Assessment of Above-Ground Biomass in Pakistan Forest Ecosystem’s Carbon Pool: A Review

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Abstract: Climate change is acknowledged as a global threat to the environment and human well-being. Forest ecosystems are a significant factor in this regard as they act both as a sink and a source of carbon. Forest carbon evaluation has received more attention after the Paris Agreement. Pakistan has 5.1% forest cover of its total land area, which comprises nine forest types. This study covers the studies conducted on above-ground biomass and carbon stock in various forest types of Pakistan. Most of the studies on biomass and carbon stock estimation have been conducted during 2015–2020. The non-destructive method is mostly followed for carbon stock estimation, followed by remote sensing. The destructive method is used only for developing allometric equations and biomass expansion factors. The information available on the carbon stock and biomass of Pakistan forest types is fragmented and sporadic. Coniferous forests are more important in carbon sequestration and can play a vital role in mitigating climate change. Pakistan is a signatory of the Kyoto Protocol and still lacks regional and national level studies on biomass and carbon stock, which are necessary for reporting under the Kyoto Protocol. This study will help researchers and decision-makers to develop policies regarding Reducing Emissions from Deforestation and forest Degradation (REDD+), conservation, sustainable forest management and enhancement of forest carbon stocks

Keywords: forest ecosystem; above-ground biomass; carbon stock; REDD+; allometric equations; agroforestry; climate change; Pakistan

1. Introduction

The forest ecosystem is considered one of the most significant ecosystems in combating climate change. Climate change is acknowledged as a global threat to the environment and human well-being. Natural systems such as glaciers, coral reefs, boreal and tropical forests, and polar and alpine ecosystems are susceptible to climate change [1]. Forests are valued as a useful tool against global warming. They regulate the carbon cycle by sequestering carbon dioxide from the atmosphere via photosynthesis and store it in their biomass and soil organic matter. Therefore, it is imperative to evaluate the source and sink of carbon at local, sub-national and national levels to assess the prospective role of different carbon pools in decreasing atmospheric carbon dioxide and preventing global warming. Hence, it is essential to obtain reliable data on forest carbon stocks and greenhouse gas emissions. Article 2.1 of the Kyoto Protocol addressed global warming issues and urged the signatory nations to protect existing forests and enhance the carbon sequestration potential through afforestation, reforestation and sustainable forest management [2,3].

Forests store more carbon than the carbon present in the atmosphere [4], likely the amount of one trillion tons—double the atmospheric carbon [5]. Therefore, protecting these forests is essential to combat climate change and protect biodiversity. In the case of
Forests consist of five carbon pools: above-ground biomass, below-ground biomass, soil organic carbon, litter and deadwood. Most of the studies are conducted on above-ground biomass, followed by soil due to its carbon sequestration potential. Litter and deadwood are often ignored due to their low contribution to carbon sequestration. However, this can result in the underestimation of the study site’s carbon content.

Pakistan has a low forest cover of 5.1%, which translates into an area of 4.51 m² ha from a total land area of 87.98 m² [6,7]. Pakistan forest cover map is shown in Figure 1. Pakistan has diverse ecological zones, divided into various forest types based on altitude and species composition. These forests are mangrove forest, tropical thorn/scrub forest, tropical dry deciduous forest, sub-tropical broad-leaved evergreen forest, sub-tropical chirpine forest, moist temperate forest, dry temperate forest, sub-alpine forest and alpine scrub. Numerous studies on carbon stock estimation have been conducted in different parts of Pakistan [5,8]. Different techniques are used for carbon stock estimation across the globe: destructive, non-destructive and remote sensing. Non-destructive is the most common method used all over the world, while the destructive method is particularly used for developing an allometric equation. Remote sensing techniques, on the other hand, require field data for validation.

![Forest cover in Pakistan](image_url)

**Figure 1.** Forest cover in Pakistan (Buchhorn, M.; Smets, B.; Bertels, L.; De Roo, B.; Lesiv, M.; Tsend-bazar, N.-E.; Herold, M.; Fritz, S. Copernicus Global Land Service: Land Cover 100 m: collection 3: epoch 2019: Globe 2020).

Reducing emissions from deforestation and forest degradation (REDD+) is an initiative to protect existing forests and enhance forest cover. Under the REDD+ framework, developing countries are encouraged to enhance their forest cover in return for carbon credits to prevent people from cutting trees and instead earn their livelihood from preserving the forests. As a benchmark to evaluate the country’s success in implementing REDD+ activities, the United Nations Framework Convention on Climate Change (UNFCCC) needs REDD+ countries to create a baseline of forest carbon stocks and emissions. Thus, an extensive forest inventory is needed in each forest type of Pakistan to report REDD+ related activities. To create a precise forest inventory, carbon stock estimation should be documented. In short, REDD+ deals with carbon stock estimation in terms of above-ground, below-ground and other carbon pools. This paper’s main objective is to highlight above-ground biomass, carbon stock and evaluation methods used in Pakistan’s forest ecosystem.
2. Carbon Stock Estimation Status in Pakistan

Since 1948, forest inventories (FIs) in Pakistan have been conducted for each designated forest located in a particular area. FIs are species-based compartment working circles [9]. The government of Pakistan developed a master plan for forestry development for 25 years (1993–2018) based on forest valuation at a national level using remote sensing (54 Landsat satellite images at a scale of 1:250,000) and fieldwork. Mountainous northern areas were not considered due to poor image quality. Sparse coniferous was not distinguishable from scrub forests, so about 4.7 m ha of a total of 7.04 m ha of northern areas remained unclassified [9]. Later in 2003–2004, the National Forest and Range Resource Assessment Study (NFRRAS) was conducted by the Ministry of Environment to assess the country’s total forest cover, and the study stated that the forest cover in 1997 and 2001 was 3.62 and 3.32 million ha, respectively [10]. Recently, Bukhari et al. [7] conducted a national level study and reported a total forest cover of 5.1%. The comparison of these three significant studies of forest cover is given in Table 1, while the output of these studies and other reports are given in Table 2.

### Table 1. Major national studies of forest cover in Pakistan.

| Study                                           | Satellite Data Used (Resolution) | Year of Acquisition | Method Used | Aim of the Study |
|-------------------------------------------------|---------------------------------|---------------------|-------------|------------------|
| Forestry Sector Master Plan (FSMP)              | Landsat Thematic Mapper™ (30 m) | 1989–1990           | Manual interpretation of hard copies at a scale of 1:250,000 | Assessment of forest cover at provincial level |
| National Forest and Range Resources Assessment Study (NFRRAS) | Landsat Enhanced Thematic Mapper (ETM) (30 m) | 1997–2001 | Supervised classification, forest inventory plots were used to facilitate the assessment | Forest cover assessment of the country |
| Land Cover Atlas of Pakistan (LCAP)             | SPOT-5 (2.5 m)                  | 2007                | Visual interpretation | Preparing an atlas for each district regarding natural resources, assessing forest change, and capacity building of professionals |

The FSMP study was conducted by the Ministry of Environment, while NFRRAS and LCAP were conducted by Pakistan Forest Institute, Peshawar. Source: [10].

### Table 2. Values for Pakistan forest cover from different reports.

| Study                                           | Forest Area (Million ha) | Remarks                                                                 |
|-------------------------------------------------|--------------------------|-------------------------------------------------------------------------|
| FSMP                                            | 3.59                     |                                                                         |
| NFRRAS                                          | 3.62 3.32                | Alpine pastures, farmland trees, and linear plantation were not included |
| LCAP                                            | 4.34                     |                                                                         |
| Food and Agriculture Organization (FAO)         | 2.5 2.1 1.7 (3.14)       | This study excluded other wooded land for 2010, which (forest and wooded land) was about 3.14 million ha |
| World Bank                                      | 1.9                      | Year of forest cover assessment is not given                           |

Procured from: [10].
Pakistan ratified the Kyoto Protocol and UNFCCC (United Nations Framework Convention on Climate Change) in 2005 [8]. Therefore, it is necessary to quantify carbon stocks in all forest types to report it under the Kyoto Protocol.

In Pakistan, provincial forest departments continuously carry out forest inventories to prepare the working plan and evaluate existing forest growing stocks. However, they have never undertaken a carbon stock estimation in these forests before 2015. In 2005, FAO prepared the Global Forest Resources Assessment (GFRA). For this purpose, FAO consulted with experts at ten regional and subregional workshops to have growing stock calculations of the country. This report contains the total carbon stock of the country. However, no scientific work has been carried out on actual biomass and carbon stock measurements in any forest in Pakistan, and the GFRA (2005) calculations are focused on remotely sensed data and may be prone to error [4].

Few research studies have been conducted on forest ecosystem biomass and carbon stock in the first decade (2000–2010) of the 21st century. Most research on biomass can be found in the second decade of the current century. These research studies on carbon stock assessment are broadly based on provincial territories, such as Khyber Pakhtunkhwa (KP), Sindh, Punjab, Balochistan, Azad Jammu and Kashmir (AJK) and Gilgit Baltistan (GB).

2.1. Khyber Pakhtunkhwa (KP)

Khyber Pakhtunkhwa, located in the north-west of Pakistan, has the highest forest cover area compared to other provinces. It has about one-third of the country’s forest and forty percent of its natural forest [5]. According to Bukhari et al. [7], the forest area of the entire province is 1.504 million ha, while Ali [11] has estimated the forest cover as 1.133 million ha. This discrepancy is mainly due to how the forest was defined in both studies. More than half of the country’s coniferous forests exist in this province, making it quite relevant for carbon sequestration.

Furthermore, the KP government has made substantial progress in planning for REDD+. They have developed (i) a sub-national strategy for REDD+, (ii) land-use maps, (iii) allometric models for biomass and carbon evaluation and (iv) a comprehensive forest carbon inventory at provincial level. Moreover, the Billion Tree Afforestation Project (BTAP) has recently been completed, which will further increase this territory’s carbon stock. KP has heterogeneous climatic conditions, thus supporting various types of forests, such as subalpine forests, dry temperate forests, moist temperate forests, oak forests, subtropical pine forests, subtropical broad-leaved forests and dry tropical thorn forests [12].

Various studies related to land-use change [13], deforestation, forest degradation [14], and environment–vegetation relationships in coniferous forests [15] were conducted in the Khyber Pakhtunkhwa province. These studies were limited to their specific objectives, not considering biomass and carbon stock estimation. It was only recently when a comprehensive study on biomass and carbon stock was conducted at provincial level [5].

Ali et al. [5] have estimated the carbon stock at the subnational level, covering all forest types of the province. Data were collected through a stratified cluster sampling method from 449 sample plots, and the total carbon stock quantified was 144.71 million tons with an average of 127.66 ± 9.32 ton ha⁻¹. Above-ground carbon stock was estimated as 68.15 million tons (48%), while below-ground biomass was 10% and litter was 1% of the total carbon stock. They further stated that dry temperate forests contain the most carbon (99.41 ton ha⁻¹), followed by moist temperate (85.04 ton ha⁻¹). Subalpine and oak forests have aboveground carbon stock of 34.27 and 34.58 ton ha⁻¹ respectively. Similarly, subtropical pine forests have aboveground carbon stock of 24.77 ton ha⁻¹, whereas subtropical broad-leaved and dry tropical thorne forests have aboveground carbon stocks of 4.52 and 4.48 ton ha⁻¹. This was the first ever attempt of carbon stock at the provincial level. Before this, most studies only focused on carbon stock estimation for a particular area, species or forest type.

Pakistan Forest Institute has developed a forest reference emission level/forest reference level for Khyber Pakhtunkhwa province, which can be used as a baseline to calculate
the reduction in emissions under the REDD+ program [11]. According to the defined reference level, the total annual carbon sequestration is near 6 million tons, where the annual accumulation of above-ground and below-ground carbon is 4.627 and 1.341 million tons, respectively.

*Olea ferruginea* forest structure was studied using the Point Centered Quarter method in lower Dir and it was found that the study sites’ density and basal area ranged from 56–1089 trees/ha and 6.62–37.90 m²/ha, respectively [16]. Quercus forests of Chitral were assessed and the total tree density and basal area were estimated, ranging from 166.42–351.55 per ha and 12.11–30.13 m²/ha, respectively [17]. The study also reported a low tree density per ha and low basal area m²/ha at a lower height. The basal area of *Monotheca buxifolia* and other associated tree species was studied, and the results revealed that the basal area ranged from 8.40 to 33.51 m²/ha [18]. Regeneration status was also investigated, where 34% of species showed good regeneration status while 50% of species showed low status and 16% with zero regenerating status. These studies focused on tree density and basal area. The biomass of tree components was determined in 30 trees by selecting ten trees from each diameter class (up to 10 cm, 11–20, and above 20 cm) following the non-destructive method [19]. Total above-ground biomass for an individual tree was calculated as 20.59, 58.041 and 197.214 kg/tree for diameter classes of up to 10 cm, 11–20 cm, and above 20 cm, respectively, while the total biomass for an individual tree of diameter up to 10 cm, 11–20 cm and above 20 cm was 24.71, 69.649, and 236 kg, respectively. This study further reported that the mean biomass expansion factor was measured as 1.44 t.m⁻³ for all diameter classes. A coniferous forest of Dir Kohistan had 129.49 Mg.ha⁻¹ as the mean carbon stock, while the total carbon content of the forest was 8.06 Tg [20]. A study was carried out to evaluate biomass expansion factors for an indigenous species (*Picea smithiana*) using a destructive method in Kumrat valley [22]. They have found out the mean above-ground biomass and mean total biomass as 2104.055 ± 264.814 and 2539.87 ± 341.80 kg, respectively. Their report further stated that stem contributed 66.28% in total biomass, followed by root, branches, foliage and twigs as 17.05, 11.28, 2.62 and 2.193%, respectively. They also estimated root-to-shoot ratio as 0.206 ± 0.011 and the mean biomass expansion factor as 0.686 ± 0.0027 t m⁻³. A study was conducted to calculate the growing stock of Karaker forest. Average tree density, basal area and volume of the study area were 18 trees per ha, 1.3 m²/ha, and 15.19 m³/ha, respectively [23]. They also predicted the growing stock for the next ten years while keeping in mind the demand of the local people and reported a reduction in tree density, basal area and standing volume. Their study was limited to volume and did not estimate the area’s biomass and carbon stock. Munawar et al. [24] studied the absorption and emission capacity of District Dir forest with remote sensing and reported that the site contains a net carbon storage worth a million US dollars. This study further reported that the forest area increased with time and has a potential for REDD+ implementation. The carbon stock of the oak scrub forest of the Sheringal valley was calculated using field inventory data. The study area has a calculated mean carbon stock of 25.80 ± 0.47 t/ha [25]. Khan et al. [26] studied the *Olea ferruginea* forests of the Malakand division and reported that the tree density ranged from 153 to 2602 plants per ha, where *Olea ferruginea* has a relative density of 51–87%. The study site’s basal area varied from 19.55–2353 m² ha⁻¹ where *Olea* have a basal area of 48–93%. Ahmad and Moazzam [27] evaluated carbon stocks in three different land uses (forest, agriculture and rangeland) in Kumrat valley. They further divided the forest land based on the pure and mixed species. The study reported carbon storage in the forested
land as $349.84 \pm 30.79$ t/ha, while rangeland and agriculture land stored $50 \pm 6.5$ and $28.62 \pm 13.85$ t/ha or carbon, respectively.

Total annual carbon sequestration and biomass in the coniferous forest of Dir Kohistan were estimated [28] as $1.65$ t/ha/yr and $3.31$ t/ha/yr, respectively. Khan et al. [29] examined the pine communities of Indus Kohistan and reported the tree density and basal area of seven different species. Above-ground biomass, using GIS and remote sensing, in coniferous forests of Murree and Abbottabad was estimated as 235 and 261 Mega g/ha, respectively [30].

Muslim graveyards are considered the least disturbed micro ecosystem because of cultural and religious rights. Ali et al. [31] carried out their study in Muslim graveyards of the Malakand division and found that the basal area ranged from 20–2523 $m^2$/ha. Similarly, Ali et al. [6] studied the structure of temperate forests of the Kaghan valley using a systematic random sampling method with a grid of $700 \times 700$ m. The study reported that most of the trees were young and probably 17% were mature. Poor regeneration status was reported. According to Ahmad et al. [32], carbon stocks varied between agricultural land and dense forest as 30 to 538 MgC/ha, respectively. The results revealed the carbon storage as follows: Cedrus deodara, Pinus wallichiana, mix coniferous and Abies pindrow with an average of 538.14 $\pm 100.58$ MgC/ha, open forest, agricultural land and rangeland with an average of $183.04 \pm 79.6$, $29.80 \pm 4.3$, and $35.63 \pm 3.98$ MgC/ha, respectively. This study further mentioned that the tree contains the highest carbon stock in forests. Cedrus deodara forest stored a greater amount of carbon than other forest types. Interestingly, Abies pindrow (AP) forest has mature trees but contained low carbon compared to Pinus wallichiana (PW) forest.

The biomass and carbon content of the Siran forest division were quantified through remote sensing [33]. The highest above-ground and below-ground biomass were recorded as 246 t/ha and 64 t/ha, respectively, while the lowest above-ground and below-ground biomass were 55 and 14 t/ha, respectively. Likewise, the uppermost above-ground and below-ground carbon stock were calculated as 116 and 30 t/ha, whereas the lowermost above-ground and below-ground carbon stock were 26 and 6.7 t/ha, respectively. The total carbon stock of the subtropical scrub forest of Khanpur Range, Haripur in six forest types was 43,570.9 t [34]. Ahmad et al. [35] studied the carbon sequestration potential of Cedrus deodara forest at three different altitudes. The study reported that the forest stored more carbon at high elevation due to less external influence, as compared to the carbon stored at lower elevation due to excessive human intervention. The tree biomass and carbon stock of Pinus roxburghii and Eucalyptus camaldulensis were examined in the district of Buner [36]. Eucalyptus plantations are mainly for commercial use, and it is harvested at the age of 4 or 5 years depending on the site conditions. These plantations help reduce the pressure on natural forests. Forest carbon stock in the Balakot region was calculated as 243.79 t/ha with an average tree biomass of 207.41 t/ha. Simultaneously, the soil carbon was estimated as 36.38 t/ha [37]. Another study was carried out by Ali et al. [38] to estimate the biomass and carbon stock of subtropical broad-leaved forests of the Malakand division. The study showed the mean biomass as 100.1 $\pm 22.6$ t/ha and mean carbon stock as 49.54 $\pm 11.3$ t/ha. The total average carbon stock in different carbon pools was estimated as 568.63 t/ha [39]. Similarly, Ahmad et al. [40] inspected different types of forests of Kumrat valley and reported its potential for carbon sequestration with field inventory and remote sensing. They stated that the forest vegetation covered 51.13% of the area of the valley. The mean total carbon stock of the area was reported as 393.70 $\pm 270.09$ MgC/ha.

In this context, Shah et al. [41] have conducted a study on agroforestry to highlight its carbon stock potential. They used a stratified random sampling with a plot size of $100 \times 100$ m$^2$ for the linear plantations and $33 \times 33$ m$^2$ for block plantations. Carbon stock data were taken in three different agroforestry systems: agrisilviculture system, silvopastoral system and agrisilvopastoral system. The result shows that the silvopastoral system’s carbon storage was the highest (76.33 t/ha), followed by the agrisilvopastoral system (68.05 t/ha), while the agrisilvicultural system stored the lowest carbon (11.61 t/ha).
Agroforestry is an excellent approach for climate change mitigation and reducing pressure on natural forests. The above-ground biomass and carbon content of the moist temperate forest of district Battagram were calculated as 148.79 t/ha and 69.93 t/ha with a mean CO\(_2\) equivalent value of 322.5 t/ha [42]. An allometric model was developed for *Pinus roxburghii* in the subtropical pine forest of Hazara forest division using destructive sampling [43].

2.2. Punjab

Punjab is the most populous province of Pakistan and has a low forest cover of about 4%. Scrub forest is the most dominant type with 2%, while riverine and broad leaf cover about 0.7% [7].

Various studies in Punjab, such as the status of natural tropical thorn forest [44], Lahore city land cover changes [45], and the forest cover change of Murree hill with remote sensing [46], were limited to changes in forest cover and did not include biomass and carbon stock estimations.

Nizami et al. [47] measured the carbon content of subtropical pine forest at two different sites; 126 + 2.94 t/ha in Ghoragali and 99 + 1.58 t/ha in the Lehterar forest ecosystem. The biomass of *Olea ferruginea* was estimated through destructive sampling [48]. They concluded that the stem contains the major portion of 49.01% of the total tree’s biomass. Likewise, Nizami [8] estimated the carbon stock of two different forest types: subtropical chirpine and sub-tropical broad-leaved forest. The study revealed that both forest types store an average of 114.5 ± 2.22 t/ha of carbon, where tree biomass contains 92% of the carbon while soils holds only 8%. The carbon content and biodiversity of Karore reserve forest were assessed using field inventory [49]. Allometric relation for calculating above-ground and below-ground biomass at four various ages of *Dalbergia sissoo* using destructive sampling was examined [50]. The total biomass calculated varied from 144.83 to 456.37 kg/tree. The result shows that the stem contributes more (38%) while leaves contribute only 5%. Since the study was performed in monospecific and closed-canopy forests, the allometric relationships mentioned in this study may not be appropriate for mixed and open forests. The total wood volume of the Karore reserve forest was estimated at 2,261,621,047 cubic feet [51]. The carbon stock of Bela forest Jehlum was calculated and it is revealed that the total carbon stock (upper story vegetation, understory vegetation and soil) was 198.18 ± 18 t/ha [52].

Ali (2018) estimated aboveground carbon stock in scrub forests of Chakwal as 8.20 t/ha. Parerah reserve forests have aboveground carbon stock of 11.08 t/ha whereas Ara and Diljabbra reserve forests have carbon stocks of 6.76 t/ha [53]. Olea ferruginea, Acacia modesta and Zizyphus were the dominant tree species of this tract. Similarly Ali (2019) has found aboveground carbon stock in subtropical pine forests of Kahuta, Rawalpindi Forest Division as 42.28 t/ha [54]. Mahmood et al. [55] also estimated the biomass of four different species using the destructive method. The estimated root biomass of *Dalbergia sissoo* was 2.0 t/ha [56]. Baig et al. [57] made the first attempt to study the above-ground biomass of *Dalbergia sissoo* (irrigated plantation) in Chichawatni using remote sensing. Above-ground carbon stock was estimated for citrus acreage using the non-destructive method [58]. The result shows that the study area’s total carbon stock was 1176 tons, with an average density of 40 plants per ha. Nawaz et al. [59] studied agroforestry potential and concluded that the area has an average sequestration rate of 2.05 to CO\(_2\)/ha/yr with an average density of 31 trees/ha. Agroforestry is essential in this context, particularly for a country with low forest cover such as Pakistan. Carbon stocks of *Eucalyptus camaldulensis* in sandy marginal lands were evaluated as 1.80 megaton carbons [60]. The study area has more carbon sequestration potential in case of afforestation on 6.5 million ha saline and waterlogged marginal land. Arif et al. [61] have estimated the carbon stock of plantations in Chichawatni, Punjab. The study concluded that the mean carbon stock in upper-story, under-story and soil was calculated as 68.20 mg/ha, 1.8 mg/ha and 21.57 mg/ha, respectively. It was further highlighted that plantations in open spaces with proper and sustainable management practices can improve carbon stock potential. Carbon stock was measured in different tree...
species at the early age of plantation, and it was concluded that *Populus deltoides* stores more carbon in above-ground pools and soil [62]. The above-ground biomass in Murree and Abbottabad’s coniferous forests was estimated using GIS and remote sensing [30]. The estimated above-ground biomass for Murree and Abbottabad was 235 and 261 Mega g/ha, respectively. Agroforestry carbon stock was calculated at three different age classes, ranging from 0.89–26.58 Mg/ha [63]. They also reported that with increasing tree age, the soil organic carbon also increased. The urban forest structure of the old Christian Gora Cemetery of Lahore was studied by Pervaiz et al. [64]. They also used Normalized Difference Vegetation Index (NDVI) to monitor the decline in the tree cover. The carbon sequestration potential of three different aged (young, mature and over-mature) forests was investigated and the result revealed an increasing trend of live tree carbon stock from young to overmature forest of *Pinus roxburghii*, while there was a decreasing trend in soil organic carbon in the same stand [65]. A similar study was carried out by Amir et al. [66] and they also reported that the soil organic carbon decreases with an increase in stand age. Similarly, Yasin et al. [67] evaluated the carbon stock potential of agroforestry in three districts of Punjab using an allometric equation. The study revealed that the total carbon potential of trees was 950,470 Mg, while the estimated soil carbon was 22,743,008 Mg. The study also highlighted the possibility of increasing carbon sequestration by two-fold under managed plantation schemes.

Mannan et al. [68] examined the land-use land cover changes and estimated the carbon stock of three different forest types of the foothills of northern Pakistan’s Himalayan Mountains through remote sensing and GIS. They reported a decrease in forest cover while there was an increase in agricultural land. The calculated carbon stocks of moist temperate, subtropical chirpine, and sub-tropical broad-leaved forests were 313.94 ± 44.78 Mg C/ha, 221.34 ± 44.78 Mg C/ha and 131.77 ± 44.78 Mg C/ha, respectively. Carbon stock was estimated using two different allometric models in *Olea ferruginea* and *Acacia modesta*, where *Olea ferruginea* had the highest tree density and biomass [69]. It was observed that the model considering height and dbh as covariates performed better in estimating the biomass compared to the model that considered diameter at breast height only. Hammad et al. [70] investigated the carbon stock potential of different land uses and concluded that forest land stores more carbon than others. They further reported that the amount of carbon in soil decreases with increased depth. Akhtar et al. [71] have reported the above-ground biomass of the subtropical pine forest of Murree hill using different data inputs of remote sensing.

Islamabad, the capital city of Pakistan, is known as Islamabad Capital Territory (ICT). It has a forest cover of about 22.6% of its total land area. As most of the forest of Islamabad is mixed with Punjab, it is therefore included in Punjab province.

Changes in the carbon storage of Margilla Hill National Park were studied using remote sensing and GIS along with field data for 1990–2017 [72]. According to the results, the site stored 2131, 2076, 2034, and 1987 GgC for 1990, 2000, 2010, and 2017, respectively. This declining pattern was due to land-use change. Likewise, Mannan et al. [73] examined Margilla Hill National Park’s carbon content in terms of altitudinal gradient. The results revealed that the carbon content was high at a higher elevation and decreased at a lower elevation. The study area’s carbon stock for elevation 1 (ELV-1), ELV-2, ELV-3, and ELV-4 was 76.53, 157.46, 156.01, and 279.89 Mg C per ha, respectively.

### 2.3. Sindh

Sindh contains 6% forest cover of its total land area where two types of forests exist: mangroves (3.5%) and riverine (1.4%) [7]. Various floristic studies have been carried out in the province, but limited studies are available on carbon stock assessment.

Maguire et al. [74] have developed a yield model for *Acacia nilotica* plantations and reported that they could produce 40-ton dry weight/ha/year. They have followed a random sampling technique with a circular plot of 0.004 ha. They also used 0.002 ha and 0.1 ha plots for premature, thick and old, open/sparse plantations, respectively. The structure of the *Avicennia marina* species in mangrove forests was studied, and it was found...
that the basal area of the study site ranged from 0.22–4.09 with an average of 1.33 m² per 0.1 ha [75].

Various studies were carried out to investigate the spatial and temporal changes in different forest types at different periods [76–78]. These studies have not covered the biomass and carbon stock aspect. Ajani and Shams [79] estimated the carbon content of two different species at the University of Karachi following non-destructive methods. They reported that *Azadirachta indica* and *Conocarpus erectus* store carbon at an average of 662.32 + 1144.81 kg and 192.70 + 322.60 kg, respectively.

Pakistan Forest Institute (2018) conducted a study to assess carbon stock in mangroves forests of Karachi, Sindh. Mean aboveground biomass carbon stock was estimated as 24.4 t/ha and belowground biomass was estimated as 10.22 t/ha. Soil organic carbon was found as 233.73 t/ha in this ecosystem. Carbon sequestration potential in biomass was determined as 9.10 t/ha/year [80]. Similarly Ali et al. (2018) reported aboveground carbon stock in riverine forests of Sukkur as 4.6 t/ha. They reported that there is a potential of 20 tCO₂/ha/year in highly fertile landscape [81].

A study was conducted in Sandspit mangrove forest to estimate its carbon content in three different carbon pools. The study revealed that the total carbon content of the ecosystem was 183.99 ± 11.02 t/ha, where above-ground stored almost half of the total carbon while below-ground and sediment stored 21.19% and 28.07%, respectively [82]. The carbon potential of two species was calculated using the non-destructive method and it was found that *Azadirachta indica* stored more carbon than *Conocarpus erectus* [83]. Sindh province has consequential forest types, but unfortunately, no systematic study has yet been conducted to explore its role regarding climate change and ecosystem services.

2.4. Balochistan

Balochistan is the largest province regarding land area with less population. It has a low forest cover of 1.5% and 26.7% rangeland [7].

The structure of *Juniperus excelsa* in Balochistan was studied, and the results revealed that the tree density varied from 56–332 stems/ha while the basal area ranged from 8.8–152.2 m²/ha [84]. Earlier, Ahmed et al. [85] studied the vegetation structure of *Pinus gerardiana* forest and reported that the mean tree density was 266 trees/ha, while the average basal area was found to be 25.5 m²/ha. They have also estimated the average growth rate for this species as 0.08 cm/year. Another study was carried out to study the status of juniper forests of Balochistan by Ahmed et al. [86]. Their study revealed that the density and basal area varied from 112–469 trees/ha and 12.4–132 m²/ha, respectively.

Balochistan has a unique juniper forest ecosystem facing human intervention. Juniper forest can play a significant role in carbon sequestration in the case of sustainable management. According to the literature review, no study has been performed to estimate the carbon content of these forests. Different studies worldwide have stated that juniper forest stores a significant amount of carbon dioxide. Thus, it is necessary to assess these forests’ carbon stocks for reporting under the Kyoto Protocol.

2.5. Azad Jammu and Kashmir (AJK)

AJK is a region administered by Pakistan. It has a total land area of 1,329,729 hectares, out of which 566,740 hectares or 42.6% comprises forest cover [87].

Shaheen et al. [88] examined the total carbon stock of subtropical forest types of Kashmir, Pakistan. They reported an average carbon content of 186.27 t/ha. The Musk Deer National Park’s mean carbon stock was estimated through non-destructive techniques as 44.64 ± 12.44 Mg/ha [89]. The total average carbon content of three carbon pools (above-ground, below-ground, and soil) of alpine and sub-alpine forest ecosystems was estimated as 356.73 t/ha using destructive and non-destructive methods for herbs and trees, respectively [90]. Temporal changes in the forest cover and carbon stock of subtropical pine forest were assessed for 1989–2018 using remotely sensed data along with field inventory [91]. Total (above-ground and below-ground) biomass and carbon stock were
estimated as 182 and 91 t/ha, respectively. The study also reported a decline of 11% in forest area during 1989–1999 due to legal logging of mature trees with the permission of the government of AJK, but a net increase of 561 ha in a forest area during 1999–2018 due to the ban on cutting trees and reforestation.

2.6. Gilgit Baltistan (GB)

Gilgit Baltistan, formerly known as Northern Areas, expands over an area of 72,971 km² with 1582 km² of forest cover [92].

Akbar et al. [93] studied the forest structure in Skardu and reported the basal area for *Pinus wallichiana*, *Juniperus excelsa*, and *Betula utilis* as 42.38, 14.63 and 13.12 m²/ha, respectively. The volume of the different tree species of Chilas forest was calculated, and the result shows that the average volumes of Kail, Fir, Deodar and Chalgoza were 1.92, 1.57, 0.46 and 0.291 m³/tree, respectively [94]. A study was carried out to examine the Chalgoza forest of District Diamer and the result revealed that the basal area ranged from 3.98–16.16 m²/ha [95]. An allometric equation is essential to estimate the biomass of a forest accurately. Ali et al. [96] developed an allometric equation for *Cedrus deodara* of dry temperate forest in northern areas by harvesting 32 trees of different diameter classes. The results revealed that the mean Biomass Expansion Factor of *Cedrus deodara* was 1.37 ± 0.039 for a tree with a diameter at breast height greater than 20 cm, while the basic wood density was found to be 0.46 g/cm³. They also reported that bole, branches and brushwood contributed to total dry biomass as 72.95, 10.43, and 16.62%, respectively. Forest inventory was performed in the forests of Gilgit Baltistan, and the total above-ground biomass was estimated using an allometric model as 12,887 tons [92].

Carbon stock was estimated as a regulatory ecosystem service while assessing the ecosystem services of oak forest [97]. The results revealed that the mean above-ground biomass of the study area was 72.46 t/ha, while the mean carbon stock was found to be 34.06 t/ha. An allometric equation for naturally occurring *Cedrus deodara* species was developed through destructive sampling for 60 trees at different sites [98].

Carbon stock studies conducted in Pakistan at different time intervals are shown in Figure 2. Figure 2 explains only above-ground biomass and carbon stock studies, excluding studies related to other carbon pools or basal area and volume. Studies regarding above-ground biomass and carbon stock are presented province wise with current status in the following Table 3. We generally overviewed the present status of each forest type following published materials.

![Carbon Stock studies in Pakistan](image_url)

**Figure 2.** Graphical bars show the estimated carbon stock studies in Pakistan. Kpk = Khyber Pakhtunkhwa, AJK = Azad Jammu and Kashmir, and GB = Gilgit Baltistan
Table 3. Current status of each territory with respect to above-ground biomass (AGB) and carbon stock studies.

| Province/Territory     | Forest Types Exist in Each Territory                                                                 | Current Status of AGB and Carbon Stock Studies |
|------------------------|--------------------------------------------------------------------------------------------------------|-----------------------------------------------|
| Khyber Pakhtunkhwa     | Subalpine, Dry temperate, Moist temperate, Oak, Subtropical pine, Subtropical broad-leaved, and Dry tropical thorn forest. | [5,12] [5,11,19,20,22,25,27,28,30,32–42,99] |
| Punjab                 | Coniferous forest, Scrub forest, Irrigated plantation, Riverain forest.                                | [100] [8,30,47–50,52–55,57–73]               |
| Sindh                  | Riverine forest, Mangroves, Irrigated plantations                                                    | [101] [79–83]                                 |
| Balochistan            | Juniper forest, Chilghoza pine forest, Olive forests, Kohistan forest, Mangrove forest, Invasive forest, Tropical desert thorn forest. | [102]                                        |
| Azad Jammu and Kashmir | Dry subtropical scrub forest, Subtropical Pine forest, Moist temperate, Dry temperate, Sub-Alpine, and Alpine Scrub. | [87] [88–91]                                 |
| Gilgit Baltistan       | Alpine pastures, Sub-alpine, Dry temperate, Oak                                                     | [7,97] [92,97]                                |

The literature review was carried out during October 2020 to December 2020 using Google Scholar, Scopus, government reports, as well as Ministry of Climate Change reports to obtain information from current studies on forest types, biomass, carbon stock and basal area of various forest types of Pakistan.

Various keywords such as forest types of Pakistan, forest biomass, carbon stock estimation, allometric equation, carbon stock of agroforestry, plantations, forest inventory and forest structure were searched. To collect more information of the previous studies, forest type wise (e.g., biomass/carbon stock of moist temperate forest) and territory wise (e.g., forest types of Sindh) searches were also carried out. This study’s only objective is to highlight the current state of knowledge with the help of a literature review.

3. Methods Used for Carbon Stock Estimation

Accurate forest biomass assessment through forest inventory is essential for various applications such as temporal changes in biomass/carbon stock and global carbon cycle. Forest inventory includes tree enumeration, volume, species composition, size, age, longevity and potential growth. Monitoring and assessing biomass distribution in forests is a primary requirement for implementing REDD+. Accurate analysis of biophysical attributes of the plantation is essential for biomass calculation in forests [103].

Forest biomass can be estimated through ground survey and remote sensing. Field measurements can be divided into two groups: destructive and non-destructive sampling. The destructive method involves harvesting all trees and measuring different parts’ biomass [104]. Nonetheless, this method is considered useful only for a small area since it is time consuming and labor intensive [105,106]. However, it can be used for developing a biomass equation for large forest areas [107,108].

Non-destructive sampling methods involve various forest attribute measurements such as diameter at breast height (dbh) and height [109] and biomass/carbon stock assessment through allometric equations [3]. Allometric models are developed using forest inventory data [43,108,110].

Remote sensing and Geographic Information System (GIS) is a new method for forest biomass estimation. Various studies have been carried out for calculating forest biomass with the help of remote sensing [33,34,42]. Nonetheless, biomass calculation through
Field data is crucial for the calibration of remote sensing models and verifying results for remote sensing methodologies. Tree allometric equations of the same species and the same ecological conditions are more reliable and precise for forest biomass and carbon stock estimation [2]. Methods used for above-ground biomass estimation in Pakistan are given in Figure 3.

![Figure 3. Above-ground biomass estimation methods used in Pakistan.](image)

Allometric equations have been developed for some major species existing in Pakistan (Table 4).

| Forest Type                     | Location             | Species             | Allometric Equations (AGB) | Source |
|--------------------------------|----------------------|---------------------|-----------------------------|--------|
| Moist Temperate Forest         | Khyber Pakhtunkhwa   | Cedrus deodara      | 0.0491(D^2H)^{0.9167}      | [5]    |
| Moist Temperate Forest         | Khyber Pakhtunkhwa   | Pinus wallichiana   | 0.0594(D^2H)^{0.881}       | [5]    |
| Dry Temperate Forest           | Gilgit Baltistan     | Pinus gerardiana    | 0.0253(D^2H)^{0.6977}      | [5]    |
| Moist Temperate Forest         | Khyber Pakhtunkhwa   | Abies pindrow       | 0.0452(D^2H)^{0.9029}      | [5]    |
| Moist Temperate Forest         | Khyber Pakhtunkhwa   | Picea smithiana     | 0.0821(D^2H)^{0.8356}      | [5]    |
| Subtropical Broad-leaved forest| Khyber Pakhtunkhwa   | Eucalyptus camaldulensis | 0.023(D^2H)^{0.9985}    | [5]    |
| Dry Temperate Forest           | Gilgit Baltistan     | Quercus ilex        | 0.8277(D^2H)^{0.6635}      | [5]    |
| Subtropical Pine Forest        | Khyber Pakhtunkhwa   | Pinus roxburghii    | 0.0224(D^2H)^{0.9767}      | [43]   |
| Dry Temperate Forest           | Gilgit Baltistan     | Cedrus deodara      | 0.1797(D^2H)^{0.8103}      | [96]   |
| Subtropical Broad-leaved Forest| Khyber Pakhtunkhwa   | Acacia modesta      | 0.2267(D^2H)^{0.8226}      | [99]   |
| Subtropical Broad-leaved Forest| Khyber Pakhtunkhwa   | Olea ferruginea     | 7.8863 + 0.0556(D^2H)      | [99]   |
| Dry Tropical Thorn Forest      | Khyber Pakhtunkhwa   | Acacia nilotica     | 0.0493(D^2H)^{0.9728}      | [99]   |
| Farmland                       | Khyber Pakhtunkhwa   | Populus deltoides   | 0.0194(D^2H)^{0.9654}      | [99]   |
| Subtropical Broad-leaved Forest| Khyber Pakhtunkhwa   | Robinia pseudoacacia| 0.2386(D^2H)^{0.7786}      | [99]   |
| Dry Tropical Thorn Forest      | Khyber Pakhtunkhwa   | Ziziphus mauritiana | EXP((−9.46108 + 0.52923*Ln(H) + 2.15113*Ln(Di)))*0.8*1.4*1000 | [99]   |
| Farmland                       | Khyber Pakhtunkhwa   | Paulownia spp       | 0.0165(D^2H)^{0.9969}      | [99]   |
| Subtropical Broad-leaved Forest| Khyber Pakhtunkhwa   | Dodonea viscosa     | 0.928(D)^{0.0218}          | [99]   |

Besides allometric models, there are tree volume allometric equations developed for some forest species which can be used to calculate forest stand volume. The details of location and species are given in Table 5.
### Table 5. Volume allometric models for forest stand volume calculation.

| Forest Type                              | Tree Species   | Location | Tree Component | Allometric Model (Variable)                          | Source |
|------------------------------------------|----------------|----------|----------------|------------------------------------------------------|--------|
| Subtropical Broadleaved Evergreen forest | *Olea ferruginea* | Lehterar  | Stem           | \( V = -0.320 + 0.041(x) - 1.44(x)^2 \) (DBH)        | [48]   |
| Sub Alpine forest                        | *Betula utilis* | Kalam    | Stem           | \( V = 0.9589 + 0.05625(x) - 0.001367(x)^2 \) (DBH) | [19]   |
| Dry Temperate forest                     | *Cedrus deodara* | Chilas   | Stem           | \( V = 0.038(D^2H) \) (DBH and H)                   | [98]   |

### 4. Research Needs and Future Directions

At a national level, the first study was carried out in 1992, which has not been repeated to this day. The availability of data is a requirement for good management and monitoring of resources. Current data are less reliable, and therefore it is suggested that an extensive study should be conducted on a country level for each forest type, which can be compared to the previous study conducted back in 1992 at a national scale.

The past decade (2010–2020) can be considered as a good era for forest biomass estimation research. There are few studies available on allometric equations for biomass estimation. Allometric models have mostly been developed for some of the major species in KP and GB (coniferous and broad leaved), which is not the case for other provinces. For accurate and precise carbon stock estimation, it is imperative to develop allometric equations for all major species found in Pakistan’s various ecological conditions. It is essential to understand that allometric equations can only be applied for the same species with the same ecological conditions for accurate carbon stock estimation. An allometric equation of monospecific forests can yield biased results when used for mixed forests [111]. Many studies in monocultures have stated that stand density and resource availability affect allometry [112–114], which can vary significantly between pure stand and mixed forests [115].

Allometric equations have been developed for coniferous species, but they still need to be developed for each ecological zone. For example, if the allometric model is developed for *Cedrus deodara* for dry temperate forests, it is necessary to develop it for the same species in the moist temperate forest. Furthermore, it has been revealed with the help of the literature review that a regional study for forest reference emission level is only available for one province i.e., Khyber Pakhtunkhwa, while the rest of the provinces/territories have not yet attempted to fill this gap. To obtain a benefit from REDD+, a country’s forest reference emission level at a national or subnational level is necessary.

Mangroves are one of the most important forest ecosystems in Pakistan, but unfortunately, the biomass and carbon stock data of this forest are not available. Furthermore, the specific allometric equation is not yet developed. Studies show that the forest cover of mangroves has been increased during the past few years [116], but its biomass and carbon stock are yet to be evaluated. Riverine forest is another important forest ecosystem in Sindh and Punjab. While temporal and spatial changes have been monitored for riverine forests, the carbon stock has not been studied systematically. It is one of the most productive forests in Sindh, and it is vital to estimate the biomass and carbon stock of this ecosystem to report under REDD+.

Similarly, Balochistan province has a centuries-old juniper forest, but its carbon stock potential has not been assessed up till now. It is a slow-growing forest and considered one of the world’s largest and oldest forests globally. Punjab has about half of the area of agricultural land, which means that agroforestry contains a significant amount of carbon, but unfortunately, it has not been given that much importance in this context. It is similar to the case with Sindh, which has about one-third of the agricultural land area. Therefore, it is essential to highlight and promote agroforestry and its services. Pakistan is a signatory to the Kyoto Protocol and needs to evaluate the carbon stock of various forest ecosystems.
that exist in the country. For the assessment of carbon stocks and carbon change, the permanent sample plot technique should be followed in the future across Pakistan’s different forest types.

5. Conclusions

Forests are important in the context of climate change as they act as a sink and a source of carbon emissions. Tropical forests are more crucial in this regard as they have more potential to remove carbon from the atmosphere and have a role in regulating the surface temperature. Data available on above-ground biomass and carbon stock in Pakistan are less reliable and fragmented. The only scientific study on a national scale was conducted back in 1992. Therefore, there is an urgent need to update forest inventory on a national scale.

This research attempts to review all studies in Pakistan conducted on the above-ground biomass and carbon stock of forest types, plantations and agroforestry. The methods used for carbon stock estimation were categorized as destructive and non-destructive. The destructive method is not commonly used due to the strict environmental protection law but is only used in a small area to develop an allometric model or biomass expansion factor for accurate carbon stock estimation. In contrast, the non-destructive method is used by measuring different tree parameters, such as diameter at 1.37 m, height of the tree, and tree height, to calculate the above-ground biomass. Remote sensing is also used for carbon stock estimation, but it also needs field data for validation.

Coniferous forests seem to store more carbon compared to other forest types. Most of these forests are young and therefore have a high potential for carbon sequestration and climate change mitigation under REDD+ and other carbon trading schemes. Khyber Pakhtunkhwa province has more comprehensive data on carbon stocks and allometric models than other provinces of the country. Allometric equations were used for carbon stock estimation, but they may not give an accurate calculation in other areas due to the different ecological conditions. Therefore, it is necessary to develop an allometric model of notable species from various habitats and conditions.

This review can be used for generating a database that could be helpful for decision-makers primarily related to climate change mitigation and forest conservation.

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