 cm and an average height of 18.88 m and linear regression of 0.4732, BA of 2.74 m², RA of 36.74%, RF of 54%, and RD of 37.93%, underlining its ecological significance and dominance with an average AGB of 88.99 kg per tree, contributed a total AGB of 37,982 tonnes (Fig. 5).

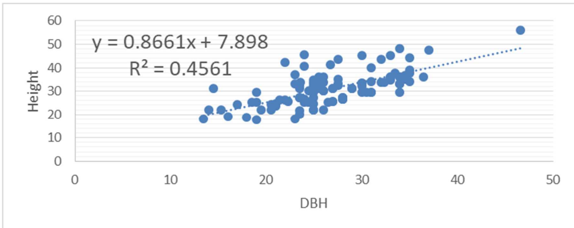

Fig. 6. Regressional Model DBH to height of *P. wallitana*

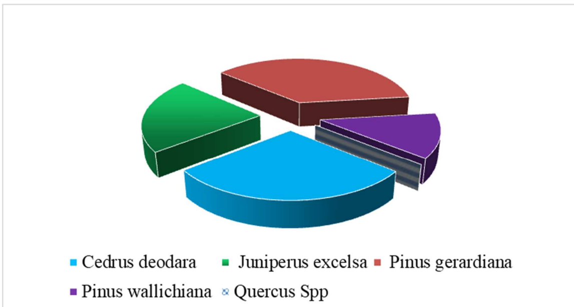

Fig. 7. No. of conifers in comparison

The biomass per hectare for *Pinus gerardiana* was 3.38 tonnes, contributing to a carbon stock of 17,851 tonnes and sequestering approximately 65,456 tonnes of e-CO_2. *Pinus wallichiana*, although small in number exhibited the highest average AGB, with 444.07 kg per tree (Fig. 6). The biomass per hectare for *Pinus wallichiana* was 5.84 tonnes, contributing to a carbon stock of 30,884 tonnes and sequestering around 113,242 tonnes of e-CO_2. The DBH was 26.61

cm and of 30.94 m in average, and R^2 equal to 0.4561. It has BA/Hac of 0.40 m^2 and highest among other conifers (Fig. 7).

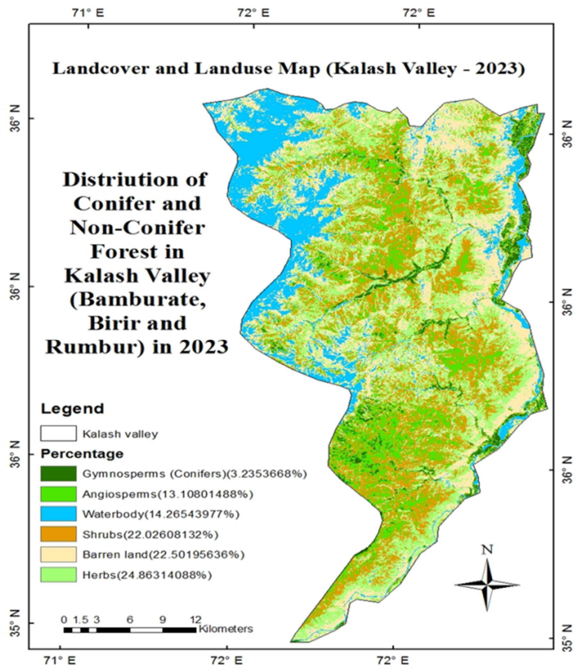

Fig. 8. LULC Map of conifer and non conifer in Kalash valley using NDVI 2023

Data obtained from Land-sat 8, detailing land cover and land use change (LCLUC) (Fig. 8) in the Kalash Valley to validate ground studies, presents an analysis of the distribution of other vegetation categories, revealing a nuanced landscape composition. Gymnosperms, specifically conifers, although lower in composition in niche covering 3.23% of the Kalash Valley but of significant important mostly dominating High elevation. Among other categories, water bodies account for 14.26% of the total area, barren land comprises a 22.5% of the landscape, a substantial presence of herbaceous vegetation in 24.86% of the area. Shrubs contribute to 22.02% of the area, a diverse group of flowering plants, occupying 13.1% of the landscape.

Discussion

UN -FAO estimate that the world has lost one-third of its forest and 10 million hectares of forest are being cleared per year which is damaging natural balance irreparably. Forests, integral in the climate change landscape, serve as long term carbon sinks (Ali *et al.*, 2023). To undo such catastrophic loss scientific evaluation to chart counter measure is crucial. As they are largest reservoir or Carbon so necessitate accurate biomass assessments to track temporal changes carbon cycle. The estimation of forest biomass involves ground surveys or remote sensing, with field survey with destructive and non-destructive sampling. The former, as elucidated by Gibbis (2007), includes harvesting all trees and measuring various parts' biomass. On the other hand Allometric, explained by Ghafoor (2020), provides a mathematical and statistical understanding in relation to biomass.

Various researchers in Pakistan have contributed to Biomass estimation of the country. Sarangzai *et al.*, 2012 studied aboiut Juniper in Balochistan and revealed 278 trees with an estimated average carbon content of 1.96 tons per hectare. Amir *et al.* (2018) revealed about the aboveground biomass of *Pinus roxburghii* and found weak correlations between tree characteristics and biomass. Ali *et al.* (2020) reported variations in tree dimensions, while Sheikh *et al.* (2012) provided estimates for diameter at breast height (DBH), height, and stand density. Ali and Anwar's (2020) research in Khyber Pakhtunkhwa highlighted diverse soil carbon densities across different forest types. Martin *et al.* (2013) found the substantial role of tropical forests in the terrestrial carbon balance. Arif *et al.* (2017) conducted a thorough assessment of carbon sequestration in the Chichawatni Irrigated Plantation in Pakistan. Akbar *et al.* (2023) reported on the forest structure in Skardu, while Ali *et al.* (2023) developed an allometric equation for *Cedrus deodara* in northern areas. Raqeeb (2020) conducted a comprehensive forest inventory in Gilgit Baltistan, estimating above-ground biomass. Similarly, a study in Malakand, Khyber Pakhtunkhwa, provided estimates for aboveground and belowground carbon, as well as the total tree carbon stock. Ahmad *et al.* (2014) conducted a study on biomass and carbon stocks in coniferous forests of Dir Kohistan, KPK. They reported an average biomass of 264.53 Mg ha^{-1} across all forest stands, with mean carbon stocks were

140.37 Mg ha^{-1} for deodar forest, 134.60 Mg ha^{-1} for deodar kail forest, 142.40 Mg ha^{-1} for mixed coniferous forest, and 111.68 Mg ha^{-1} for mixed fir-spruce forest.

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