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Spatial variability of biomass and carbon stock in Jhelum and Chakwal districts of Pakistan: implications for environmental management

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Abstract:

Rural areas in underdeveloped countries are grappling with numerous environmental challenges, with increasing population pressure significantly contributing to environmental degradation. This study conducts a comprehensive survey to analyse carbon stock in the rural communities of the Jhelum and Chakwal districts of Punjab, Pakistan. The low carbon levels in these areas pose a severe threat to ecosystem services. The carbon stock assessment as a regulatory service of forests involves measurements from standing trees. Descriptive statistics and spatial distribution analyses of Above-Ground Biomass (AGB), Below-Ground Biomass (BGB), Total Biomass (TB), and Biomass Carbon (BC) were conducted, utilising inverse distance weighting interpolation in ArcGIS 10. The results of the study identified several carbon stock hotspots. The mean concentrations of carbon stock were 28.00 t/ha for AGB, 796.72 t/ha for BGB, 255.33 t/ha for TB, and 127.38 t/ha for BC. The lowest mean values at selected sites were 4 t/ha for AGB, 3 t/ha for BGB, 11 t/ha for TB, and 7 t/ha for BC. These findings highlight critical areas where carbon stock is alarmingly low, with the potential to significantly impact the ecosystem. This emphasizes the need for targeted environmental management and conservation efforts to enhance carbon sequestration and sustain ecosystem services.

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1. Introduction

Forests cover a significant portion of the Earth's surface and supply various products and services. When there were wood shortages, forest evaluation inventories were started. They are the driving force behind gathering data on forest areas, stand composition, and products (Sousa *et al.*, 2017). The forest ecosystem is a crucial part of the global carbon cycle. The UNFCCC's Kyoto Protocol identifies the forest as a possible source of mitigation and stabilisation of rising CO_2 levels in the atmosphere. Forest ecosystems store the most carbon among terrestrial ecosystems (Adnan *et al.*, 2014). Forests can store 20 to 50 times more carbon than other land uses. Forests operate as carbon storage factories and have a major power to moderate global climate change among terrestrial ecosystems. Forests contribute significantly to global climate stability and carbon circulation (Saeed *et al.*, 2011; Ahamad *et al.*, 2024).

Degradation and deforestation clearly impact the carbon stored by the aboveground living biomass of trees, which is often the greatest pool. The biomass of a forest ecosystem can be used to assess its productivity. Estimating biomass is critical for assessing forest ecosystem productivity and managing carbon budgets (Zianis & Mencuccini, 2004). An accurate biomass forecast is required to understand better the carbon cycle in forest ecosystems, which operate as primary carbon sinks (Ahamad *et al.*, 2020). It was initially focused on timber volume and forest planning (Middle Ages). Demand for products and services has evolved, causing them to shift focus (Sousa *et al.*, 2017; Siddiqui *et al.*, 2023).

The escalating environmental degradation in rural areas of underdeveloped countries is a growing concern, largely driven by increasing population pressures. These pressures lead to deforestation, soil erosion, and biodiversity loss, which significantly undermine the ecosystem services that rural communities depend on (Millennium Ecosystem Assessment, 2005). Carbon stock assessment in forest ecosystems plays a crucial role in understanding and mitigating these impacts, as forests act as major carbon sinks, helping to regulate atmospheric carbon dioxide levels and support climate stability (Pan *et al*., 2011).

The amount of biomass has been estimated using a variety of methodologies, including ground measurements and satellite photography (Günlü *et al*., 2014). Forests store 45 percent of the earth's surface carbon; in 2005, forests covered 4 billion ha; of this, African forests covered 635 million hectares, accounting for about 16% of the world's forests (Aslam *et al*., 2023; Pearson, 2008). As a result, forests serve as both carbon sources and sinks. They act as a source when releasing carbon stored in their biomass into the atmosphere, and they act as a sink of carbon when they absorb from the atmosphere and store it as biomass. Forests are global net sinks, absorbing more carbon from the atmosphere than they emit. Deforestation, on the other hand, releases 60% of the 2.6 billion tons of carbon that forests absorb each year back into the atmosphere (Assefa *et al.*, 2013; Zafar *et al.*, 2021).

The current study focuses on the rural communities of the Jhelum and Chakwal districts in Pakistan, which exemplify the environmental challenges many rural areas face in developing countries. Previous research indicates that these districts have been experiencing substantial environmental degradation due to anthropogenic activities such as overgrazing, deforestation, and unsustainable agricultural practices (Ali, 2013). Low carbon levels in these ecosystems severely threaten their capacity to provide essential services, e.g., soil fertility, climate, and water regulation (Lal, 2004; Aslam *et al*., 2022).

Utilising spatial distribution analysis with advanced tools such as ArcGIS 10, this research aims to provide a detailed evaluation of carbon stock in the standing trees of Jhelum and Chakwal (Mehmood *et al*., 2022). We can identify carbon stock hotspots and critically low areas by applying descriptive statistics and interpolation techniques. This spatial variability insight is vital for informing targeted conservation and management strategies to enhance carbon sequestration and sustain ecosystem services. Such efforts are essential for promoting environmental sustainability and resilience in rural communities (Brown, 2019).

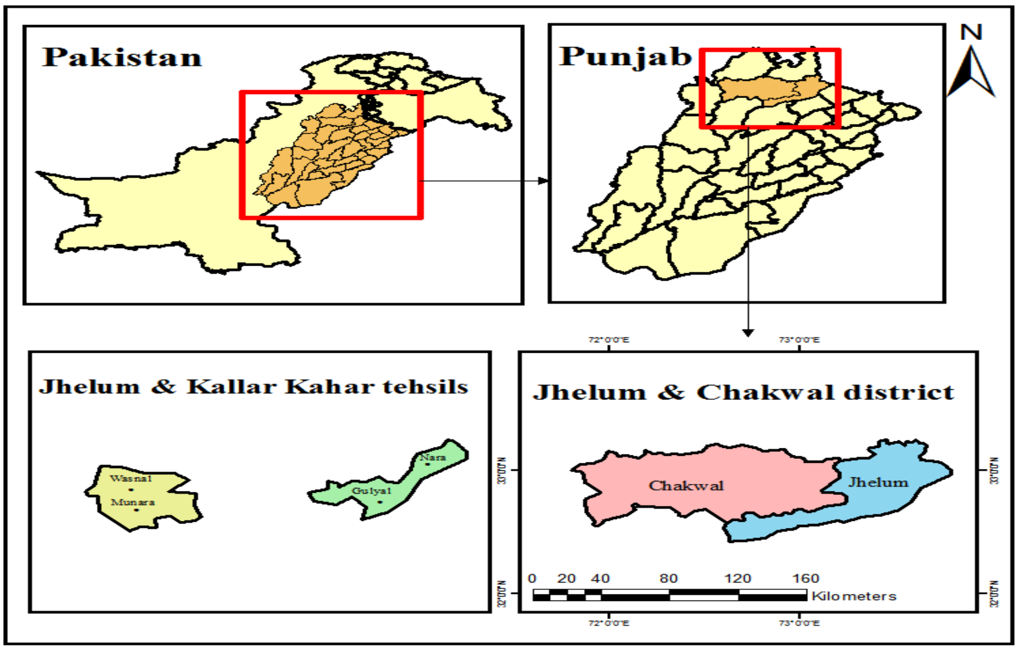
With 432 million hectares of natural forests and 116 million hectares of cultivated forests, Asia accounts for 14% of the world's forests. Pakistan has only 3.1 percent of total forest land, with the overall forest land of Pakistan declining rapidly from 3.3 percent in 1990 to 1.9 percent in 2015. Deforestation, which emits over 2 gigatons of carbon annually, is the second largest source of GHG emissions globally (Pervaiz *et al*., 2023). Most of the research in this area uses various statistical techniques, but geospatial and geostatic methodologies were used in this study. The major goal of this study was to use the spatial interpolation approach to determine the spatial distribution patterns of forest stand biomass in Jhelum and Chakwal.

2. Study area and methods

2.1. Study area

The current study was conducted in the districts of Chakwal and Jhelum of the Punjab province. Jhelum district is located 32°56′ N and 73°44′ E. (Figure 1). District Jehlum is surrounded by Rawalpindi (north), Mirpur (northeast), Mandi Bahauddin and Sargodha (south), Khushab (south-west), Gujrat (east), by Chakwal (west), and Jhelum River (south). The district is elevated 250 meters above mean sea level, having an area of 3,587 km^2. Climatic conditions of the district are very intense, with extremely cold winters and very hot summers, and the average annual rainfall is 850 mm. The Jhelum district consists of four tehsils: Jhelum, Dina, Pind Dadan Khan and Sohawa. The total population of the district is approximately 1,222,650.

Figure 1: The study area map



Chakwal is situated in the Pothohar Plateau, north of the Punjab province, Pakistan. Chakwal is surrounded by Khushab (south), Rawalpindi (northeast), Jhelum (east), Mianwali (west), and Attock (northwest). The district is located at 33°40′38″N 72°51′21″E. The larger parts of district Chakwal are in the Potohar plateau and mainly comprise the salt range. The southeastern parts of the district are hilly, and the northern and northeast parts contain undulating plains with rocky patches. The Chakwal district lies in the sub-tropical region, and the mean temperature remains 25º to 40º C. However, annual rainfall is between 558 to 640 mm (Huda *et al.*, 2023; Mahmood *et al.*, 2024). A wide variety of tree species is present in the Chakwal district. Chakwal consists of five tehsils, including Chakwal, Choa Saidan Shah, Talagang, Lawa, and Kallar Kahar, having an area of 6,524 km². The total population of the district is approximately 1,495,982.

2.2. Methods

The current study is based on a field survey carried out in 02 districts, i.e. Chakwal and Jhelum (Table-1). A total number of four villages, two from each (Jhelum and Kallar Kahar) were selected as sample sites.

Table-1: Villages surveyed for carbon stock data

Sr.	Districts	Tehsils	No.	Forest areas
1	Chakwal	Kallar Kahar	5	Munara
			5	Wasnal
2	Jhelum	Jhelum	5	Gulyal
			5	Nara

Source: Kahlon (2020)

The field survey was conducted in the summer of 2020, from June to July. During the field survey, non-destructive techniques for measuring individual tree height, tree breast height, tree diameter, and soil sampling were used to estimate carbon supply. With the cooperation of locals, 20 forest locations were chosen, considering forest accessibility, resource utilisation, and species density available. A total of ten quadrats were obtained from each 0.5-hectare site. All trees diagram heights at breast height in each sampling quadrat (DBH, 1.35 m from the ground) were measured by standard methods (Shahzad *et al*., 2019; Ahmed & Shaukat, 2012). The Microsoft Excel (version 365) was used to process further the data (Zafar *et al.*, 2020). The analysis was carried out using the formulas listed below in the Microsoft Excel, and the findings were displayed as graphs. An allometric Equation (1) was used to calculate the AGB of each tree, as follows.

$$AGB = Volume\ of\ trees\ \times density\ of\ wood \quad (1)$$

The volume of trees was measured by using Equation (2).

$$V = \pi r^2 H \quad (2)$$

Where π = 3.14, from tree diam radius, was driven, and from the world agroforestry database, wood density was taken (Shahzad *et a*l., 2019).

Above-Ground Biomass (AGB), for Pinus species (Shahzad *et al*., 2019; Shaheen *et al*., 2016), was measured as Equation (3).

$$AGB = 0.0509 \times \rho D^2 H \quad (3)$$

From Equation (4) Below-Ground Total Biomass (BGB) can be calculated.

$$BGB = 0.0509 \times \rho D^2 H \quad (4)$$

Total Tree Biomass (TB) was calculated using Equation (5).

$$TB = \text{AGB} + \text{BGB} \quad (5)$$

Total carbon is half of the total biomass in a tree (Shahzad *et al*., 2019), therefore

$$Total\ Carbon = \text{Total Biomass } \times 0.5 \quad (6)$$

Mapping and data analysis of biomass were done through the Inverse Distance Weight (IDW), interpolating by Arc GIS 10. The descriptive statistics and box plots were generated with SPSS version 19.

3. Results and discussion

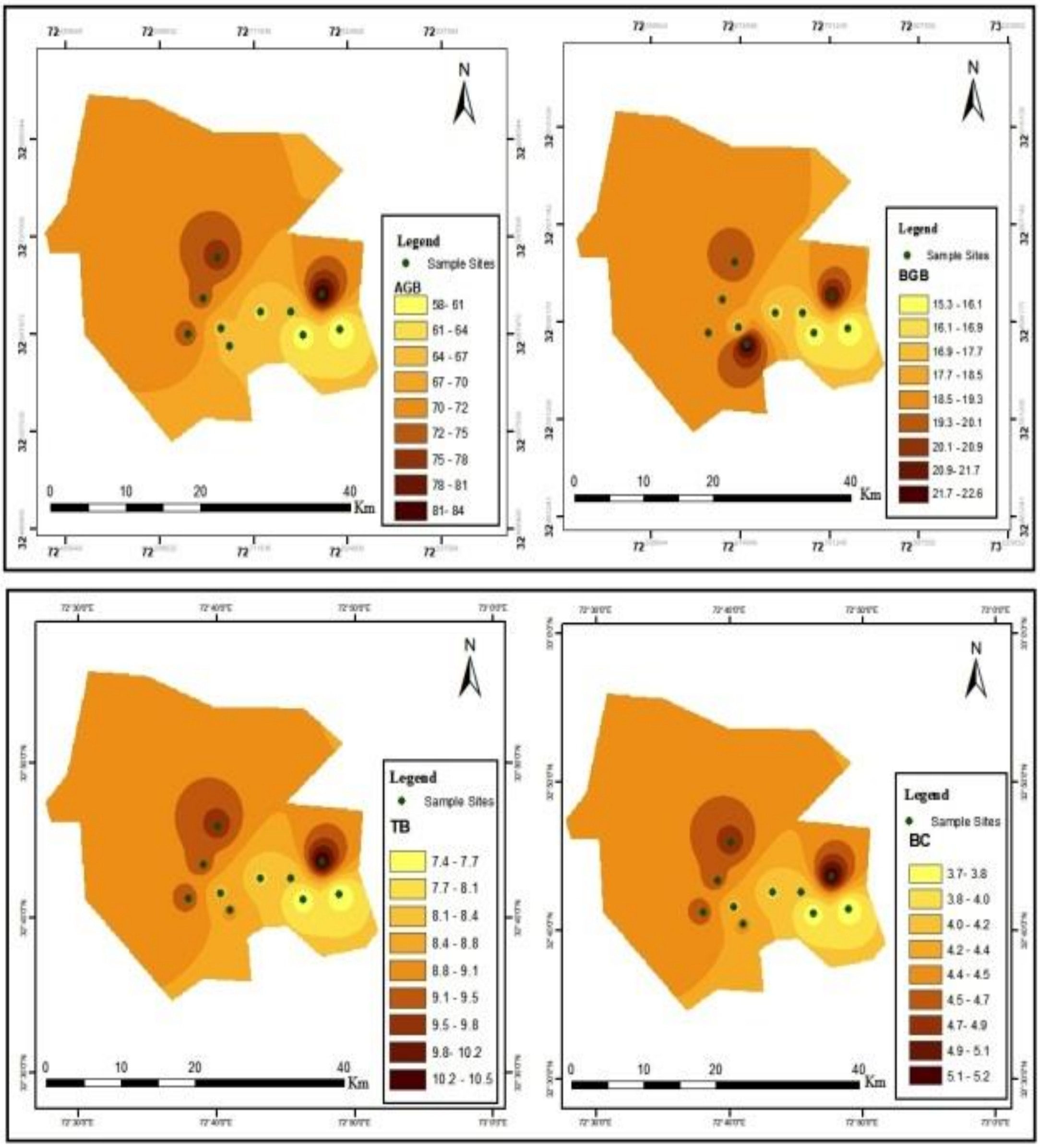
The present research findings have provided a comparison of the permissible level of Biomass Carbon (BC) in districts Chakwal and Jhelum. The highest investigated level of carbon stock observed at site 6 ranged from 452.98t/ha (Figure 4). The forest biomass is usually affected by anthropogenic activities, therefore, higher grazing and human habitat pressure lead to lower forest productivity (Shahzad *et al*., 2019; Rosenfield & Souza, 2013). The maximum amount of carbon stock was at Nara village, which is much beyond the WHO's acceptable limits (Table-2). The lowest amount of carbon stock 83.595 t/ha was observed in sample site 4 (Figure 4). The values of the study area are much lower than the previous studies conducted in the previous part of Pakistan. The fluctuation in carbon stock value was attributed to vegetation type, and the allometric measurement method was used for the results (Shaheen *et al*., 2016; Zhang *et al*., 2012).

Table-2: Descriptive statistics

Villages	Range	Minimum	Maximum	Sum	Mean	Std. Deviation
Gulyal	28.00	330.00	358.00	1377.91	344.4775	11.53564
Nara	796.72	89.23	885.95	1163.82	290.9550	396.68513
Munara	255.33	41.66	296.99	669.66	167.4150	142.98828
Wasnal	127.38	20.82	148.20	334.55	83.6363	71.41344

Figure 2 comprises four maps that illustrate the spatial distribution of various forms of biomass and carbon stock across the districts of Jhelum and Chakwal. The top left map represents the AGB with values ranging from 6-11 to 81-84 tons per hectare (t/ha). Areas with higher AGB concentrations are shown in darker brown shades, while lighter yellow shades indicate lower concentrations. Green dots mark the sample sites. The top right map shows the BGB distribution, with values ranging from 15.3-161.1 to 218.2-231.7 t/ha. Like the AGB map, darker shades indicate higher concentrations, and lighter shades indicate lower concentrations, with sample sites marked by green dots.

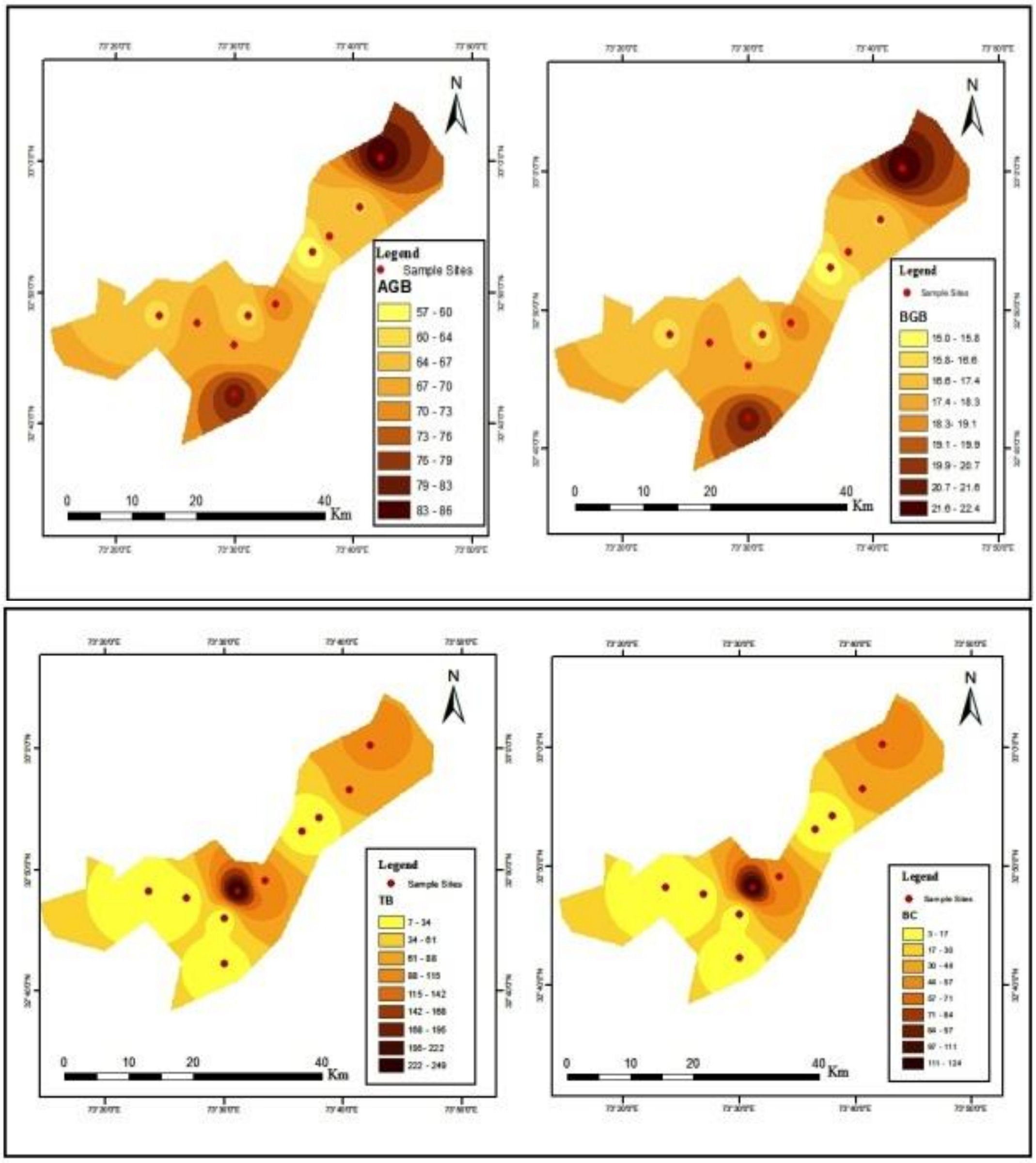
Figure 2: IDW map AGB, BGB, TB and BC in Chakwal District



The bottom left map displays the TB, combining aboveground and below-ground biomass, with values ranging from 7.7-77.7 to 99.2-105.5 t/ha. Higher TB values are depicted in darker shades, while lighter shades represent lower values. Again, green dots indicate the sample sites. The bottom right map shows the distribution of BC with values ranging from 3.1-3.8 to 5.1-5.2 t/ha. Darker shades represent higher BC concentrations, and lighter shades represent lower concentrations, with sample sites marked by green dots.

Overall, the maps utilise Inverse Distance Weighting (IDW) interpolation to depict the spatial distribution of the respective biomass and carbon stocks. They reveal hotspots with higher concentrations, predominantly in the central and southern parts of the study area. These maps highlight critical areas where targeted conservation and management efforts could significantly enhance carbon sequestration and improve overall ecosystem health.

Figure 3: IDW map AGB, BGB, TB and BC in Jhelum District



The AGB and BGB concentration in the village of Chakwal district is 58-84 and 15.3-22.6 t/ha and Jhelum district is 57-86 and 15-22.4 t/ha, respectively. The carbon equilibrium of the Chakwal and Jhelum districts' rural ecosystems seems to be endangered due to logging, grazing, and anthropogenic activities. An interpolation shows that the range of TB and BC is 07-249 and 03-124 t/ha (Figure 3). This maximum extent of TB and BC was observed in the tree Gulyal and Nara village revealed by the map. It can be observed from Figure 4 that six sites have less than 90 while 3 sites have lower than 80 range (It is agreed that the carbon level is strongly associated with human activities (FAO, 2011). Besides these sites, the rest of the sites 8, 9, 13,16,18,19, and 20, situated in the Chakwal district, have carbon stock ranging from 100-300 t/ha.

Figure 4: Total amount of Carbon stock at selected sites

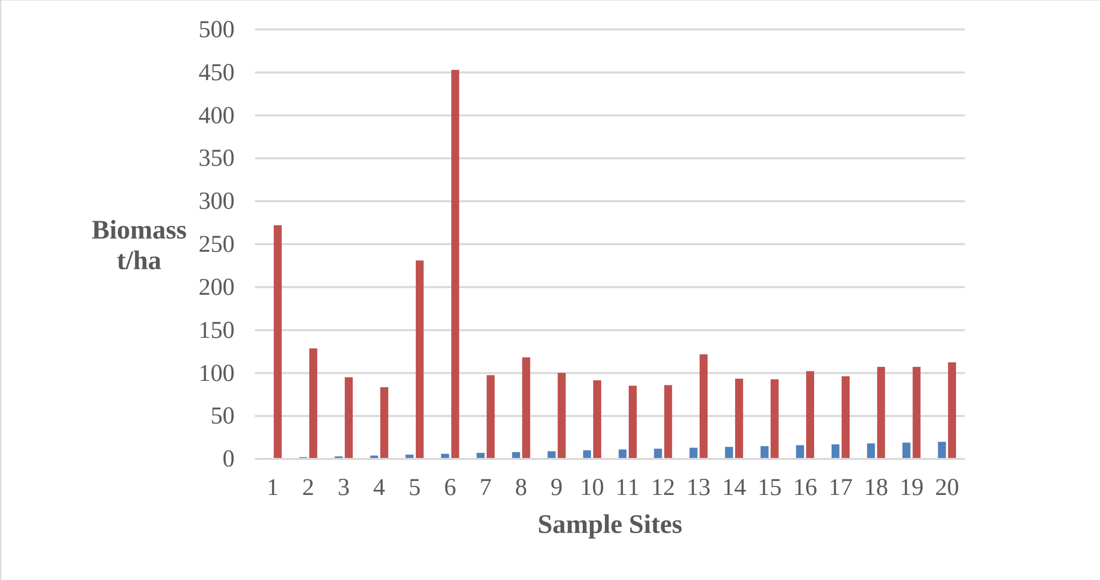


Figure 4 illustrates the biomass distribution in tons per hectare (t/ha) across 20 sample sites. Notably, Site 6 exhibits the highest biomass concentration, exceeding 450 t/ha, indicating a significantly dense or highly productive vegetation area. Sites 1 and 5 also show relatively high biomass values, around 250 t/ha and 200 t/ha, respectively, suggesting regions with substantial vegetation density. In contrast, Sites 2, 3, 4, 7, and 13 display moderate biomass levels, ranging between 50 t/ha to 150 t/ha. The remaining sites, numbered 8 through 20, exhibit lower and more uniform biomass values, generally below 100 t/ha, indicating less dense or productive vegetation. This variability in biomass distribution underscores the presence of ecological hotspots, particularly at Sites 6, 1, and 5, which are crucial for targeted conservation and management strategies to enhance biomass and carbon sequestration. The chart effectively highlights the need for differentiated environmental management approaches tailored to the specific biomass levels observed across the various sample sites.

The observed variability in biomass distribution across the sample sites in the Jhelum and Chakwal districts underscores the critical need for targeted environmental management strategies. Site 6, with its exceptionally high biomass concentration, likely represents areas of significant forest cover or high vegetation productivity, which are vital carbon sinks and biodiversity reservoirs (Pan *et al*., 2011). Conversely, the lower biomass values observed at most other sites suggest areas where vegetation density and productivity are suboptimal, possibly due to anthropogenic pressures such as deforestation, overgrazing, and unsustainable agricultural practices (Ali, 2013). These findings are consistent with global patterns observed in other rural regions of underdeveloped countries, where population pressures and inadequate land management practices lead to significant environmental degradation (FAO, 2020). To enhance carbon sequestration and improve ecosystem services, it is imperative to implement localised conservation efforts, such as sustainable land use practices, reforestation and community-based natural resource management (Brown, 2019). Integrating these strategies with technological tools like ArcGIS for spatial analysis can significantly aid in identifying and prioritising critical areas for intervention (Esri, 2021). Such data-driven approaches are essential for fostering environmental resilience and sustainability in the face of ongoing climatic and anthropogenic challenges.

4. Conclusion

The current study is based on an extensive carbon stock survey in rural localities of Jhelum and Chakwal districts, Punjab, Pakistan, to assess the present status of biomass concentration in the forested area. The statistical and geographical analyses were done through the Arc GIS 10. The low concentration of carbon stock in the rural environment can mostly be linked to the livelihood of locals that depend upon the area's natural resources. It has been observed that carbon stock shows mean concentrations ranging from 28.00, 796.72, 255.33, and 127.38 t/ha, respectively in surveyed villages. The study's research findings will be worthwhile for environmentalists and policymakers as they will help conserve the resources that are under anthropogenic pressure. Sustainable forest management is needed to support local communities and natural resources in highly vulnerable and marginalised regions. The findings of this study can provide an essential background for the future work in similar areas. It is recommended that further research of this nature should be conducted on large geographical areas. Finally, future researchers should also emphasise more on impacts of carbon sequestration on ecosystem health and analyse the same for urban ecological stability in different parks and forested areas of Pakistan.

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