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Assessment of Agroforestry Carbon Sequestration Potential in irrigated Plains of Khyber Pakhtunkhwa: A Study of District Charsadda, Pakistan

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Abstract

The study highlights the significant role of agroforestry in carbon sequestration within six selected villages of District Charsadda, Khyber Pakhtunkhwa. Agroforestry, particularly mixed-dense systems, enhances carbon absorption and promotes sustainable land use. Google Earth images were the primary source of data coupled with fieldwork to determine the plantation characteristics. The image analysis reveals that Mera Umerzai, with the highest vegetation cover, and Matta Rustum Khel, the largest contributor by total area, play key roles in carbon capture.

The analysis highlights that Mira Umerzai and Matta Rustum Khel exhibit the highest CO_2 sequestration potential due to their extensive vegetation areas and large tree populations. Mira Umerzai, with the largest vegetation area (357.9 hectares), achieves a CO_2 sequestration peak of 2,899.82 million pounds. Similarly, Matta Rustum Khel, with a high tree count of 1.7 million in Scenario 1, shows its greatest sequestration potential of 4,718.04 million pounds in Scenario 2. Other mouzas, like Sherpao and Chak Sherpao, show consistent CO_2 sequestration ranges, while Kabli has the smallest area and lowest sequestration. Collectively, the villages have sequestered 20,157.7 million pounds of CO_2. Poplar trees, known for their rapid growth and high biomass, are particularly effective, with a 100-hectare plantation capable of absorbing 700-1,500 tons of CO_2 annually. This contributes significantly to climate change mitigation and local economic development. Considering agroforestry's effectiveness in contributing to carbon capture and storage, it is suggested that such initiatives be expanded, particularly in high-potential villages. Scaling up these activities across more locations can increase carbon absorption and help to mitigate climate change.

Keywords: Agroforestry, Poplar plantation, CO_2 sequestration, Land Use Land Cover, Image Analysi

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Introduction

Agroforestry is a land-use management system that integrates two distinct sectors, forestry, and agriculture, to generate multifunctional landscapes (Bijarpas et al., 2015; Verma, 2017; Anwar et al., 2017; Paudel, 2019). Agroforestry practices can provide a variety of environmental benefits/services (Cherubin et al., 2018), such as increased biodiversity, nitrogen fixation, carbon sequestration, soil erosion reduction, and reduced demand on forest resources (Glover et al., 2013; Nguyen et al., 2013; Maluki et al., 2016; Farooq et al., 2017). Agroforestry is regarded as an important driver of socioeconomic uplift due to the provision of wood and non-wood tree products, additional income, increased crop productivity, and resilience to natural hazards (Bijarpas et al., 2015; Sun et al., 2017; Quandt et al., 2017; Hanisch et al., 2019). Thus, through ecological and economic interactions among the many components, it not only sustains but often maximizes land production (Zerihun et al., 2014).

Agroforestry is as ancient as farming itself (Nair, 2011; Hanisch et al., 2019) and has been practiced in numerous places where the technologies were practicable, economical, and available to farmers (Nguyen et al., 2013). Agroforestry was a regular practice in industrialized nations of Europe, notably Germany, until the Middle Ages, whereas it was introduced as a system in a few regions of South Africa in the last decade of the nineteenth century (Nair 1993). Because of its strong potential for food security, climate change adaptation, and mitigation, its use has increased significantly in other regions of Africa (Luedeling et al., 2014; Ariom et al., 2022). Agroforestry is now widely regarded as a well-developed system (Dollinger & Joes, 2018). Around 1.2 billion individuals in low and medium-income countries (LMIC) rely on agroforestry methods to increase agricultural output as well as generate income (Chao, 2012; Maluki et al., 2016). Furthermore, this system can help achieve several Sustainable Development Goals (SDGs), such as poverty reduction, hunger elimination, affordable energy provision, slowing the rate of deforestation, reversing land degradation, and combating climate change through carbon sequestration (Khan et al., 2017; FAO, 2019; Singh et al., 2023). For these reasons, agroforestry is gaining popularity as a sustainable, climate-smart agricultural system (Dobhal et al., 2024; Chavan et al., 2024).

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One of the most significant and recent environmental benefits of the agroforestry system (AFS) is its carbon sequestration potential (CSP). Carbon sequestration is the act of storing carbon in plants, soils, oceans, and geological formations through natural or human processes (Nair et al. 2009; Murthy et al. 2013). In today's context of global climate change caused by higher carbon dioxide concentrations in the atmosphere, there is tremendous interest in the prospect of boosting the rate of carbon sequestration through an increase in vegetative cover. Carbon sequestration rates are determined by the growth characteristics of the three species, the density of tree wood, and the growing conditions where the tree is planted (Sharma et al., 2016; Rizvi et al., 2019).

Pakistan is essentially an agricultural country but has never been self-sufficient in agricultural goods due to several restraints such as climatic conditions, farming system, fragmentation, poverty, and limited arable availability. Climate change and Global warming pose an additional threat to the food supply, as the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report predicts that the negative effects of climate change will severely impact Pakistan because the economies in the country rely on agriculture and natural resources (Saeed & Athar 2018; Hussain et al., 2020). Agroforestry is one such alternative that can address food insecurity, improve the financial security of local farmers, strengthen their capacity for adaptation to natural catastrophes, and help mitigate climate change through carbon sequestration (Duffy et al., 2021; Montagnini & Metzel 2024).

Agriculture in Pakistan is under tremendous stress due to limited acreage as a result of rising urbanization and changing weather patterns, making rural farmers more vulnerable (Ullah et al., 2019; Hussain et al., 2020; Shah et al., 2022). Agroforestry is widely regarded as a strategy that can not only reduce farmer vulnerability but also assist in minimizing the effects of climate change (Bogale & Bekele 2023; Rolo et al., 2023). However, no scientific study has been conducted in this area to explore and assess its role in climate change mitigation. In the Charsadda district fertility of the soil, suitable climatic conditions, and availability of complex irrigation systems support agriculture. Farmers grow trees on field sides as boundary markers, shade trees, and windbreakers while on some farm trees are also accommodated in the middle in the form of rows, and between the rows grow crops (Khan, et al. 2017). Vast cultivated land availability and water resources support the adoption of agroforestry. Therefore, the current study attempts to assess the CO_2 sequestration potential of agroforestry in district Charsadda, where agroforestry is widely practiced.

Methodology/Research Methods

Study Area

Geographically the study area is located in the central part of Peshawar valley which is a semi-circular depression covering an area of about 8800 km^2. The absolute location of Charsadda district is between 34°, 2′, 14″to 34^0, 27′, 56″ north latitude and 71^0, 29′, 00″ to 71^0, 56′, 22″east longitude, covering an area of 996 kms^2 (Figure 1). Malakand district is located in the north of Charsadda while Peshawar and Nowshera districts lie to the south. The Mardan district forms the eastern boundary while the Mohmand district is situated on the western border of Charsadda district (Figure 1 shows the location of the study area). Charsadda has a typical continental-type climate. In June the temperature reaches its peak, with an average annual maximum temperature of 40.4°C while in January it falls to its minimum level with an average minimum temperature of $25.7C^0$. The average annual rainfall recorded in the area is 27.7 mm (GoP, 1999). The district has rich and fertile soil, deposited by the River Kabul and its tributaries flowing into the area from the surrounding hills. Channels from rivers Kabul and Swat are used to irrigate the cultivated area. Charsadda district is one of the most vulnerable areas to floods. In the 2010 super flood, this district was worst hit and the agriculture sector was badly affected (Iqbal et al., 2018) This region is known for the cultivation of sugarcane, wheat, tobacco, fruits, vegetables, etc. owning to fertile land and plenty of irrigation water majority of the farmers are practicing agroforestry. A Variety of trees both fruit and non-fruit are grown in fields as well in specified plots. According to the population census in 2017, the total population of Charsadda district was 1,616,198. The majority of the population of the area is directly or indirectly dependent on agriculture for livelihood (GoP, 2017).

Data Collection and Analysis

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The high-resolution Google Earth images were downloaded from Google Earth Pro 4.2. The images were classified into various land use land cover classes using a maximum likelihood classifier algorithm. The area under various LULC classes was computed subsequently. The area under agroforestry/plantation in selected mouza was determined by taking into account the area under linear plantation. The following procedure was adopted to compute the Carbon Sequestration potential of each mouza:

- A field visit was carried out to all the selected mouzas, a sample plot was selected and the number of trees was counted along with measurement of tree height, width, and age of plantation. The area of the plot was determined by field measurements and subsequently the area occupied by a single tree was computed.
- To determine the number of trees in a village, the total area of the plantation was divided by the area occupied by a single tree.
- Various methodologies have been used for the assessment of Carbon Sequestration potential, however, for the present study the methodology suggested by Chavan & Rasal (2010) and Eneji, (2014) has been used. The adopted methodology estimates the amount of carbon dioxide sequestered by different tree species through the following five steps:

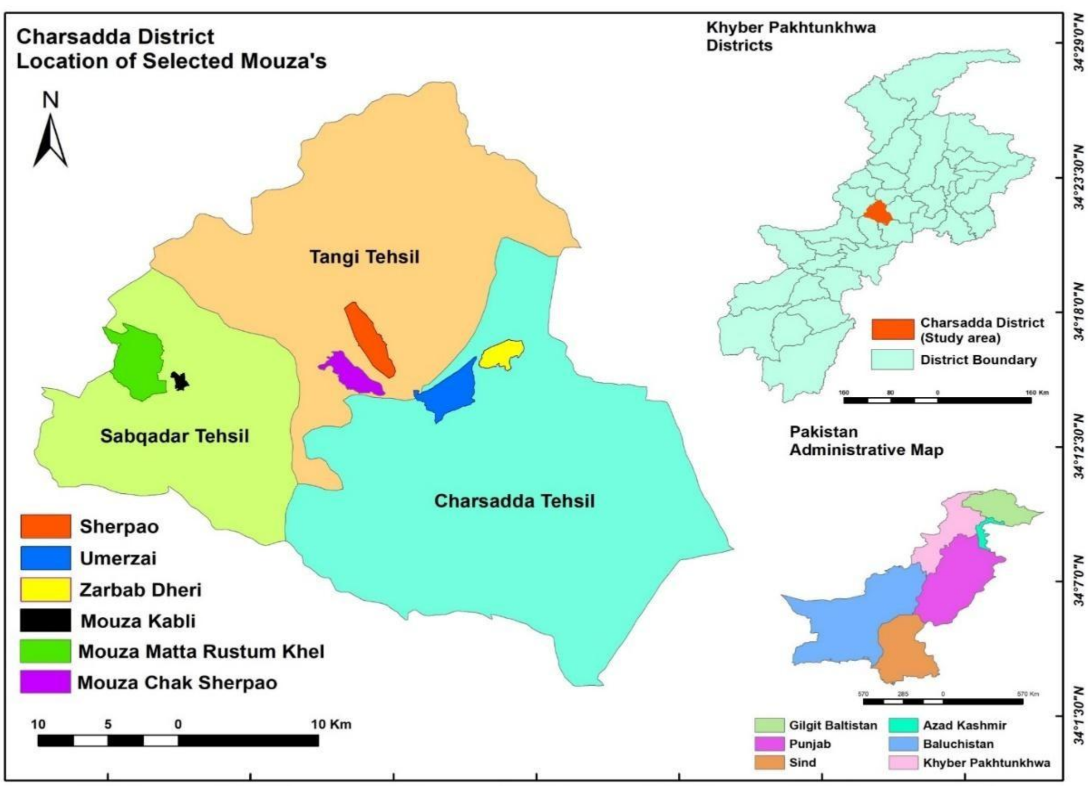

Figure 1. Illustrating the Location map of the study area

Step 1: Determine the total green weight of the tree

The green weight is the weight of the tree when it is alive. First, to calculate the green weight of the above-ground weight as follows:

Weight above-ground= 0.25 D2 H (for trees with D<11 inches)
Weight above-ground= 0.15 D2 H (for trees with D>11 inches)
Where D = Diameter of the trunk in inches, H = Height of the tree in feet

The root system weight is about 20% of the above-ground weight. Therefore, to determine the total green weight of the tree, multiply the above-ground weight by 1.2:

Weight total green weight = 1.2* Weight above-ground

Step 2: Determine the dry weight of the tree

The average tree is 72.5% dry matter and 27.5% moisture3. Therefore, to determine the dry weight of the tree, multiply the total green weight of the tree by 72.5%.

Weight dry weight = 0.725 * Weight total green weight

Step 3: Determine the weight of carbon in the tree

The average carbon content is generally 50% of the tree's dry weight total volume1. Therefore, in determining the weight of carbon in the tree, multiply the dry weight of the tree by 50%.

Weight of carbon = 0.5 * Wdry weight

Step 4: Determine the weight of carbon dioxide sequestered in the tree

CO_2 has one molecule of Carbon and 2 molecules of Oxygen. The atomic weight of Carbon is 12 (u) and the atomic weight of Oxygen is 16 (u). The weight of CO_2 in trees is determined by the ratio of CO_2 to C is 44/12 = 3.67. Therefore, to determine the weight of carbon dioxide sequestered in the tree, multiply the weight of carbon in the tree by 3.671.

Wcarbon-dioxide = 3.67 * Wcarbon

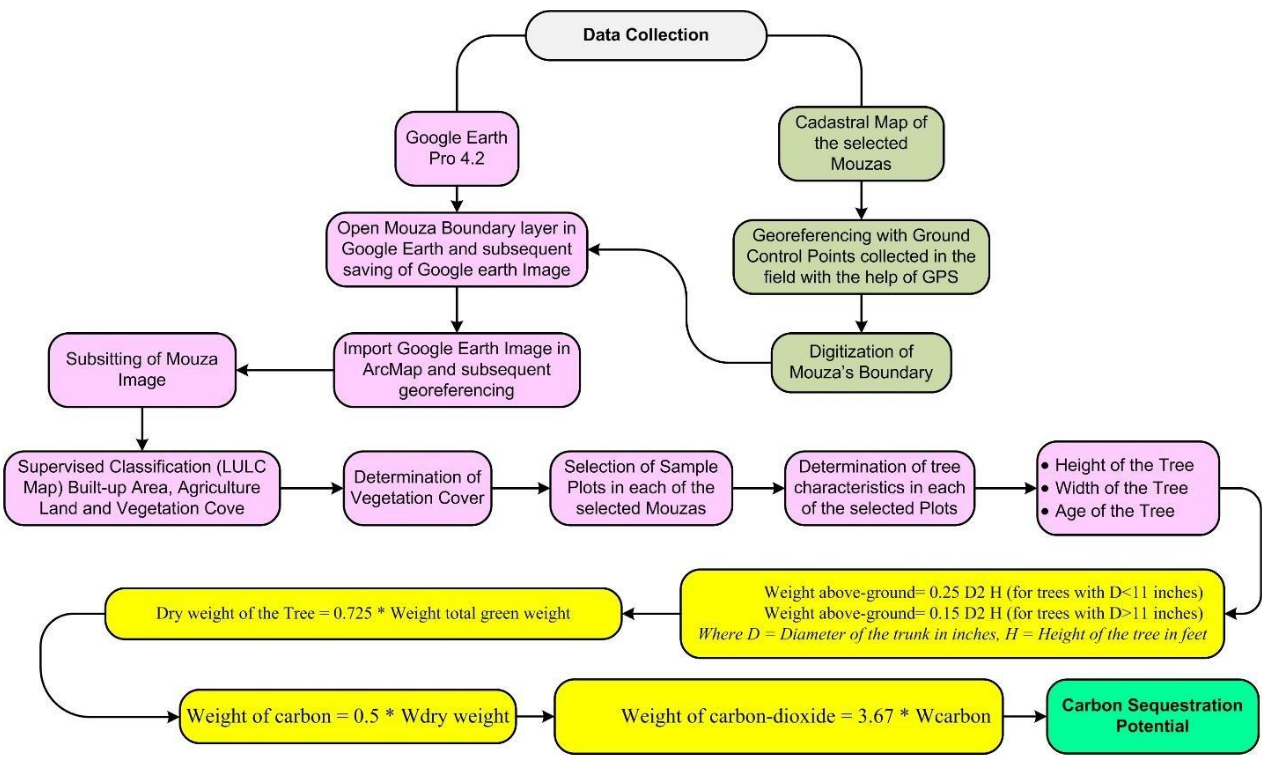

Figure 2. Illustrating Methodology Flowchart after Chavan & Rasal (2010) and Eneji, (2014)

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Results and Discussion

Land use land cover of the selected Mouza's

Mera Umerzai

Mira Umerzai is one of the largest selected mouza with 2325 number of households. Table 1 depicts the land use land cover of Mera Umerzai. The analysis reveals that almost 11% of the mouza land is covered by built-up area while 43.45 % of the area is under agriculture. Unlike other mouza, Mera Umerzai has a larger vegetation cover (45.63 %). Figure 3A illustrates the Google Earth image of Mouza Mera Umerzai and Figure 3B illustrates the classified image of Mera Umerzai. The analysis of Google Earth image and field survey suggest that farmers practice various types of agroforestry systems like mixed dense, mixed sparse, and strip plantation which indicates, that farmers become aware of this system and take an interest in adopting it. The small landholdings the farmers of the area focus on tree cultivation to get more economic benefits.

Zarbab Garhi:

Zarbab Garhi is located in tehsil Charsadda. The village is composed of vast agricultural land and vegetation cover. Table 1 shows different land use and land cover of the area, the analysis reveals that more than half of the village is composed of agricultural land (53.73%) while a quarter of the land is covered by linear vegetation (25.65%). The remaining land (20.62%) is built-up areas i.e. residential and commercial etc. Figure 3C shows the Google Earth Image of Zarbab Garhi while Figure 3D illustrates the spatial distribution of land use land cover for Zarbab Garhi. The analysis reveals that almost all parts of the village have cultivated land except the north, northeast, and south which have vast residential areas. The majority of the farmers adopted the strip plantation system. In this system, woody plants (trees and shrubs) are grown on field boundaries while crops are in the center. The strip plantation becomes so common that one can hardly find any field boundary without trees. Tree species can be maintained either by managing existing trees or by planting new trees. Mixed dense type of agroforestry is practiced in the area. In agroforestry trees are usually planted on field boundaries in lanes and in between farmers grow fodder or crops such as red clover, wheat, maize, barley, etc.

Mouza Sherpao

Sherpao is another mouza selected for the present study, it is located in tehsil Tangi of district Charsadda. Sherpao is predominantly an agriculture mouza with some vegetation growing on the field boundaries. The built-up area is comparatively very small. Table 1 shows the land use land cover of mouza Sherpao for the year 2021. Figure 4A shows the Google Earth Image of Mouza Sherpao while Figure 4B illustrates the spatial distribution of land use land cover for Mouza Sherpao. The analysis reveals that a quarter (25.57%) of Sherpao is composed of built-up area. In this Mouza 57.67% of land is still covered by agriculture which is more than half of the total land area of the mouza. Despite the large cultivated land, the vegetation cover is very small comprising only 16.76% of the total land. Figure 3A illustrates the Google Earth image of the mouza, while Figure 3B illustrates the spatial distribution of the LULC across the mouzaSherpao.

Mouza Kabli

Mouza Kabli is comparatively a small village selected for the current study. It is part of tehsil Shabqader tehsil district Charsadda. It has a total area of only 76.78 hectares. Table 1 summarizes the image analysis results for mouza Kabli showing the area under various LULC classes. The analysis of Table 2 reveals that 24.76 % of the land was covered by vegetation. The built-up area accounts for only 4.47% of the total area, while the agricultural land is 77.70%. Figure 4C illustrates the Google Earth image, and Figure 4D illustrates the spatial distribution of various LULC across the mouza Kabli. The analysis reveals that the built-up area is very small and mostly located near the eastern border. However, the village is predominantly composed of agricultural land. The farmers still adopted the ways of their forefathers and were not interested in practicing the new techniques. Only a small area is covered by vegetation. Mixed dense agroforestry is widely seen in the area. On major plots can be noticed dense vegetation cover in irregular ways and also in the form of rows.

Chak Sherpao

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Chak Sherpao is another village selected for the present study, it is located in tehsil Tangi, district Charsadda. Table 2 summarizes the image analysis results depicting areas under various LULC classes. The analysis of Table 1 reveals that in this mouza the built-up area is small, accounting for just 2.67 percent of the total land. Besides Chak Sherpao is a very sparsely populated mouza. More than 66 percent of the land is covered by agricultural land while the rest of 30.57 percent is vegetation-covered area. Figures 5A and 5B illustrate the Google Earth image and classified image of the mouza, showing the spatial distribution of various LULC classes across the Chak Sherpao. The analysis reveals that the land use land cover of Chak Sherpao is predominantly comprised of cultivated land. Strip plantation is commonly practiced in all parts of the village. Besides, mixed dense type of agroforestry is also practiced and vegetation can be seen dominantly in the middle of the mouza near the settlements. Unlike the other villages here built-up area is very small while mixed dense agroforestry is very prominent.

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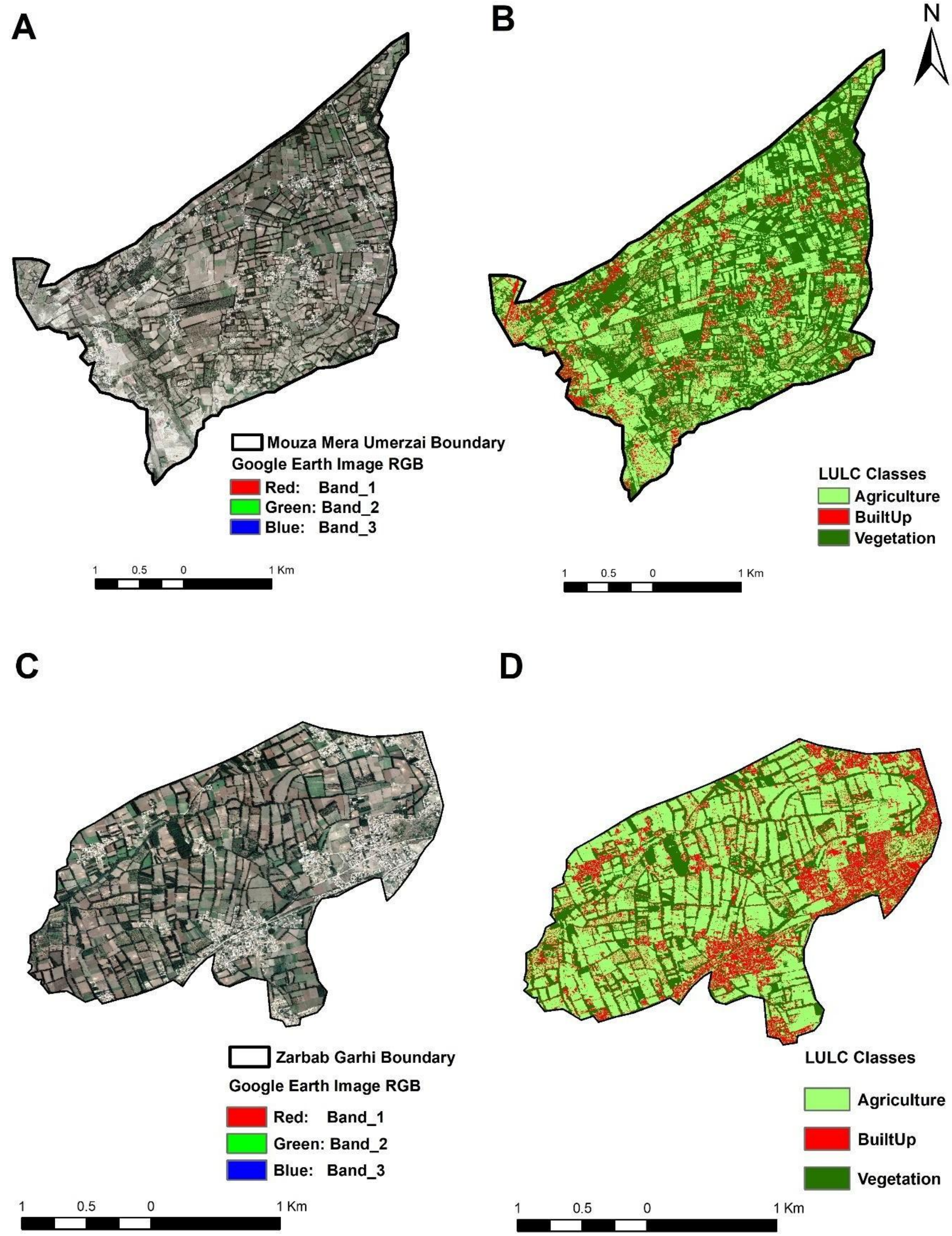

Figure 3. ***(A)*** Illustrating the Google Earth Image of Mouza Mera Umerzai ***(B)*** Classified image of Mouza Mera Umerzai, illustrating the spatial distribution of various LULC classes ***(C)*** The Google Earth Image of Mouza Zarbab Gahri ***(D)*** Classified image of Mouza Zarbab Gahri , illustrating the spatial distribution of various LULC classes

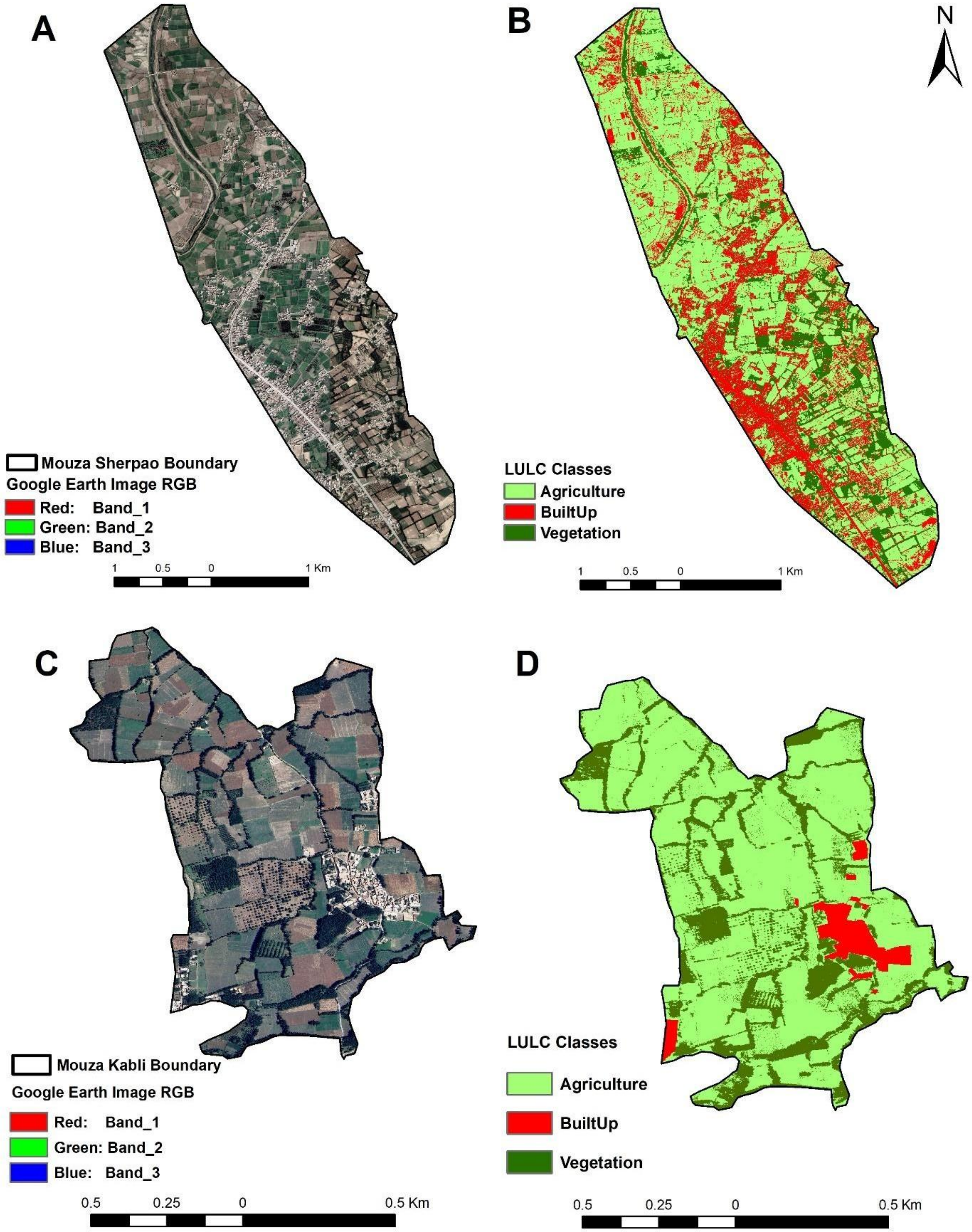

Figure 4. ***(A)*** Illustrating the Google Earth Image of Mouza Sherpao ***(B)*** Classified image of Mouza Sherpao, illustrating the spatial distribution of various LULC classes ***(C)*** The Google Earth Image of Mouza Kabli ***(D)*** Classified image of Mouza Kabli, illustrating the spatial distribution of various LULC classes

Matta Rustum Khel

Matta Rustum Khel is another mouza selected for analysis, it is located in tehsil Shabqader of district Charsadda. This is a relatively large mouza as compared to the other selected mouza's of study area. Table 1 summarizes the image analysis results, showing the area and percentage of area under various LULC classes. The analysis reveals that the total land of Matta Rustum Khel is 1341.81 hectares. Only 16.36 % of which is under vegetation cover. More than half of the land (51.80%) is agricultural land. A large portion (16.59%) of this village remains barren and 15.26% is built-up area.

Figures 5C and 5D illustrate the Google Earth image and classified image of the mouza Matta Rustum Khel respectively. Figure 4D illustrates the spatial distribution of various LULC classes in Mouza Matta Rustem Khel. The analysis reveals the built-up area and the barren land account for more than 30% of the total area. The rest of the land is predominantly comprised of agricultural land with a small area under the vegetation cover. This image analysis also suggests that Matta Rustum Khel is densely populated in the north and central parts while the rest of the village is sparsely populated as suggested by the distribution of settlements. The north and southwestern part of the mouza is covered by barren land, while the east and south of the village are mostly comprised of agricultural land. The strip plantation and mixed dense type of agroforestry can only be seen in the eastern and southern parts of the mouza.

Table 1. The area under Various Land use Classes 14-05-2021

S.No	Name of Mouza	Area in Hectare				
		Vegetation	Built-up Area	Agriculture	Barren Land	Total Area
1	Zarbab Garhi	98.83	79.45	207		385.28
2	Mera Umerzai	357.90	85.65	340.76		784.30
3	Sherpao	112.19	171.15	386.09		669.43
4	Chak Sherpao	158.46	13.86	346.06	-	518.38
5	Matta Rustum Khel	219.46	204.71	695.02	222.62	1341.81
6	Mouza Kabli,	19.01	3.43	54.34	-	76.78

Source: Image analysis and area calculation in in ArcMap 10.8

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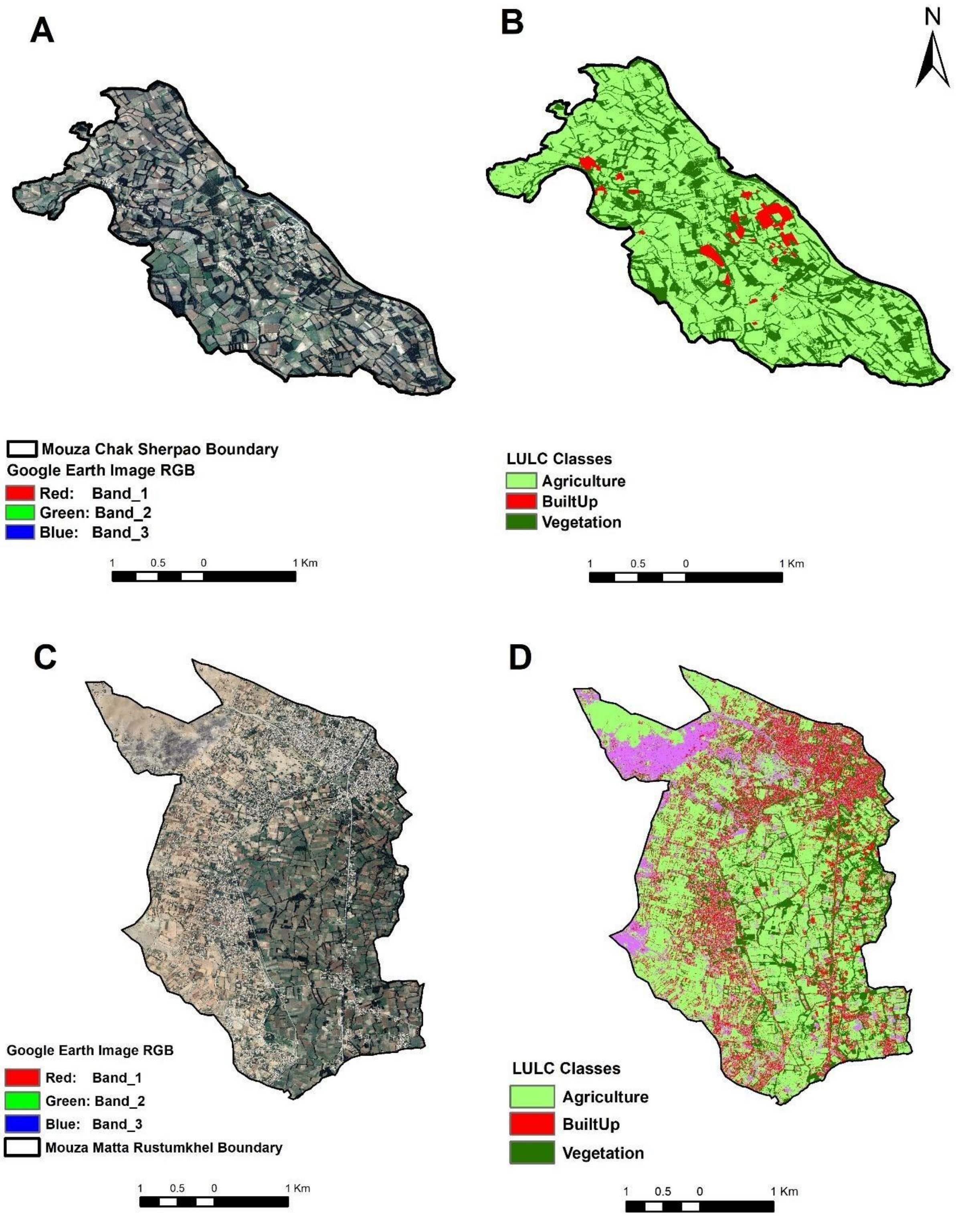

Figure 5. ***(A)*** Illustrating the Google Earth Image of Mouza Chak Sherpao ***(B)*** Classified image of Mouza Chak Sherpao, illustrating the spatial distribution of various LULC classes ***(C)*** The Google Earth Image of Mouza Matta Rustum Khel ***(D)*** Classified image of Mouza Matta Rustum Khel, illustrating the spatial distribution of various LULC classes

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Area under Vegetation Cover in the Selected Villages of District Charsadda

District Charsadda features some of Khyber Pakhtunkhwa's most fertile soil. The region encompasses around 996 square kilometers (243753 acres). The overall cultivated area is 210255 acres (61%), with the irrigated area accounting for 180339 acres (86%). Charsadda relies heavily on irrigation from three rivers: the Jindi, Kabul, and Swat. The area bounded by the Swat and Kabul rivers is known as Doaaba. Sugarcane, sugar beet, wheat, and maize are the principal crops grown in Charsadda. Spinach, potatoes, tomatoes, cabbage, brinjals, and okra are the important vegetables grown here. Famous among orchards are the apricot, citrus, plum, strawberry, and pear varieties. This region has a vast cultivation of tobacco, sugarcane, and strawberries.

In Khyber Pakhtunkhwa, agroforestry is performed in a variety of ways, from intentionally planting trees on farmlands to just protecting naturally occurring trees. It is typically used for subsistence, but more recently, donor-funded social forestry programs have transformed this system into more commercial agroforestry, encouraging the integration of quickly growing exotic wood species (Zada et al., 2022). The district of Charsadda, which is situated in Khyber Pakhtunkhwa's core irrigated zone, has made substantial progress in agroforestry. That can be regarded as Pakistan's greatest example of agricultural forestry. Nearly all farmers have cultivated trees on their farms. In Charsadda, exotic poplars have grown so popular that it is rare to locate a plot of land without poplar trees because of their rapid growth and swift economic return (Khan et al., 2022).

Table 2 depicts the area under vegetation in all the selected mouzas of district Charsadda. Figure 6 depicts the area in the percentage of vegetation in the selected mouzas of district Charsadda. The analysis reveals that in Mouza Kabli 24.76% and in Matta Rustum Khel 16.36% of land area is covered by vegetation. Similarly, in mouza Chak Sherpao 30.57 %, Zarbab Garhi 25.65%, and Sherpao 16.76% of the total land is covered by vegetation. Within all the selected villages, only in mouza Mera Umerzai, the vegetation covers a larger area compared to agricultural land. In Mera Umerzai 45.63% of land was under vegetation. Collectively, in all study areas, 25.58 percent of the land is under vegetation.

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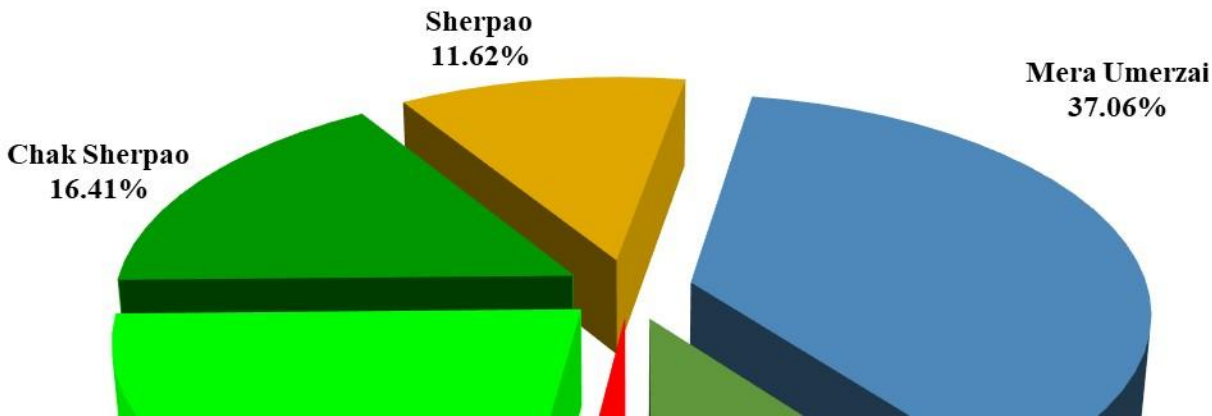
Table 2. Area under Vegetation 14-05-2021

S. No	Mouza Name	Total area of the Mouza (Hectare)	Area under vegetation Hectare	%age of Total Area of the mouza	% age of Total Area under Vegetation	%age of the total study area
1	Mouza Kabli	76.78	19.01	24.76	1.97	25.58
2	Matta Rustum Khel	1341.81	219.46	16.36	22.72	
3	Chak Sherpao	518.38	158.46	30.57	16.41	
4	Sherpao	669.43	112.19	16.76	11.62	
5	Mera Umerzai	784.30	357.9	45.63	37.06	
6	Zarbab Garhi	385.28	98.83	25.65	10.23	
Total		3775.98	965.85		100	



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Carbon Dioxide (Co_2) Sequestered in Selected Mouza's

Mouza Mira Umerzai

Mira Umerzai is a large village of Charsadda tehsil having a total area of 357.90 hectares covered by vegetation. The fieldwork was carried out to determine the height, width, and age of the trees grown in various parts of the mouza. Based on tree characteristics (height and width) 3 different scenarios were considered for CO_2 sequestration potential**.** Table 3 depicts the area under the strip plantation and CO_2 sequestration potential of the Mouza Mira Umerzai. The analysis reveals that the total area covered by strip plantations is 357.9 hectares, having a total of 2,127,612 trees. These trees collectively sequestrated 6095.59 million pounds of CO_2 in 5 years.

Zarbab Garhi:

In Mouza Zarbab Garhi the total land under vegetation is 98.83 hectares. The total vegetation-covered land is classified into three categories based on the characteristics of trees i.e. height and diameter of the trees. The total number of trees on 26 hectares of land was 559728 which sequester 386.03 million lbs. of Carbon in five years. Table 3 depicts the CO_2 sequestration potential of the Mouza Zarbab Garhi under three scenarios.

Sherpao

In Mouza Sherpao the total land under vegetation is 112.19 hectares (11.62 % of the total area). The total vegetation-covered land is classified into three categories based on the characteristics of trees i.e. height and diameter of the trees. The total number of trees computed was 2415226, which sequesters 1027.62 million lbs. of Carbon in five years. Table 3 and Table 4 depict the plantation characteristics and CO_2 sequestration potential of the Mouza Sherpao respectively.

Kabli:

Kabli is a small village having 19.01 hectares of land covered by plantation/vegetation. Based on the tree characteristics two different types of plantations were identified during the fieldwork, therefore, the CO_2 sequestration potential is computed under two different scenarios. On a total of 9 hectares of land, the total number of trees was 19,367 and has the potential to sequester 261.27 million lbs. of CO_2 in five years. Tables 3 & 4 depict the vegetation Characteristics, area under vegetation, and amount of CO_2 sequestration in Mouza Kabli in 5 years.

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Chak Sherpao:

The total land under vegetation in Chak Sherpao is 158.46 hectares. Based on the tree characteristics the CO_2 sequestrated was computed under three scenarios. Table 2 summarizes the results of the analysis. The analysis reveals that the total area under plantation is 159.46 hectares, having a total of 3,432,826 trees which sequestrated 2137.87 million lbs. of CO_2 in the last 5 years. Tables 3 and 4 depict the area and characteristics of the strip plantation and CO_2 sequestration potential of the Mouza Chak Sherpao respectively.

Matta Rustum Khel:

The image analysis reveals that the total area under vegetation cover is 219.46 hectares. Table 3 depicts the vegetation Characteristics, and area under vegetation, Table 4 and Figure 6 depict the amount of CO_2 sequestration in Mouza. The analysis reveals the area has 1726,531 trees and has a CO_2 sequestration potential of 38847.45 million lbs. in 5 years. The analysis of Tables 3, 4, and Figure 6 reveals that being the largest selected mouza, Mera Umerzai accounts for the largest area under plantation (357.9ha or 37.06% of the total area) and hence one of the largest contributors to carbon sequestration accounts for 30.24% of the total CO_2 sequestrated by selected mouza's. Mouza Matta Rustum Khel with 219.46ha (22.72% of the total area) area under plantation, is the largest contributor, responsible for sequestering 43.73% of CO_2. Mouza Kabli has the lowest sequestration potential, responsible for sequestering only 2.6% of the total CO_2 sequestrated by selected mouza.

The analysis reveals that CO_2 sequestration potential varies by mouza's, with some mouza's contributing much more than others. The mouza of Matta Rustum Khel (43.73%) and Mera Umerzai (30.24%) are significant in sequestering CO_2, decreasing greenhouse gasses, and minimizing the consequences of climate change. Areas with lower sequestration potential, such as Kabli (2.6%) and Sherpao (5.1%), however, contribute to the total effort. The study area (selected Mouza) has sequestered 20,157.7 million pounds of carbon, indicating that they have absorbed and stored a significant amount of CO_2 from the atmosphere. The sequestration of 20,157.7 million tons of carbon represents a substantial removal of CO_2 from the atmosphere.

This is a huge step forward in the fight against climate change. Figure 7 illustrates the spatial distribution of percent area under Plantation and No. of Trees in selected Mouza of District Charsadda. Figure 8 illustrates the CO_2 sequestration Potential of the selected Mouza of District Charsadda.

Table 3 Vegetation Characteristics, area under vegetation and amount of CO_2 sequestration in Selected Mouza's in 5 years

	Scenario	Tree detail		Area under Vegetation		Number of trees	Total Number of Trees	CO_2 sequestration	
		height (feet)	diameter (inches)	Hectare	Total			(million pounds)	Total
Zarbab Garhi	Scenario- 1	22	14	28.64	98.83	616562	2,127,612	318.33	1557.04
	Scenario- 2	20	12	30.19		649930		448.24	
	Scenario- 3	23	10	40		861120		790.47	
Mira Umerzai	Scenario- 1	25	15	100	357.9	2152800	7704871	2899.82	6095.59
	Scenario- 2	18	9	125.90		2710375		1598.88	
	Scenario- 3	22	8	132		2841696		1596.89	
Sherpao	Scenario- 1	26	14	52	52	1119456	2415226	1027.62	1027.62
	Scenario- 2	20	12	30.19		649930		448.24	
	Scenario- 3	30	18	30		645840		1503.27	
Chak Sherpao	Scenario- 1	25	12	55.4	159.46	1192641	3,432,826	1028.15	2137.87
	Scenario- 2	25	9	57.2		1231391		995.17	
	Scenario- 3	24	10.5	46.86		1008794		1109.72	
Kabli	Scenario- 1	25	15	9.01	19.01	19367	234647	261.27	523.98
	Scenario- 2	26	14	10		215280		262.71	
Matta Rustum Khel	Scenario- 1	29	18	80.2	219.46	1726,531		3884.75	8815.01
	Scenario- 2	32	20	71.5		1539,239		4718.04	
	Scenario- 3	27	15	67.76		1458,725		212.21	

Source: Image analysis in ArcMap and determination of Tree characteristics in the field

Table 4 Area under Plantation and CO_2 sequestration Potential of Selected Mouza in 5 years

Name of Mouza's	Area under Plantation (ha)	%age of Total Area	CO_2 sequestration Potential (million lbs.) in 5 years	%age of Total CO_2 sequestration

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Sherpao	112.19	11.62	1027.62	5.10
Mera Umerzai	357.9	37.06	6095.59	30.24
Zarbab Garhi	98.83	10.23	1557.64	7.73
Chak Sherpao	158.46	16.41	2137.87	10.60
Matta Rustum Khel	219.46	22.72	8815.01	43.73
Kabli	19.01	1.97	523.98	2.60
Total	**965.85**	**100**	**20157.7**	**100**

Source: Image analysis in ArcMap and determination of Co_2 Potential in MS Excel

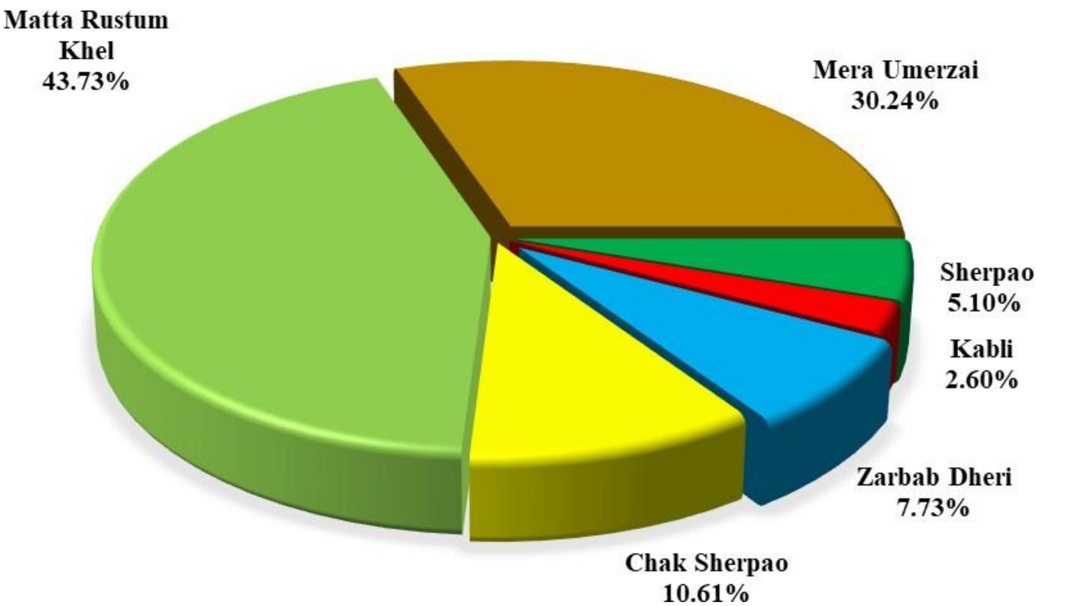
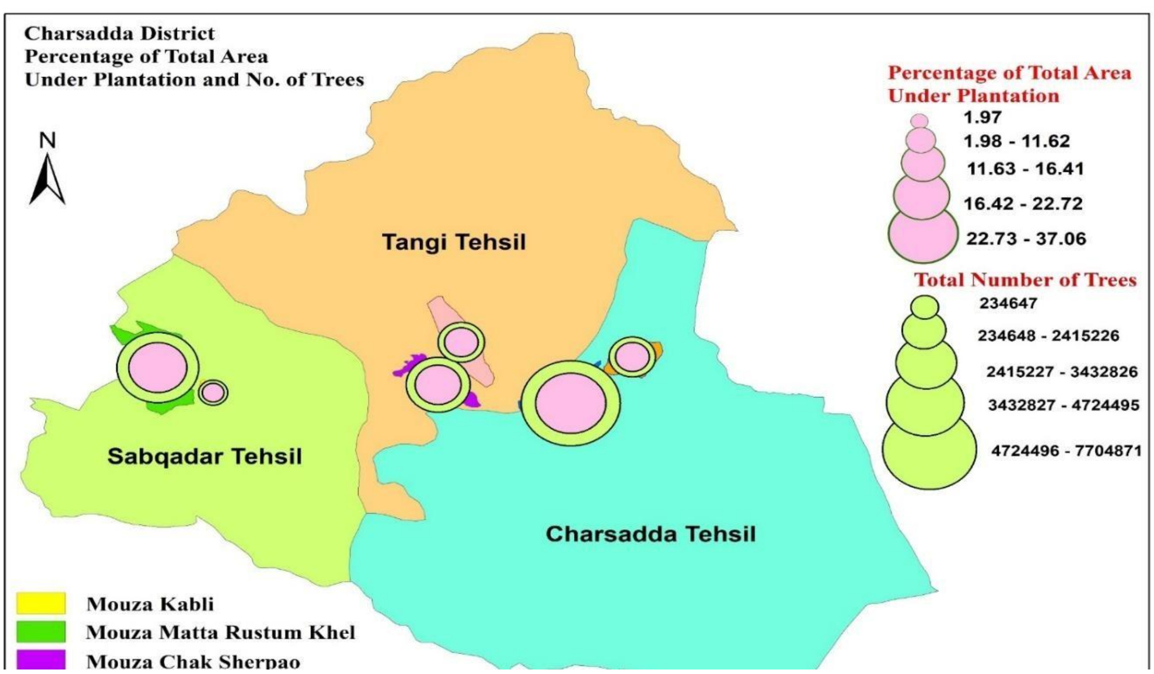


Figure 7 Percentage wise CO_2 sequestration Potential of Selected Mouza's



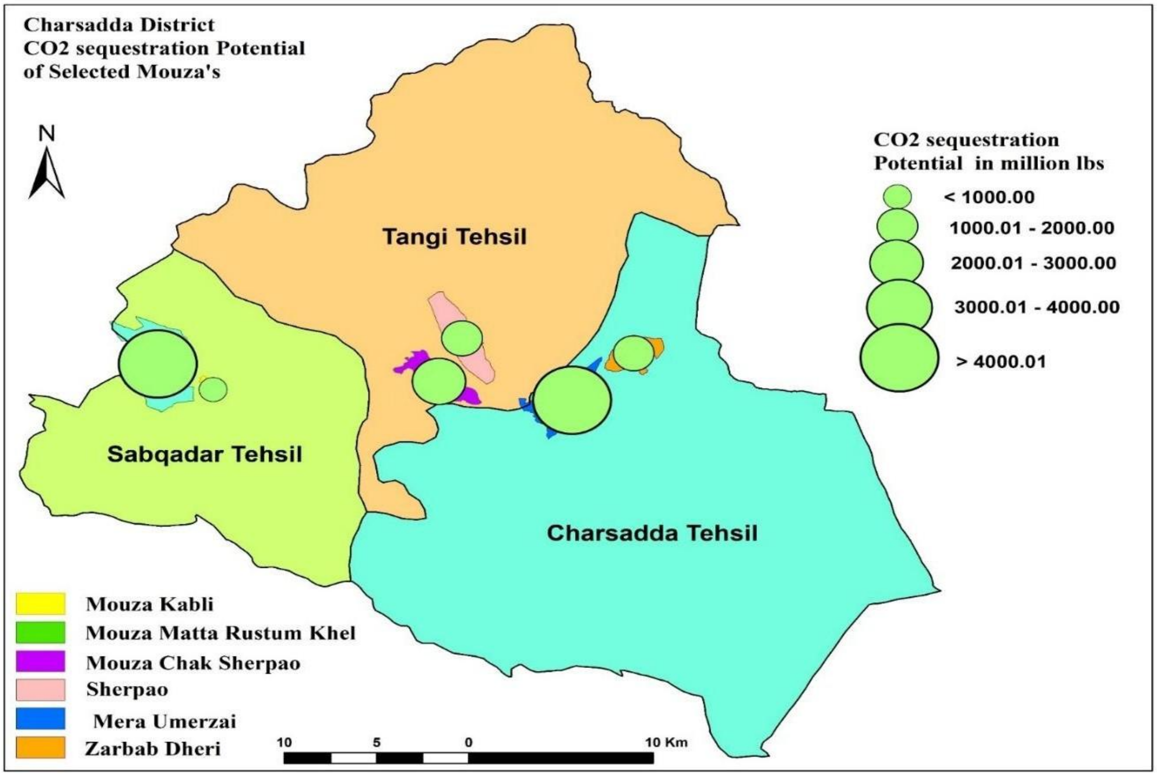


Figure 8 CO_2 sequestration Potential of selected Mouza of District Charsadda for a period of 05 years

Discussion

During the field survey the farmers pointed out that mixed dense type of agroforestry is adopted by those farmers having small holdings and agriculture products are insufficient to fulfill their domestic needs so they do job, business etc. and cultivate trees on farm boundaries for some extra cash. Respondents also said that very large-scale farmers also practice strip plantation, because of large holdings, these plantations have minimum adverse effects on crops production. The respondents' farmers pointed out that there are two main reasons for practicing mixed farming, firstly, it needs little care, laborers and secondly on tree plantation total cost is very meager as compare to crops. After 5 or 6 years when trees are grown properly, they are sold for some extra cash. Some time they cut trees after a period of 3-4 years depends on the need of farmers to earn cash for their subsistence.

Carbon sequestration decreases CO_2 levels in the atmosphere, contributing to climate change mitigation efforts. Carbon sequestration is an important approach in combating climate change.

Capturing CO_2 from the atmosphere and storing it in natural or artificial systems helps lower greenhouse gas concentrations and limit global warming. To optimize the efficiency of global carbon sequestration initiatives, both natural and technological solutions need to be used.

Agroforestry systems integrate agricultural and forestry activities (Anwar et al., 2017), resulting in a more diversified ecosystem capable of absorbing and storing more carbon than conventional agriculture. Agroforestry integrates trees and shrubs into agricultural systems to sequester CO_2 and mitigate climate change (Tefera et al., 2019; Ghale et al., 2022). Photosynthesis allows trees and perennial plants to absorb CO_2 and store it in their biomass (roots, trunks, branches) and soil (Dai et al., 2019). Agroforestry improves soil health by increasing organic matter and decreasing soil erosion. Trees in agroforestry systems help to store soil carbon through leaf litter, root systems, and microorganisms (Fahad et al., 2022). Assessing agroforestry's CO_2 sequestration potential highlights its role in improving soil carbon storage, which can contribute significantly to overall carbon absorption. Agriculture is a major source of greenhouse gas emissions, particularly methane and nitrous oxide (Rehman et al., 2020). Agroforestry, which integrates trees into agricultural systems, helps reduce a part of these greenhouse gas emissions through carbon sequestration (Ghale et al., 2022).

Agroforestry improves sustainable land use by improving agricultural output and carbon sequestration. Assessing agroforestry's potential helps to evaluate how much more carbon can be trapped as compared to traditional agricultural methods. It is crucial to identify the ability of agricultural systems to trap carbon and improve agricultural sustainability, biodiversity, and resilience. Agroforestry provides a unique chance to reduce climate change by combining productive land use with major environmental and socioeconomic advantages. Incorporating it into carbon sequestration evaluations enables a more comprehensive and effective strategy to fulfilling global climate targets.

Since the end of the 20th century, when global warming and climate change became an established worldwide concern, agroforestry has attracted immense interest as a land-management method with significant potential for addressing it. The basic idea is the fact that carbon capture by trees is a successful approach for controlling the global rise in CO2

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concentrations and that agroforestry would result in greater rates of carbon Sequestration than traditional agricultural systems (Nair et al., 2021).

Situated in Khyber Pakhtunkhwa's core irrigated zone, District Charsadda has had great success with agroforestry. In Pakistan, it's considered the best agroforestry model. In almost every farmer's field, trees have been planted. It's hard to find any farmland in Charsadda without exotic poplar trees because of their quick growth and high financial return (Iqbal et al., 2022. Poplar trees have a quick growth rate, reaching 1 to 3 meters per year under ideal conditions (Christersson, 2010). Rapid growth (Vornicu et al., 2023), allows them to absorb more CO_2 in their early years than slower-growing species (Yao et al., 2023). Poplar plantations may produce large biomass in short rotations (5-12 years), resulting in increased CO_2 storage in the stems, branches, roots, and leaves. Poplar trees are suitable for agroforestry, where they may be intercropped with crops to increase land productivity and sequester carbon. According to a study by Wotherspoon et al., (2014) on the "Carbon sequestration potential of five tree species" in southern Ontario, Canada, poplar intercropping systems had the highest mean C content per tree both above- and belowground i.e. 239kg, followed by red oak, black walnut, Norway spruce, and white cedar systems, with a total of 139, 132, 114, and 146 kg C, respectively.

The average sequestration potential of poplar trees may vary, however, based on known studies and worldwide averages the young poplar plantations (5-10 years old) may trap 5-10 tons of CO_2 per year because of their fast development and biomass buildup. Mature poplar plantations (15+ years) have higher sequestration capacity, with a single hectare capable of absorbing 15-20 tons of CO_2 per year, depending on growth circumstances and management approaches (Riccioli et al., 2022; Sivaranjani & Panwar 2023). If the plantation sequesters an average of 7 tons of CO_2 per hectare per year, the total sequestration could be around 700 tons of CO_2 per year (for 100 hectares) (Chauhan et al., 2010).

Poplar plantations in Charsadda District have high CO_2 sequestration potential, because to their rapid growth. Poplar trees have the potential to store hundreds of tons of CO_2 over time, making them a significant tool in climate change mitigation efforts. A 100-hectare poplar plantation can sequester 700-1,500 tons of CO_2 per year, based on tree age and maturity. In addition to climatic advantages, these plantations may boost local economies and promote sustainable land management.

Conclusion

Carbon sequestration, which captures and stores CO_2, is vital in reducing climate change by lowering greenhouse gas concentrations. Agroforestry, which incorporates trees and shrubs into agricultural systems, improves carbon absorption compared to traditional agriculture. Agroforestry encourages sustainable land use, increases agricultural output, and provides environmental and socioeconomic advantages, making it a viable method for reaching global climate targets. The current study examines land use and land cover (LULC) in six mouzas (villages) in Tehsil Charsadda, focusing on the predominance of agroforestry systems. The investigation demonstrates that the LULC varies significantly. Mera Umerzai has a substantial vegetation cover of 45.63%, indicating a preference for mixed-dense agroforestry. Strip plantings and mixed dense agroforestry are common in Chak Sherpao. Agroforestry, particularly mixed dense systems, is utilized by both smallholders and large-scale farmers to produce extra revenue from tree production. The overall area under vegetation in all mouzas is 965.85 hectares, with variable contributions from each mouza. Mera Umerzai has the largest percentage of plant cover, accounting for 45.63% of total land and 37.06% of total vegetation in the research region. Matta Rustum Khel, while having the highest overall area (1341.81 hectares), has a lower vegetation percentage (16.36%) but still accounts for 22.72% of the total plantation. Chak Sherpao stands out with 30.57% of its land covered in strip plantations, accounting for 16.41% of the total. Sherpao and Zarbab Garhi have moderate vegetation coverage, accounting for 11.62% and 10.23%, respectively, while Mouza Kabli, the smallest, accounts for just 1.97%. The study emphasizes the importance of agroforestry in carbon sequestration in Charsadda District, Khyber Pakhtunkhwa, with Mera Umerzai and Matta Rustum Khel being the primary contributors. The chosen mouzas have sequestered 20,157.7 million pounds of CO_2, 9143389791 Kg (9.4 MGC/hectare where MGC= Metric Gigagrams of Carbon. A gigagram (Gg) is equivalent to 1,000 metric tons or 1,000,000 kilograms of carbon) making a significant contribution to climate change mitigation efforts. Poplar trees, commonly planted in the region, are highly effective at absorbing CO_2 due to their quick growth and large biomass buildup. A 100-hectare poplar plantation can trap 700-1,500 tons of CO_2 yearly, adding to both climate change mitigation and local economic benefits. The study found that mixed-dense agroforestry systems are more successful in absorbing carbon. Promoting and integrating such initiatives in all communities will enhance CO_2 sequestration. Because of their quick growth and large biomass, poplar trees are thought to be particularly effective at carbon sequestration. Encouraging farmers to plant poplar trees on their property in other areas of Khyber Pakhtunkhwa, can greatly boost carbon absorption and might give economic and environmental advantages as well.

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