Research Article

Exploring the Potential of Carbon Sequestration in Sub-Tropical Pine Forest Ecosystem: A Case Study in District Kurram, Pakistan

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Abstract | Carbon sequestration is of recent international focus to mitigate human-induced climate change. Nature has its mechanisms for carbon storage. Forests are important natural storehouses of carbon in terrestrial ecosystems. Estimation of forest biomass in various ecosystems is of key importance in the context of international climate treaties. The objectives of the current study were to assess above-ground carbon (AGC), belowground carbon (BGC) and total carbon stock in the sub-tropical pine forest in Upper Kurram District, Kurram (Pakistan). Twenty-five sample plots were marked in the study area to collect tree diameter, height and density-related information. Allometric equations were used to estimate total carbon stock from field data. The results depicted that the mean total biomass in the study area was 54.90 (t ha^{-1}) with the above-ground biomass (AGB) 43.60 t/ha and below-ground biomass (BGB) 11.34 t/ha.. The mean carbon dioxide equivalents (CO_2e) were 94.50 t/ha. The result of the correlation between mean height and mean DBH shows the R^2 value of 0.9971. This indicated that mean height and mean DBH have a strongly positive relation. The Coefficient of determination (R^2) between AGB and the diameter of Chir Pine forests is 0.6358. This study indicated that sub-tropical pine forests have a strong potential for carbon sequestration. The findings of this study will help policymakers in decision-making and developing future scenarios for climate change mitigation.

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Introduction

Global climate change is the Primarly concern for all the environmental protection agencies around the globe (Houghton *et al*., 2009; Awan *et al*., 2015). Global temperature has upsurged to 0.6-1°C between 1850 to 2005. Greenhouse gases (GHG) are responsible for capturing the earth's outgoing energy in the atmosphere and warming the earth (Parashar, 2019). The natural greenhouse effect upholds the planet's temperature sustainably, making life possible on earth. Without the natural greenhouse effect temperature of the earth would become more excellent like mars and the existence of life on the planet would become impossible (Kennedy *et al*., 2011; Kweku *et al*., 2018). Theindustrial revolution, disrupted this natural balance of incoming and outgoing sunlight due to the enhanced concentration of GHG in the atmosphere. Hence, the natural greenhouse effect was transformed into the enhanced greenhouse effect (Liang *et al*., 2019). If the GHG concentration keeps rising, the temperature might increase by 1 to 6°C till 2050 (IPCC, 2014).

Carbon dioxide is the most important and dominant GHG in terms of concentration and its contribution to global warming. According to the Keeling curve, the concentration of CO_2 in the atmosphere has exceeded the optimal level (350 parts per million), Currently, the CO_2 level is 409 parts per million (Hall *et al*., 2018). Terrestrial and oceanic ecosystems are the Significanat sinks of CO_2 globally. Among terrestrial ecosystems, forests are natural carbon-storing factories (Sharma *et al*., 2011; Danquah *et al*., 2012). The estimation of carbon stock in the specific forest is the Primary defining element in regional contribution (Sharma *et al*., 2011). Six hundred fifty billion tons (48%) of carbon has been sequestered by the worlds exsisting forests, of which 45% is stored in the soil, 44% in biomass and 11% in litter and deadwood (Keenan *et al*., 2015).

There are five carbon pools in the terrestrial ecosystem. These include above-ground biomass (AGB), below-ground biomass (BGB), the dead mass of litter, woody debris and organic matter of the soil. The carbon stock is mainly described as biomass and soil carbon in a forest ecosystem: as the tree grows, it sequesters carbon in its tissue. The dry biomass of trees contains 43-50% carbon (Malhi *et al*., 2002; Negi *et al*., 2003). During photosynthesis, CO_2 is fixed by plants and is transmitted through different carbon pools. AGB acts as a primary part of the carbon pool. D ifferent features that impact forest biomass, such as geographical attributes, soil, and climate conditions (Melkania, 2009).

The rapid increase in the human population, cutting of trees for timber, fuelwood, grazing, and land use changes has reduced forest biomass and its percentage throughout the globe (Vgen and Gumbricht, 2012). According to the Forest Resource Assessment, the forest area globally has declined from 31.6% to 30.6% between 1990 and 2015 (FAO, 2015). Forest cover and biomass increase by adopting proper land-use management, which helps to mitigate and increase carbon storage capacity by improving soil fertility and sequestration capacity (Lal, 2001, 2004; Abaker *et al*., 2016). The program Reducing Emissions from Deforestation and Forest Degradation (REDD+) of the United Nation Framework Convention on Climate Change has come up with the idea of paying forest users for reforestation in developing countries. This concept is a win-win solution to mitigate climate change. Implementation of REDD+ is very important to provide various income sources to the communities that rely primarily on forests, to provide distinct livelihoods, the sustainable management of biodiversity, the unbiased benefit of income from emissions reduction, etc. with the financial and non-monetary reimbursements. REDD+ assists the local community with financial benefits consisting of direct money incomes from REDD+ payments while enhancing and preserving the natural advantage of environmental assets. Proper use of environmental assets and the REDD+ mechanism economic flow can potentially create a significant contribution to poor individuals in different environmental circumstances. Developed countries would have to pay underdeveloped and developing nations for services to prevent or decrease deforestation and degradation (Ebeling and Yasue, 2008).

Pakistan is a subtropical country with a forest cover of 4.8 million ha, which is 5.2% of the total land area, where 0.2% is irrigated plantation (Bukhari *et al*., 2012). Pakistan is among the countries taking part in REDD+ and is currently compiling its national inventory data and producing different allometric equations to estimate forest biomass and carbon sequestration. The main objectives of this research were to estimate above-ground and below-ground biomass and carbon (AGB, BGB, AGC, BGC) and to estimate the carbon sequestration potential in the sub-tropical pine forest of the study area. The outcomes of the study will be helpful in the REDD+ program and for emission trading.

Materials and Methods

Study area

The present study has been conducted in the former

Kurram Agency, one of the newly merged districts of Khyber Pakhtunkhwa Province. Kurram has been the second oldest agency after Khyber and was integrated into British India in 1892 District Kurram (Sahai, 1905) 190 (It is located between 33˚ 20' to 34˚ 10' N latitude and 60˚ 50' to 70˚ 50' E longitude (Figure 1).

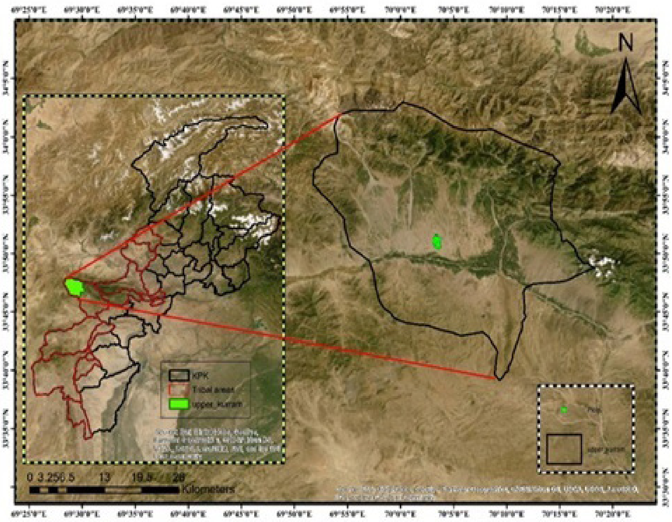

Figure 1: *Map of the study area.*

Administratively, it is divided into three tehsils, Central, upper and lower Kurram. Our research focuses on Upper Kurram, which is rich in forest resources (Khan, 2008).

Due to its remoteness, mountainous, terrain and the war on terror in FATA, research on the forestry sector in the study area is nearly impossible. Keeping in view the above problems it was tried to do some research on the area to add new information in the forest sector of the area. This will help the government and private agencies in future research.

Field inventory

A random sampling technique was used to sample the forest area. In total, 25 plots were selected for data collection. The size of the plot was one-tenth (1/10) of a hectare was taken as the standard for all sampling units. The plots were circular with a radius of 17.84m or one-tenth of a hectare. The sampling intensity for the plot was standardized at 0.5% because of the tough terrain. Plots were given numbering for identification (P1, P2, P3…..). This research is a pilot project for future inventory and research. The diameter of the trees in each sampling plot was recorded at the breast height point using a tree caliper. A measuring tape was used for Plot measurement, with help of GPS coordinate was noted.

When I was Collecting data, I observed in the field that there is a severe threat of urbanization to this forest, which is noted in the study area map. Because this site is only 6 km away from Parachinar, Parachinar is the headquarter of the district kurram I also observed that there few houses were also built in the forest area. There is a main road pass in the forest, Which connecte many villages to the main city, due to war and terror also affect the forest growth All these factors will affect the forest as well as also affect my results (study area map) (answer 2.3, 2.4, 3.1).

Tree height calculation

Tree height was calculated from tree diameter using the following formulae:

*Tree height = 0.0044 * Diameter ^ 2 + 0.6863 * Diameter - 0.7196 …. (1)*

Calculation of biomass

To calculate biomass AGB and BGB were calculated using the following allometric equation:

$$\text{Above ground biomass} = 0.0224 \times (DBH^2 \times H)^{0.9767} \quad (2)$$

(Ali *et al*., 2020)

Where DBH is the diameter at the breast height of the tree in cm and H is the height of the tree in m. BGB was calculated by multiplying AGB with 0.26 according to IPCC guidelines. Furthermore, AGB and BGB were added up to calculate total biomass (Paustian *et al*., 2006).

Calculation of total carbon and carbon equivalents

Estimation of AGC, BGC, and total carbon was carried out by multiplying AGB, BGB and total biomass with 0.47 respectively. Approximately 47 % of the biomass is considered carbon (Paustian *et al*., 2006). To calculate the CO_2 sequestration in each plot, the product of ABG and 3.66 was taken (IPCC, 2014).

Regression analysis

Regression analysis was performed to analyze the relationship between AGB and mean DBH and between mean height and mean DBH.

Results and Discussion

Density and diameter class distribution of the study area

The study was carried out using 25 circular plots. Tree diameter was measured in individual plots. Figure 2 depicts the density of individual plots and diameter class distribution of the trees in the study area. In total, 791 trees were measured with, 217 trees between 10-20cm, 539 for a diameter class of 20-30cm and 35 trees for a class of 30-40cm in the study area. The most dominant plot in terms of density was P1 containing 48 trees, while the lowest density was observed in P24 and P16, with 24 trees. It is evident from the data that the highest number of trees was present between 20-30 centimeter (cm) diameter class. Furthermore, these values were extrapolated to calculate stems per hectare in the study area. Similar techniques were observed by Ekoungoulou *et al.* (2014). This extrapolation was carried out to get an estimate of the whole study area as well as to use it in future studies for comparison. The highest mean diameter was 36 cm in P15 while the lowest mean diameter was found to be 11 cm in P2. The highest height was 18.28 m in P15, while the lowest height was found at 6.30 m in P2. Summary statistics of DBH and height in the study area are described in Table 1, with mean DBH 23.47±0.64(cm) and 12.90± 030 (m), respectively.

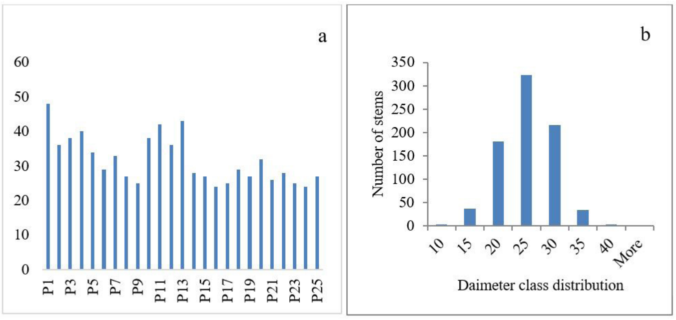

Figure 2: *Density and Diameter class distribution of Sampled trees in the study area.*

Table 1: *Summary statistics of DBH and height in the study area.*

	Mean	Standard error	Median	Mode	Standard deviation	Sample variance
DBH	23.47	0.64	23.66	24.72	3.53	13.34
Height	12.90	0.30	13.04	13.47	1.66	2.84

Distribution of biomass and carbon stocks in the study area

Estimated AGB, BGB (t/ha) and total biomass (t/ha) are summarized in Table 2. The highest stem number (density), 480/ha was calculated in P1. The highest total biomass was 91.46 with AGB and BGB 72.59 and 18.87, respectively in P11, whereas the lowest total biomass of 27.02 was found in P2 with 21.44 and 5.57 with AGB and BGB respectively. Furthermore, total biomass in the study area was 54.94 with AGB 43.60 (approx. 80%), while BGB was 11.34 (approx. 19%).

The total carbon stocks in all 25 sampling plots were 25.82, with 20.49 and 5.33 shares of ABC and BGC. The highest total carbon stocks 42.99, AGC and BGC, were 34.12 and 8.87 in P11, while the lowest total carbon stocks, 12.70, AGC and BGC were estimated as 10.08 and 2.62 in P2. The highest CO_2 equivalent was 157.33 in P11, while the lowest CO_2 equivalent was 46.47 (t/ha) in P2. A comparison of AGC and BGC is presented in Figure 3. The mean carbon equivalent per hectare in the study area was 94.50. A comparison of total biomass and total carbon is depicted in Figure 4.

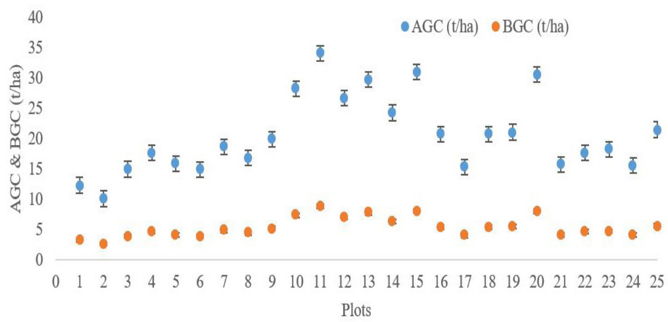

Figure 3: *Comparison of AGC and BGC stocks in the study area.*

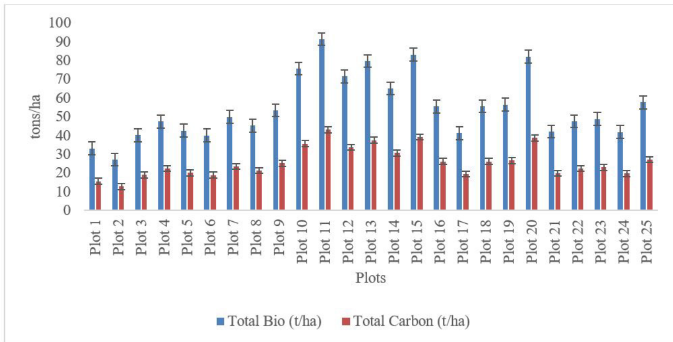

Figure 4: *Total biomass and total carbon in the study area.*

Regression between height (m) and diameter DBH (cm)

Height and diameter are important parts of the carbon pools, which have a key role in the sequestration of CO_2. At the point when the height of the trees is greater, it will increase the tree diameter, these are the fundamental element for the preservation of CO_2 in the forest. At some point, the trees show variety from one another due to the quality of the site and competition among the sunlight and water. The regression model demonstrates a similar pattern line however, at some point, they diverge from the line

Table 2: *Assembly of study area along with dispersal of carbon stocks.*

Plots	Mean dia (cm)	Mean height (m)	Stems/ ha	AGB (t/ha)	BGB (t/ha)	Total biomass	Total carbon (t/ha)	CO2e
P1	16.721	9.666	480	26.179	6.806	32.985	15.503	56.741
P2	17.250	9.759	360	21.442	5.575	27.017	12.698	46.475
P3	19.684	11.046	380	31.821	8.273	40.094	18.844	68.970
P4	20.200	11.273	400	37.633	9.785	47.418	22.286	81.569
P5	21.000	11.717	340	33.793	8.786	42.580	20.012	73.245
P6	21.689	12.053	290	31.735	8.251	39.986	18.794	68.784
P7	22.515	12.469	330	39.568	10.288	49.856	23.432	85.761
P8	23.037	12.681	270	35.864	9.325	45.188	21.238	77.733
P9	25.400	13.818	250	42.402	11.025	53.427	25.111	91.905
P10	24.895	13.603	380	60.068	15.618	75.686	35.572	130.195
P11	25.714	13.981	420	72.586	18.872	91.459	42.986	157.328
P12	24.639	13.453	360	56.745	14.754	71.498	33.604	122.991
P13	24.326	13.347	430	63.238	16.442	79.679	37.449	137.064
P14	26.357	14.278	280	51.640	13.426	65.066	30.581	111.926
P15	27.741	15.297	270	65.993	17.158	83.151	39.081	143.037
P16	26.041	14.097	240	44.023	11.446	55.469	26.070	95.417
P17	23.120	12.749	250	32.655	8.490	41.145	19.338	70.778
P18	24.310	13.298	290	44.104	11.467	55.571	26.119	95.594
P19	25.370	13.827	270	44.824	11.654	56.479	26.545	97.154
P20	26.906	14.464	320.	65.127	16.933	82.060	38.568	141.159
P21	22.923	12.649	260	33.348	8.671	42.019	19.749	72.281
P22	23.357	12.861	280	37.673	9.795	47.468	22.310	81.654
P23	24.440	13.356	250	38.688	10.059	48.746	22.911	83.853
P24	23.625	12.992	240.	33.212	8.635	41.847	19.668	71.985
P25	25.370	13.802	270	45.706	1188.360	57.590	27.067	99.066

it is a direct result of top broken, fire harm or other outside variables that influences the development of height and diameter. R^2 shows reliance on one another. Figure 5 demonstrates that diameter and height are strongly connected and have a coefficient of relationship (R^2) equivalent to 0.9971.

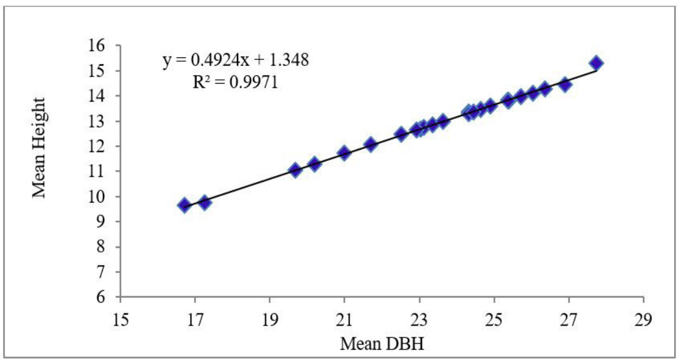

Figure 5: *Regression between mean height and mean DBH PNG.*

Regression of above-ground biomass (AGB) and height of trees

The biomass of the tree depends directly on its diameter of the tree if the diameter of the tree is greater, then biomass will be greater. The graph shows a correlation connection with one another for increasing the number of stems, which directly enhances forest biomass. The model of regression shows us the significant information for developing the greater tree diameter, the greater the biomass. In Figure 6, base inventory information taken is indicated a huge variety in trees and biomass diameter. The correlation (R^2) of AGB and the diameter of sub-tropical pine forest indications is 0.6358.

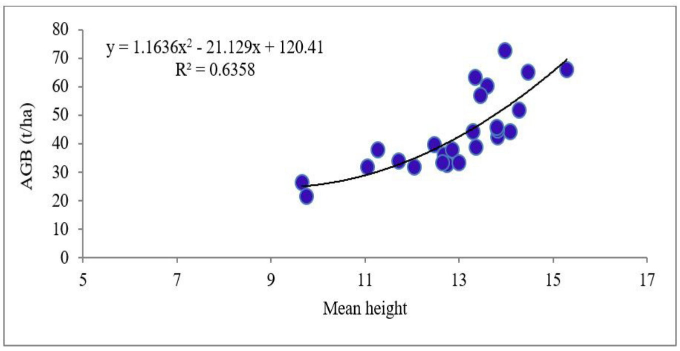

Figure 6: *Regression of above-ground biomass and mean height.*

In the present study, the highest mean DBH (27.74 cm) with 27 trees in P15, while has lowest average DBH (16.72 cm) was recorded with 43 trees in P1, while the tallest tree was having 15.30 m height and the smallest tree was 9.67 m. The results were in line with the findings of Amir *et al*. (2018) stated the mean DBH (cm) of the Chir pine forest of the young, mature, and over-mature stand was recorded at 17.4±1.5 (cm), 41±5.9 (cm), and 63.8±11.5, respectively while the mean height (m) of Chir pine forest of the young, mature, and over matured stand was recorded at 9.6±1.8, 18.9±4.2 and 19.7±5.7, respectively. Shaheen *et al*. (2016) reported a maximum mean DBH of 150.78 cm while a minimum of 43.63 cm, a mean height of a maximum of 21.8 m and a minimum of 5.95 m for *P. roxburghii*. The variation in observed value is due to different site and climatic features.

In the present research, the stem density of 316.4 trees/ha in the forest. While reported overall stem density of *P. roxburghii* in Ghoragali was 210 trees/ha and greater than 20 cm DBH. While in the sub-tropical pine forests of Lehterar the stem density of trees having more then 20 cm stem diameter was 148 tree/ha. Stem density decreases with an increase in tree diameter. Amir *et al*. (2018) reported that the average stem density ranged from 636±93.7 (trees/ha) in the young stand to 147±56.7 (trees/ha) in the over-mature stand. Our results are in line with Amir *et al*. (2018) the deviation of density from the reported data is due to variations in the phenological conditions of the study sites

The highest total biomass was 91.46 t/ha while the lowest total biomass was 27.02 t/ha. The highest total carbon was 42.99, while the lowest total carbon was 12.70 t/ha. Amir *et al*. (2018) described the total tree biomass distribution of Chir Pine forest of the young, mature, and over-mature stand was recorded at 80.0±12.4 (tha^{-1}), 343.1±167.6 (tha^{-1}), and 529.5±176.8 (tha^{-1}), respectively while the average living tree carbon varied between 40.0±6.2 ($t{\cdot}ha^{-1}$) and 264.5±88.4 (tha^{-1}), respectively.

Conclusions and Recommendations

It is concluded that sub-tropical pine forest has a high potential of storing and sequestering carbon climate change mitigation option. The results of the regression depict a strong positive relationship between mean DBH and mean height. It also highlighted the positive relationship between AGB and mean DBH. The results will be helpful for decision-making about emission trading and the REDD+ program.

Novelty Statement

The carbon stock assessment is on the high agenda due to its role in carbon sequestration and climate change mitigation. Most carbon-related approximations are based on remote sensing and GIS or derived factors, the results derived from these ultimately have low accuracy. Nevertheless, this study is based on the field-collected data and relatively high accuracy.

Author's Contribution

Jamshid Ali: Collected the data, contributed data analysis tools and wrote the manuscript.
Sabeeqa Usman Malik: Designed and supervised the research, improved the manuscript.
Muhammad Irfan Ashraf: Supervised the numerical calculations for the suggested experiment.
Jia Zhongkui: Improved the manuscript.
Zuhair Husnain and Saeed Gulzar: Facilitated in field inventory.

Conflict of interest
The authors have declared no conflict of interest.

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